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PROPER SELECTION OF HYDROSEEDING MIXTURES AND COMPONENTS TO PROMOTE RAPID REVEGETATION OF DISTURBED DEPARTMENT OF DEFENSE LANDS

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PROPER SELECTION OF HYDROSEEDING MIXTURES AND COMPONENTS TO PROMOTE RAPID REVEGETATION OF DISTURBED DEPARTMENT OF DEFENSE LANDS

1. Purpose

a. This Public Works Technical Bulletin (PWTB) provides guidance on the selection and application of hydromulch products used in hydraulically applied erosion control methods. The information is based on data collected from past studies, lessons learned from professional operators, and usage criteria from vendors. These products are a means to sow seeds over lands with a wide range of characteristics, and to provide short-term erosion control for disturbed sites and aid in vegetative reestablishment that leads to long-term erosion control. Application of the guidelines presented in this bulletin will provide personnel with the information to properly select hydromulch materials, reduce product failure due to misapplication, and reduce costs by specifying appropriate erosion control products specific to field conditions.

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 web page, which is accessible through URL:

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

c. Applicability. This PWTB applies to all U.S. Army facilities engineering activities.

2. References.

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

b. References for the appendices are listed in Appendix F.

3. Discussion.

a. Implemented in 2007, AR 200-1 requires that military installations be good stewards of land resources through the minimization of environmental impacts, which includes impacts of construction and maintenance practices, and of training. Laws such as the Clean Air Act and Clean Water Act dictate how Army training grounds are managed.

b. The cost of periodic or regularly scheduled revegetation efforts on Department of Defense lands can deplete the vegetation budgets of Public Works and Natural Resources offices, especially if revegetation is unsuccessful. Hydromulches, one of the more dominant mechanisms for seed dispersal and germination, range on average from $1500 to $3000 per acre to apply. In many instances, off-the-shelf hydromulch products are inadequate for given field soil conditions. Proper selection of the mixture is needed to match soil type, gradient, and slope length. Frequently, a lack of clear and concise application instructions result in product waste and misapplication. To further complicate the selection process, a multitude of hydromulch additives are available to consumers. Proper knowledge of hydromulch additives and their use is crucial to successful hydroseeding. Many projects will experience some form of hydromulch failure during the first application. ***A hydromulch product selectively tailored to the appropriate soil conditions, season, and seed mixture has the potential to reduce this failure and improve seed germination, eliminating the need for hydromulch reapplication***. Development of a selection process for hydroseeding including hydromulch mixture selection and materials guidance is needed to maximize the success, efficiency, and cost benefits of vegetation efforts on military installations. Alterations to existing guidelines/ specifications, if any, would help facilitate transitioning these lessons learned to end users.

c. This PWTB provides information regarding the selection of hydraulically applied seeding products for military installations. No standardized information currently exists for such methods, resulting in hydroseeding treatments that often fail to meet expectations. When used correctly, hydroseeding is a time-efficient and cost-effective way of rapidly re-establishing vegetation on areas disturbed by military activities.

d. Appendix A contains information on hydromulch materials, additives, product use, and application equipment.

e. Appendix B aids in the selection of hydromulch components with information given on environmental situations, costs, vegetation selection, and other topics.

f. Appendix C describes slope soils and topographic characteristics of each of the U.S. Army's Tier I installations in the Continental United States, as well as a Hydromulch Best Management Practices selection tool for these installations.

g. Appendix D lists some manufacturers of hydraulically applied erosion control products, equipment, and related products. This list is not an endorsement of these products but is meant to aid installations in researching individual products and provide assistance in locating product vendors.

h. Appendix E provides acronyms used commonly in this document. It also includes a short glossary for an extended explanation of terms.

4. Points of Contact (POCs). Headquarters (HQUSACE) is the proponent for this document. The POC at HQUSACE is Malcolm E. McLeod, CEMP-II, 202-761-0632, or e-mail: Malcolm.E.Mcleod@hq02.usace.army.mil.

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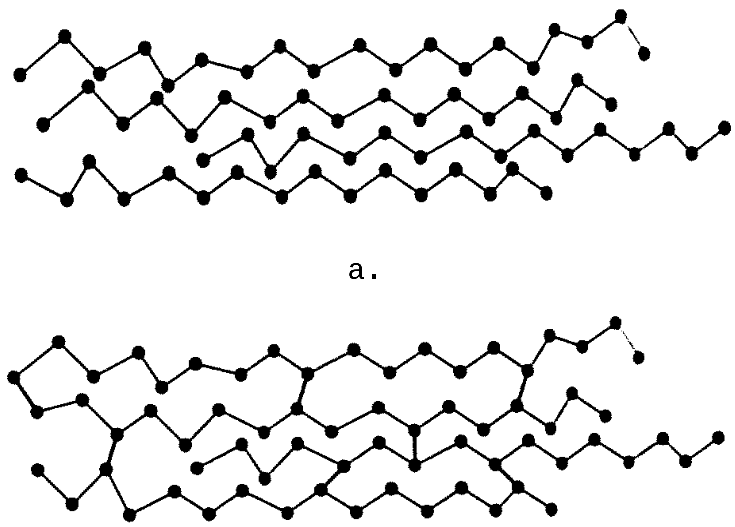
Appendix A: Hydroseeding and Hydromulch Overview

Over the past several decades, hydroseeding has become a routine alternative to traditional forms of establishing vegetation, such as drill seeding, broadcast seeding, and dry-mulch seeding. Strictly speaking, hydroseeding is the use of water as a medium through which seeds are sprayed onto the seedbed. This differs from hydromulching, where a fiber-mulch is added to a mixture of seed and water; however, these two terms are often used interchangeably in practice. Hydromulching provides a method to apply soil amendments, water, a binding agent, seed, and mulch fibers in a slurry form in one application. The slurry is often stored in a large tank mounted on a trailer or truck, and is often sprayed through a hose that can be several hundred feet long. This ability gives hydroseeding a unique advantage over traditional seeding methods in that it is possible to reach rough or otherwise inaccessible areas, including areas of high slope, where traditional techniques cannot be used (Baxter 2007).

The major component of any mulch product is the mulching fiber. Several different types are available, including wood, paper, straw, and cotton. The function of the mulch is to provide a medium for the seeds that retains moisture while simultaneously allowing the exchange of air and the passage of light. Most mulch products are composed of organic fibers that will degrade over several months. Certain types of fibers can be used to provide a longer mulch lifespan, as well as provide erosion protection from wind and water.

Another important component present in most mulch is a binding agent, or tackifier. Tackifiers serve the dual purpose of helping bind the mulch to the soil and absorbing water into the mulch matrix (Baxter 2007). Tackifiers also help the soil form aggregates, allowing for better infiltration of water into the soil. Three major types of binding agents are guar derivatives, hydro-colloidal tackifiers, and polyacrylamide (PAM). PAMs are also capable of reducing water turbidity and sediment loss, making them a useful tool in erosion control (Hayes 2005). While it has been shown that guar based products promote higher infiltration rates, the effects of PAM tackifiers last longer. However, the effectiveness of PAM depends on the moisture content of the soil, giving it limited use for soil stabilization (Cooke et al. 1994). Hydro-colloidal tackifiers work by forming a chemical bond that holds a matrix in place. When a hydro-colloidal tackifier is cross-linked, the water solubility of the tackifier is reduced, increasing its longevity (Lauro and Theisen 2007). Figure A-1 shows the difference between linear and cross-linked polymer chains.



a.

b.

Figure A-1. Linear polymers (a) vs. cross-linked polymers (b).

Although not necessarily found in all prepackaged hydromulches, soil amendments are readily found in many products on the market. They can also be purchased individually. Two major groups of soil amendments are fertilizers and soil additives. Fertilizers found in hydromulch products are essentially identical to those used in dry applications; they have a guaranteed nutrient composition (typically listed in the total N – available P – soluble K format). Since soil additives contain little to no nutrient value, they can be easily separated from fertilizers (McFarland et al. 1998). Several types of soil additives are available, including soil conditioners and soil activators. Soil conditioners are said to improve soil structure, therefore improving aeration, infiltration, and drainage characteristics. Soil activators are products that claim to inoculate the soil for microbial activity. Although microbial activity is an essential part of the soil environment, research has shown that soil activators, especially when applied at low rates, have no effect on improving soil characteristics (McFarland et al. 1998).

Mulching products

Because hydraulically applied mulches can be used under a variety of conditions and for different purposes, several different grades of mulching products are available. The three main mitigating properties that decided what category a product falls into are functional longevity, erosion control effectiveness, and vegetative establishment.

The Erosion Control Technology Council (ECTC) separates hydraulically applied mulches into one of four categories: fiber reinforced matrix (FRM), bonded fiber matrix (BFM), stabilized mulch matrix (SMM), or hydraulic mulch (HM). Figure A-2 shows the many levels of erosion control products.

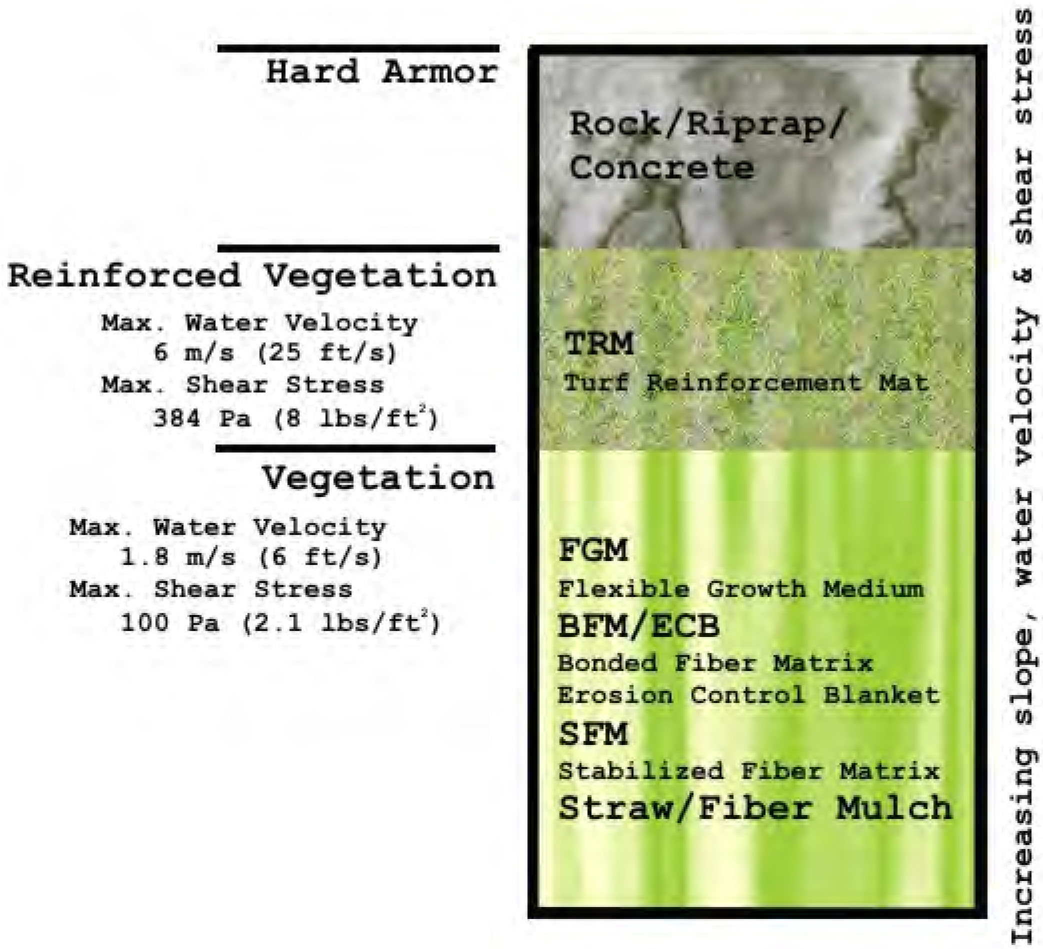


Figure A-2. Erosion control products hierarchy.

Before discussing the different categories, it is important to discuss the properties that characterize them. Functional longevity gives an indication as to how long the given product can be expected to adequately provide the seed with an environment safe from splash and sheet flow caused by precipitation. Functional longevity will depend on such climatic factors as rainfall duration and intensity as well as temperature (Lauro and Theisen 2007). Soil type, slope length, and vegetative cover are a few other factors that play a role as well. The property by which the matrix's ability to protect the soil from sheet and splash erosion is called percent effectiveness (PE). This property can be determined using the equation, $PE = (1 - C) \times 100\%$ where C is the crop or cover factor from the Revised Universal Soil Loss Equation (RUSLE). The value of C can be determined using American Society for Testing and Materials (ASTM) method D6459 or can be determined experimentally with a large-scale rainfall simulator (Lauro and Theisen 2007).

While varying environmental properties may make a product's actual percent effectiveness hard to quantify in the field, the property provides a valuable resource for comparing products tested under similar conditions. Vegetative establishment is a property measuring the product's ability to encourage germination and plant growth, and is currently tested using ECTC Rolled Erosion Control Product test method #4 (ECTC 2008). The two main factors controlling this property are the matrix's ability to hold water and the ability of the matrix to make soil contact. The higher the product's water retention capability, and the more intimate soil contact made, the higher the vegetative establishment (Lauro and Theisen 2007).

Fiber-reinforced matrix

The highest grade of hydraulic erosion control product (HECP) is a Fiber-reinforced matrix (FRM). According to the ECTC, FRMs contain cross-linked hydrocolloid tackifiers, organic fibers, and natural or synthetic fibers that provide erosion control. FRMs are intended for very steep slopes and have the longest functional longevity; a minimum of 12 months. Because the synthetic fibers present in FRM products form a mechanical bond, they require zero curing time. FRMs are sometimes referred to as flexible growth mediums.

Bonded fiber matrix

A Bonded fiber matrix (BFM) is the next highest grade HECP. These products contain organic defibrated fibers and cross-linked hydrocolloid tackifiers. BFMs are implemented on steep slopes and have a typical functional longevity of at least 6 months (ECTC 2008). BFMs are essentially equivalent to erosion control blanket (ECB) products when applied correctly; however, they take longer to implement. These products will need from 24-48 hours to completely dry to be fully effective and are well suited for sites that may already have existing desirable vegetation (Leyva et al. 2002).

Stabilized mulch matrix

Stabilized mulch matrix (SMM) is the next grade of HECP. The ECTC defines SMMs as containing defibrated organic fibers with at least one of the following additives: cross-linked tackifiers cross-linked hydro-colloidal polymers, or soil flocculants. Typical products falling under this category have a minimum functional longevity of 3 months and are used on mild to moderate slopes. SMMs are also called stabilized fiber matrices (SFMs).

Hydraulic mulch

Finally, hydraulic mulches (HM) are the lowest grade of HECPs. These products contain wood or paper fibers and may or may not contain any tackifying agents. These products are used on mild slopes only and have a maximum functional longevity of 3 months (ECTC 2008). HMs made from recycled paper products are ineffective at providing erosion control, and have a significantly shorter lifespan than HMs made from wood fibers. While wood fiber mulches are minimally effective at providing erosion control, they maintain soil temperature and moisture more effectively than paper products (Leyva et al. 2002). Table A-1 lists some key characteristics of the four main categories of HECPs.

Table A-1. Characteristics of different grades of HECP.

Matrix Type	Slope	Longevity	Composition
Hydraulic Mulch	4H* to 1V*	< 3 mo	Shredded wood/paper, stabilizing emulsion, water
Stabilized Fiber Matrix	3H to 1V	3-6 mo	Wood/paper fiber, water, stabilizing emulsion (PAM or hydro-colloidal)
Bonded Fiber Matrix	2H to 1V	6-12 mo	Wood fiber, cross-linked hydro-colloid tackifier
Flexible Growth Medium	1H to 1V	>12 mo	Wood fiber, cross-linked hydro-colloid tackifier, man-made crimped fibers
			* H = Horizontal; V = Vertical

Although the four mulch types named above are the only types of HECPs listed by the ECTC, compost is another possibility. Hydraulically applied compost, sometimes called hydrocompost, has been shown to have similar results to that of some HMs. Although several studies have stated that using compost results in better vegetative cover, this is not the only benefit that has been found. Other advantages of compost include better infiltration, increased biomass, and reduced runoff when compared to hydromulch (Faucette 2004). The U.S. Environmental Protection Agency (USEPA) recommends using a mulch layer 2 to 3 in. thick to get comparable results to hydromulch. These results are achieved because compost tends to form a thicker, more permanent vegetative growth than hydromulch (USEPA 1997). On steep slopes, compost berms can be placed at the top and/or bottom of the slope to decrease runoff velocity, further helping to reduce erosion and washout (USEPA 1997). Figure A-3 shows this technique. The type of hydroseeding equipment that is available will be a factor in the decision to use hydrocompost.

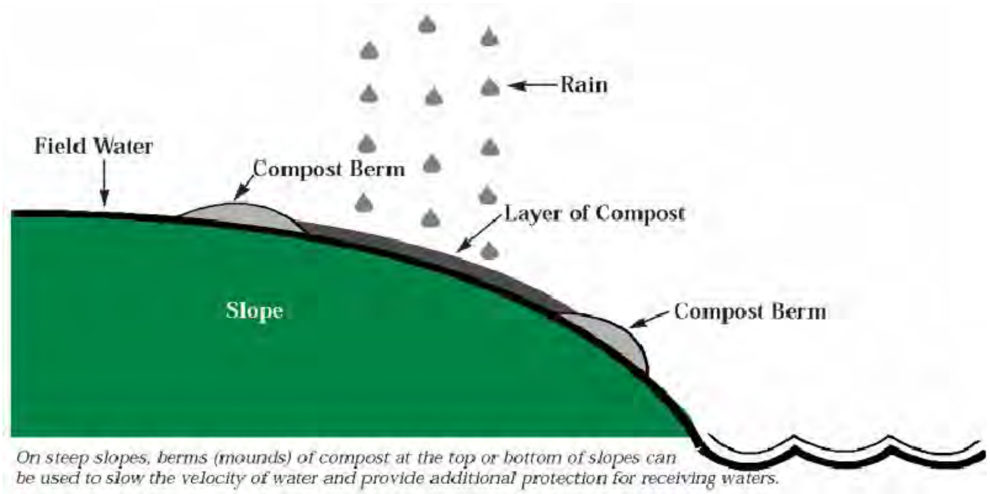


Figure A-3. Using compost berms on steep slopes (USEPA 1997).

Hydroseeding equipment and methods

The selection of the equipment used to hydroseed, as well as how the mulch is applied, is just as critical as choosing the correct slurry components. Hydroseeders come in a wide variety of sizes, pumps, and agitation schemes. It is important to take into account the viscosity of the slurry to be sprayed; for instance, a BFM will be much thicker than an HM. There are also two main types of slurry agitation: mechanical and jet propulsion. Mechanical agitation consists of turning blades mixing the slurry, while jet propulsion consists of nozzles forcing the slurry to cycle around the tank keeping mulch particles suspended in water. It has been shown that when using hydrocompost, mechanical agitation is necessary because jet agitation cannot keep heavy compost particles suspended in water (CWC 1999). The size of the hydroseeder used is another important factor to consider. A smaller unit provides the benefits of increased mobility, site access, and easy maneuverability; however it necessitates more tank refills. The contrary applies for larger tanks. It is important to consider from where the water will be supplied, especially for tasks that will require more than one tank load of slurry. Some available hydroseeders are equipped with trash pumps that will allow water to be pumped into the tank from nearby sources.

Slurry contained in a hydroseeder tank is spread in one of two ways. It is either shot from a cannon mounted directly on the hydroseeder itself, or it is pumped through a hose and sprayed out a nozzle. Figure A-4 shows the use of both a tank-mounted cannon and a hose to apply hydromulch. Typically, hoses are used when the hydroseeding unit cannot directly access the area needing to be treated. Nozzles that aid in controlling the flow of the slurry are available for both models. When treating areas from long distances, the long-range nozzle is used to loft the slurry to the area. When spraying at short distances or in a downward direction, a fan-type nozzle spray is typically used.

a. b.

Figure A-4. A tank-mounted cannon (a) or a hose (b) may be used to apply hydromulch.

Because hydroseeding treatments serve the dual purpose of acting as a soil erosion control practice and as a method of quickly re-establishing vegetation, hydroseeding after fires is becoming a common practice. Several studies have been conducted to determine the effectiveness of hydroseeding after fires with most results indicating that it is an effective means of erosion control. In large wildfires in Colorado and California, hydromulch was applied using fixed wing airplanes typically used for crop dusting. A study conducted after a wildfire in Colorado showed that hydromulching treatments reduced sediment loads by 77% or more for 3 years after the fire as compared to bare soil (MacDonald et al. 2007).

The same study indicated that an initial application of PAM reduced sediment yields. Depending on the severity of the burn and the topography, cover rates may vary; covers between 50% and 100% can produce similar erosion control results (Wohlgemuth et al. 2006). Unless fires burn at extreme temperatures, plant seeds often remain viable after fires, therefore, revegetation is unaffected by the presence of hydromulch (Wohlgemuth et al. 2006).

However, the burning of organic matter may result in the release of hydrocarbons, resulting in a waxy, hydrophobic layer beneath the soil surface; this typically happens when fires burn between 350°F and 400°F (Cilimburg 2005). This waxy layer makes infiltration of water into the soil difficult and it may be necessary to select a hydromulch product with a high functional longevity. Also, fires usually raise the alkalinity of soils; it may be necessary to add urea or sulfur as an amendment to hydromulch slurry to lower the soil pH (Cilimburg 2005). Because fires often burn hot enough to kill off the soil micro-organisms that are beneficial to plants, the addition of soil activators at sufficient levels may be beneficial. Amaranthus and Russell (2004) compared grass covers in areas treated after a forest fire with mycorrhizae against areas that were not treated and found that the addition of soil activators with seed doubled vegetation coverage.

Appendix B: Selection of Hydromulch Components

Before choosing an HECP and its components, it is first necessary to decide if hydroseeding is indeed the best application method for sowing the seed. Some site conditions that would suggest the use of a hydroseeding treatment are: (1) the need for soil stabilization before the establishment of vegetation, (2) the need for quick vegetative establishment, and (3) the need for moisture retention (Baxter 2007). Also, the presence of rough or inaccessible areas, as well as slopes that are long or too steep to machine grade are justification for using hydroseeding as the sowing method (Lauro and Theisen 2007).

Once the need for hydromulching has been established, several factors need to be considered before choosing the mix of products. Some of the major factors include soil structure and texture, the natural surrounding habitat, and impending weather conditions (Cole 1999). Soil structure and texture indicate what water retention capability the HECPs must have, to be able to provide erosion control. Impending precipitation may impair the cure time necessary for some HECPs, and the surrounding habitat will give an indication as to what type of vegetation to use. Other factors to consider are slope length, slope angle, and functional longevity. Certain HECPs are designed specifically for slopes that are steep or long. Figure B-1 illustrates the functionality between slope and different HECPs.

Another important factor that will play a role in deciding which HECP to choose is cost. Although a certain site may necessitate a particular HECP, most products cover a wide range of slopes, allowing for some flexibility in product selection. The cost of a product will not only be affected by its quality, but by its availability in the region. Often, shipping can play a large part in the overall cost of the product. However, product quality is the major factor in determining product price. High-end products such as FRMs will cover steeper slopes and last longer than other HECPs, but are also significantly more expensive. Figure B-2 shows how the application cost of an HECP will increase with an increasing slope.

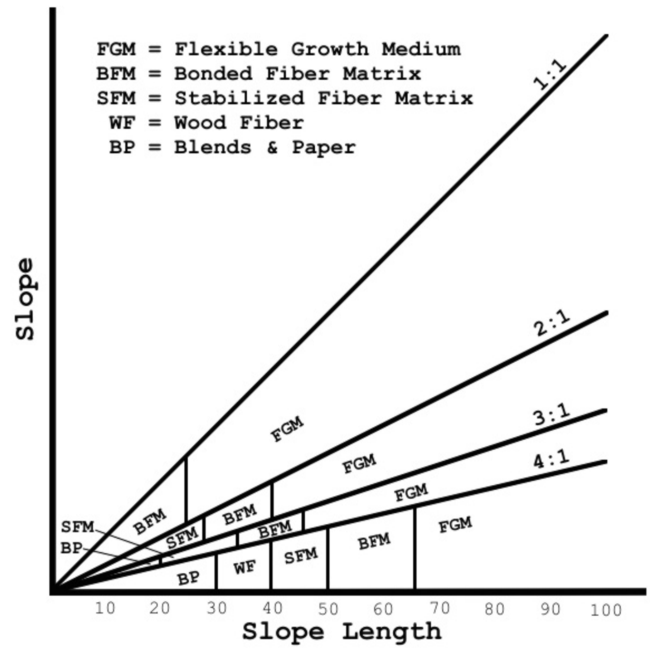


Figure B-1. HECP selection using slope and slope length.

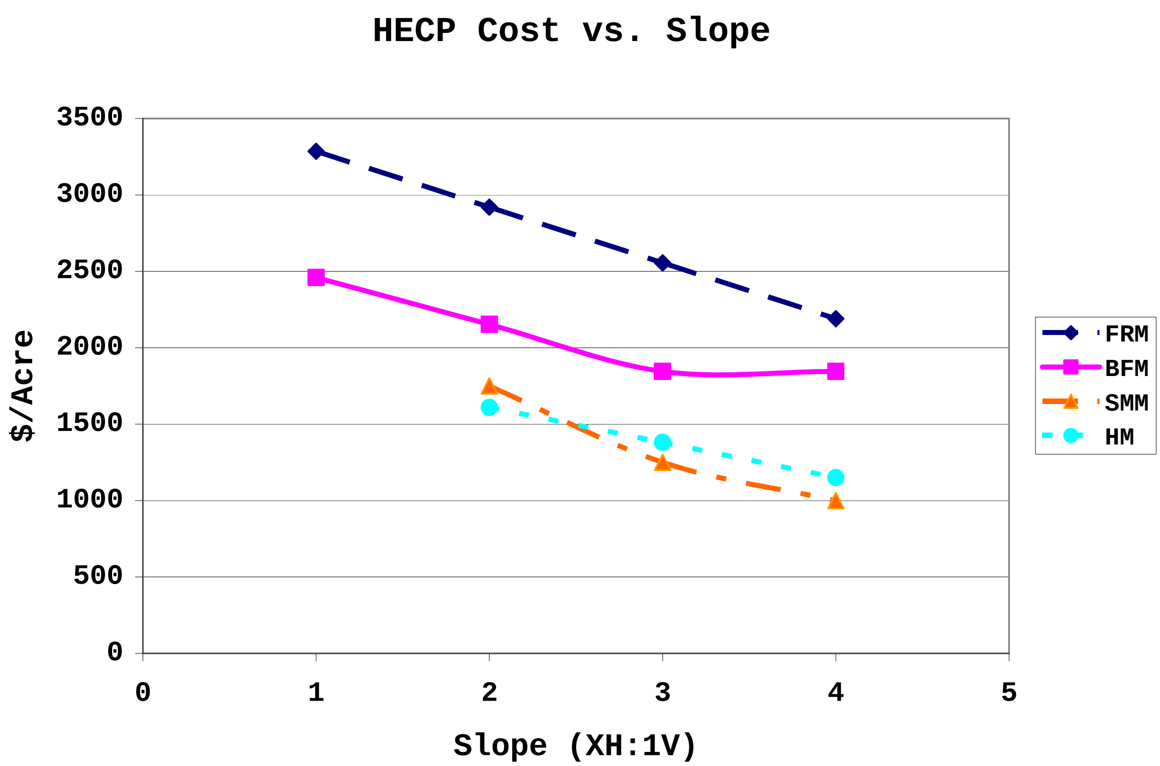


Figure B-2. Slope gradient effect on application costs per acre.

When planning for a hydroseeding treatment, it is important to consider any environmental impacts that the constituents of a hydromulch may have. Because chemical compounds are capable of leaching out of the soil and into groundwater or surface waters, knowledge of their mobility through soil, as well as their effects on the surrounding environment, is imperative. While the materials that compromise the mulch fibers are either photodegradable or biodegradable and nontoxic, this is not necessarily the case for tackifiers and soil additives.

The highest possibility for environmental impact in hydromulches is found in the tackifiers. Research has shown that non-absorbent particles exist in both PAM- and guar-based substances and that these particles may be carried as far as the soil's wetted depth (Nadler et al. 1991). For the most part, these substances are relatively immobile. The mass of PAM retained in the top 2 cm of soil is typically between 25% and 95% of the original application, and PAM content decreases dramatically in the top 4 cm of soil (Lu and Wu 2003).

PAM also shows a functional dependence on soil pore volumes, where guar gum is almost completely independent of soil pore volume. Another important aspect, shown in Figure B-3, is that a lower amount of polymer adsorption occurs on soil types with larger particle sizes, such as sandy soils (Nadler et al. 1991). If the soil is allowed to dry after an initial application of either PAM or guar tackifiers, an irreversible bond to soil particles is formed (Nadler et al. 1992). However, further research has shown that PAM will degrade to acrylamide under most natural environmental conditions, with the largest contributing factor being photolytic effects (Smith et al. 1997). Acrylamide has been shown, at high levels of exposure, to cause cancer in animals and neurological damage, including possibly Alzheimer's disease in humans (American Chemical Society 2007). Guar gum has been shown to cause mortality in rainbow and Donaldson trout, as well as zooplankton, although at fairly high levels of concentration (Kegley et al. 2007). Therefore, unless local fish species include trout, guar-based tackifiers should probably be considered for areas near marine wildlife, lakes, streams, and especially in areas that are exposed to high levels of sunlight.

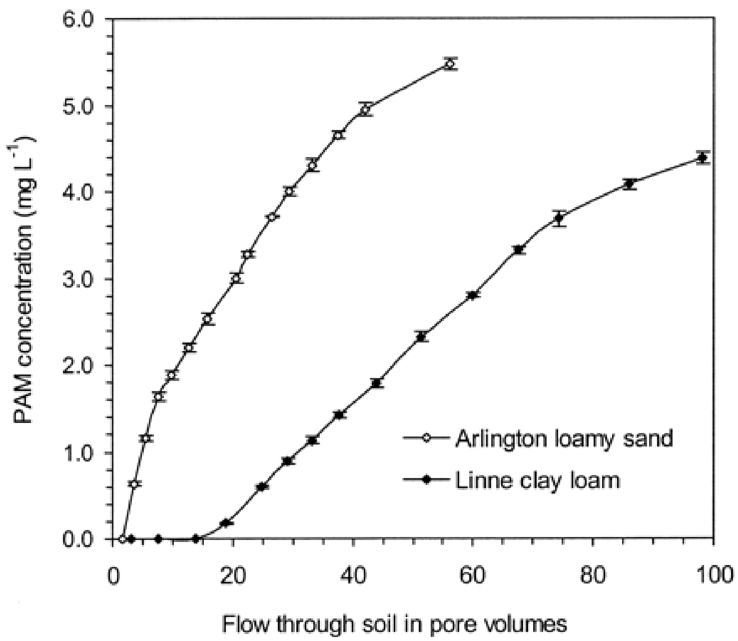


Figure B-3. Effluent PAM concentrations vs. pore volume (Nadler et al. 1991).

The goal of any hydroseeding treatment is to establish vegetative cover. As stated in Army Corps of Engineers Public Works Technical Bulletin (PWTB) 200-3-30, vegetation is effective at stabilizing soil and preventing erosion (Howard 2004). Therefore, the selection of the proper vegetation is essential in ensuring a successful hydroseeding project. PWTB 200-3-30 also states that native species are typically the best choice for revegetation as they are already adapted to current soil and climatic conditions. However, non-native species can be used for specific purposes.

Several information sources exist to aid in the seed selection process. Penn State University provides an interactive map that gives local plant species in any area at http://www.soilinfo.psu.edu/soil_lrr/. The National Resource Conservation Service (NRCS) also contains a vast database on various plants at http://plants.usda.gov/java/factSheet. Finally, VegSpec, an interactive program offered by the U.S. Department of Agriculture (USDA), allows for the input of soil, plant, and climate data and returns plant species that are suited for the selected site and the treatment intended for it. VegSpec can be found at http://vegspec.sc.egov.usda.gov. Finally, PWTB 200-3-30 offers a compilation of plant material suppliers organized by city and state. Although it is not an exhaustive list, it will aid in quickly locating plant supply resources.

A standard soil test, which provides information on nutrient value, pH, and organic matter content is needed to gain valuable insight into which amendments might be necessary. Amendments containing organic matter act as a source of plant nutrients, and can help improve soil structure by binding soil particles together (Northcutt 2004). Inorganic amendments such as gypsum or lime can also act as plant nutrient sources. Lime and sulfur are two amendments typically used to alter soil pH. The microbial component of a soil system is also important to consider when choosing soil amendments. *Mycorrhizae*, which are several different species of fungus that grow on plant roots, help plants to survive through periods of drought, extreme temperatures, and soil infertility (Steinbacher 2000). These fungi can be found both in arid and semiarid regions, as well as in conifer forests in higher rainfall areas. The two basic groups of *mycorrhizae* are *endomycorrhizae* and *ectomycorrhizae*. The former is known to be beneficial to grasses, shrubs, and hardwoods, while the latter is beneficial to evergreens (Anderson 2002). Figure B-4 shows a soil core sample taken for testing, which can determine qualities that will affect the ingredients used in the hydromulch.

Figure B-4. Soil samples provide information on soil properties.

Appendix C: Determining Best Management Practices (BMPs) for Hydromulches

Fort Benning, GA

Located in the Hot Continental ecological region (based on Bailey's ecoregions at the Province level) on the Georgia-Alabama border, Fort Benning's major soil textural class is sandy loams (CEMML, 2007). Sandy loams are a wide textural class, featuring ranges of 40-85% sand, 0-20% clay, and 0-50% silt. Slopes vary from 0-30% on Ultisol soils that are generally covered by deciduous and evergreen forests. Ultisols typically feature soils that are reddish or yellow in color due to a high oxidized iron or aluminum content. The typical annual rainfall for the area is between 40 and 50 in. per year. The heaviest period of precipitation is January through March, with about 5 in. falling each month. About 3 in. fall each month during the driest part of the year, August through November. Based on prior information, general BMPs for hydroseeding in the Fort Benning area should be the following:

> Since there is no extended period of the year when there is a combination of both high rainfall and temperatures warm enough to encourage germination, BFMs should be used throughout the year. Areas containing high amounts of sand are drained very quickly; therefore, a matrix with a high moisture retention capacity is needed. Also, the soil erosion protection provided by a BFM should exceed that necessary for slopes at or below 30%, therefore providing above-adequate erosion control.

Fort Bragg, NC

Fort Bragg is located in the Subtropical ecological region. Soil textures feature sands and loamy sands on 0-20% slopes. Sandy soils consist of 0-10% clay, 0-20% silt, and 80-100% sand, while loamy sands have a distribution of 10-15% clay, 0-30% silt, and 70-90% sand. Soils with a sand content as high as these will have low moisture and nutrient retaining capacities. Found on slopes ranging from 0-25%, typical land cover for the area consists of evergreen forests and grasslands that receives 40–50 in. of precipitation annually. Precipitation is spread evenly through the year, with 3-5 in. falling each month. Considering these factors, the general BMPs for hydroseeding at Fort Bragg should be:

> SMM products are suited for June-September, which typically has a higher amount of precipitation, although BFMs are rec-

ommended for areas that consist of both exceptionally high slope and high sand content for the area. Because of the high drainage capability of sandy soils, and the lower amounts of precipitation during the months of June through September, BFM products are recommended during that time.

Fort Campbell, KY

The border between Tennessee and Kentucky runs through the heart of Fort Campbell, which is part Hot Continental ecological region. Silty clay loams, which have a particle distribution of 25-40% clay, 40-75% silt, and 0-20% sand, make up the major soil texture of the area. The major land cover of the area is mixed forest on Alfisol soils with 0-35% slopes, and the area receives 50-60 in. of precipitation annually. Each month 3 to 5 in. of precipitation falls. General hydroseeding BMPs for Fort Campbell should be:

> The slopes of the area and the silty clay loam texture are well-suited for SMM products. If the site contains slopes of above 30%, a SMM product may be used if the slope length is below 25 ft. If the site exceeds that length, a BFM should be used to treat the slope.

Fort Carson, CO

Located in the Tropical/Subtropical Steppe ecological region, Fort Carson's soils feature mostly sand loams, which consist of 40-85% sand, 0-20% clay, and 0-50% silt. The grasslands of the area are on slopes that range from 0-50%, and the area receives 15-20 in. of precipitation on the average each year. During the wettest part of the year (which runs from April until August), 2 in. fall each month, and less than 1 in. falls each month from October until the following March. Recommended general best management practices (BMPs) regarding hydroseeding at Fort Carson should be:

> For slopes below 50%, a BFM product may be used from April through August. However, due to the low amount of precipitation and the high slopes of the area, an FRM is recommended in all other areas.

Fort Drum, NY

Fort Drum, located in the Hot Continental ecological region, features a prominent soil texture of silt loams. Silt loams have a typical particle range of 0-25% clay, 50-85% silt, and 0-50%

sand. Located on Alfisols, which are soils that formed under forest vegetation, slopes range from 0-50%, and the typical land covers are mixed forests and grasslands. Between 50 and 60 in. of precipitation falls on the area each year, and it is evenly distributed, with 3-5 in. falling each month. General BMPs for hydroseeding at Fort Drum should consist of:

> Slopes between 30% and 50% should be treated with a BFM at all times. Slopes below 30% are suitable for SMM, as precipitation is spread evenly through the year, and considering that silt loams are well-suited to retain moisture.

Fort Hood, TX

Fort Hood, located in the Tropical/Subtropical Steppe ecological region, features Mollisol soils that are mostly clay loams in texture. Clay loams consist of equal parts of sand, silt, and clay particles, with ranges of 25-40% clay, 15-50% silt, and 20-45% sand. Mollisols are generally very fertile soils that are above average at retaining moisture. The range of slopes found on soils in the Fort Hood area varies from 1–8%. Typical land cover for the area consists of mixed forests of deciduous and evergreen trees, as well as grasslands and shrubs. On average, the Fort Hood area receives between 30 and 35 in. of precipitation per year, with the heaviest amounts (5 in. per month) falling in May and June. The lightest period of precipitation is in July and August, with about 2 in. falling each month. Considering all of the aforementioned factors, general BMPs for hydroseeding should be as follows:

> If hydroseeding during the wet season, moisture retention is not necessarily a factor, since the area is already prone to high amounts of precipitation. Also, since slopes do not typically exceed 12.5:1, a strong bond to the soil is not necessarily required. Therefore, the hydroseeding BMP for wet season planting is to apply an SMM at the rate specified by the manufacturer. If it is necessary to hydroseed during the early stages of the dry season, the moisture content retention of the HECP becomes the mitigating factor. If the area can be conveniently irrigated, then an SMM should be used. If relying on natural precipitation, however, a BFM should be used for its high moisture retention characteristics. If seeding during any other time of the year, a BFM should be used; its functional longevity is such that it will provide adequate seedling shelter for an extended period of time. Irrigation of the area is not necessary due to the combination of average amounts of rainfall in these months and the high moisture retention of the matrix.

Fort Irwin, CA

Fort Irwin is in the Tropical/Subtropical Desert ecological region, which comprises a wide variety of land covers, soil types, and precipitation trends. The area around Fort Irwin features gravelly loamy sands with frequent rock outcroppings. Loamy sands have a particle size distribution of 10-15% clay, 0-30% silt, and 70-90% sand. Gravel is considered by the Natural Resource Conservation Service (NRCS) to be a collection of soil particles that vary from 2–75 mm in diameter. The rock outcroppings in the area give the soils a range from 0-100% slopes, and the annual precipitation varies from 1–10 in. January through March is the wet season, with 0.5 in. of precipitation falling each month, while almost no precipitation falls from April through July. Due to its arid locale, the local land cover consists of shrubs and scrub. General BMPs for hydroseeding in the Fort Irwin area should state:

> Given the very high sand content of the soils, along with the high temperatures and slope gradients, fiber reinforced matrices should be applied during any part of the year. Revegetation efforts should not take place in areas consisting of rock outcroppings, high rock content, and of slopes at or exceeding 1:1, or 100%. Planting early in the year is optimum, as it combines the period of the highest natural precipitation with temperatures that will encourage germination but will not scorch the seedlings; however, the mulch should still be irrigated. If the mulch is applied after the wet season, it will need to be irrigated frequently due to the lack of natural precipitation.

Fort Lewis, WA

Fort Lewis is located Marine ecological regions. Soil textures found there include gravelly sandy loams, as well as silt loams. Gravelly sandy loams have a particle size distribution of 40-85% sand, 0-20% clay, and 0-50% silt, with gravel particles 2-75 mm in diameter. Silt loams consist of 0-25% clay, 50-85% silt, and 0-50% sand. These soils are Andisols, which are formed from volcanic ashes, and the evergreen forests and grasslands of the area are found on slopes ranging from 0-70%. Fort Lewis typically receives anywhere from 50-60 in. of precipitation per year. November, December, and January see 6-8 in. of precipitation each month, while May through September is the dry part of the year, with 1.5-2 in. falling each month. General BMPs for hydroseeding in the area should include:

> Areas found on slopes greater than 50% should be treated with a FRM at all times. For areas with slopes between 30%

and 50%, a BFM product should be used. If the site in question features gravelly sandy loams, with slopes below 30%, BFM products are still recommended throughout the year due to the high drainage capacity of sandy loams, and the large period of time from April—October, when the area sees lower amounts of monthly precipitation. On silt loams where slope is below 30%, an SMM may be used if planting in March or April. However, BFM products are recommended for the rest of the year because the area sees low precipitation from May-October, which necessitates the moisture holding characteristics of a BFM. Also, since the area sees very high precipitation from November through February, SMM products may be susceptible to washout.

Fort Polk, LA

Located on sandy loams in the Subtropical ecological region, Fort Polk receives between 50 and 60 in. of rainfall annually. Precipitation is spread evenly, from 3-7 in. each month, throughout the year. The particle size distribution for sandy loams is 40-85% sand, 0-20% clay, and 0-50% silt. Slopes ranging from 0-20% feature land covers of evergreen forests, grasslands, and shrubs. Given this information, the general BMPs for hydroseeding practices in the area should be:

Due to the low slopes and high precipitation throughout the year, SMMs should be the product of choice. In areas of very high sand content, however, a BFM should be considered, especially when seeding from July-October, which is a period where monthly precipitation is consistently below average.

Fort Riley, KS

Fort Riley is located within the Prairie ecological region. The Mollisol soils of the area typically feature a silt loam texture that has particle distributions of 0-25% clay, 50-85% silt, and 0-50% sand. The grasslands and mixed forests of the area feature slopes ranging from 0-30%, and typical annual precipitation is between 30 and 35 in. About 4 in. fall each month from May-July, which is the wet season, and only 1.5 in. fall each month during December through February. General hydroseeding BMPs should be:

Stabilized mulch matrices should be used during the wet season as the slope gradient is low and the natural precipitation is high. Because the functional longevity of a SMM is about 6 months, it is suitable for use at any time during the year. However, if planting in late autumn, a BFM may be considered for its longer functional longevity and ability to retain moisture during the driest part of the year.

Fort Stewart, GA

Fort Stewart is in the Subtropical ecological region. The Ultisol soils of the area have a dominant soil texture of loamy sand, which has a particle distribution of 10-15% clay, 0-30% silt, and 70-90% sand. Slopes range from 0-20%, and the prominent land cover is evergreen forests. Fort Stewart receives 40-50 in. of precipitation each year. The wettest season occurs from June to September, with 4-8 in. falling each month. October to December is the driest part of the year when the area receives 2-3 in. of precipitation each month. General hydroseeding BMPs for the fort should be:

> Although the slopes of the area do not necessitate fiber matrices, the moisture retention of sandy soils may be the deciding factor in choosing an HECP. During the wet season, monthly rainfalls are high enough to raise concern over SMM washout, therefore necessitating BFM products. BFM products should also be used during the remainder of the year due to their moisture retention characteristics during periods of low rainfall.

Fort Wainwright, AK

The soils of Fort Wainwright located within the Subarctic ecological region are typically silt loams, which are 0-25% clay, 50-85% silt, and 0-50% sand. These soils have slopes ranging from 0-45%, and typical vegetative cover consists of evergreen forests and shrubs. The area receives 10-25 in. of precipitation each year. July through September is the wettest period of the year; 1.5-2.5 in. of precipitation fall each month. During the dry season, which runs from December to the following April, less than 0.5 in. falls monthly. General BMPs for hydroseeding at Fort Wainwright should be:

> BFM products are recommended for the wet season, as they are aptly suited for the slopes in the area, and although the precipitation is low even during the wet season, the silt loams of the area should retain moisture well. An FRM is recommended at all other times for its ability to retain the most moisture from the little amount of natural precipitation.

Conclusions

The above BMPs have been recommended using general data regarding each military installation's climate, slopes, and soil types, and also making reasonable assumptions about other factors, such as slope lengths. It is important to note that the selection of an HECP is very site specific. Figures C-1 and C-2 provide guidelines for selecting an HECP based on a given soil type; however, these recommendations may need to be adjusted due to other factors previously discussed. Clearly, efforts should be made to conduct a hydroseeding treatment during the optimum growing season; however, if this is not possible, the above recommendations may need to be increased due to the need for a longer functional longevity. They should also be adjusted for given slope lengths. Consult Figure B-1 (p B-2) for recommendations on HECPs regarding slope lengths.

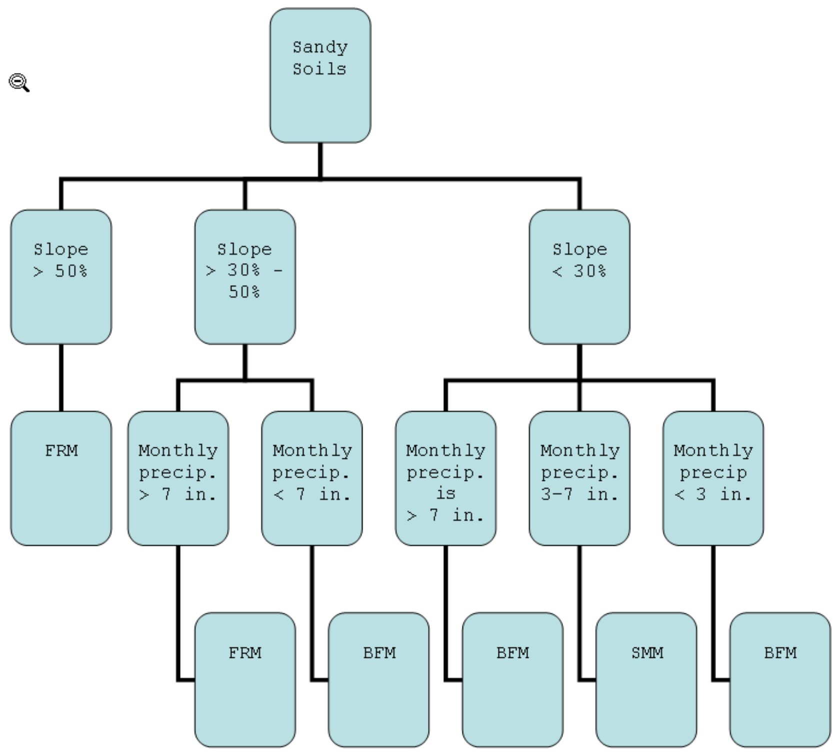


Figure C-1. HECP selection chart for sandy soils.

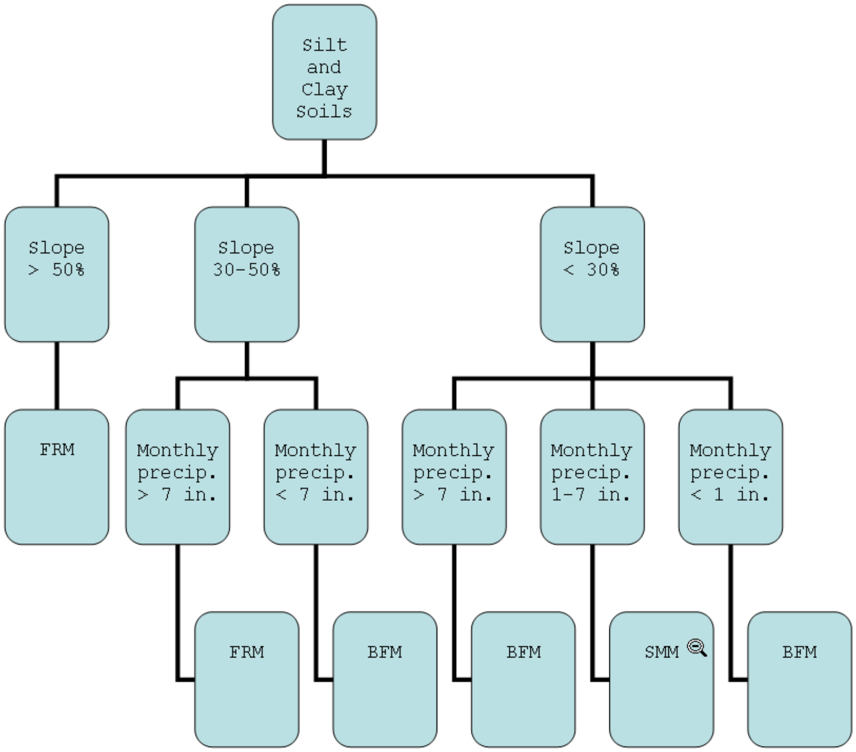


Figure C-2. HECP selection chart for silt or clay soils.

Appendix D: Major Manufacturer's of Erosion Control Products

Table D-1 lists major manufacturers of erosion control products, hydroseeders and related equipment, and related products. This list is not exhaustive, nor is it intended to be taken as a recommendation of any specific product or manufacturer. Table D-1 is intended solely to provide readers with a starting point to conduct research into the products that will best serve their needs, and to find distributors and vendors of hydroseeding products in their areas.

In several states, the Department of Transportation has compiled a list of approved products for use in road construction products. These lists are much more extensive than the one given here, and are a good place to find more manufacturers and products.

Table D-1. Major manufacturers of erosion control products.

Company	Website	Telephone Number	Products
American Excelsior Co.	http://www.americanexcelsior.com	1-800-777-7645	HECPs
Applegate Mulch	www.applegatemulch.com	1-800-627-7536	HECPs
Bowie Industries, Inc.	http://www.bowieindustries.com	1-800-433-0934	Equipment
Central Fiber Corp.	http://www.centralfiber.com	1-800-654-6117	HECPs
Finn Corp.	http://wwwqa.finncorp.com	1-800-543-7166	HECPs, equipment
HydroStraw	http://www.hydrostraw.com	1-800-545-1755	HECPs
JRM Chemical	http://www.soilmoist.com	1-800-962-4010	Fertilizers, Amendments
Kincaid Equipment	http://www.kincaidequipment.com	1-620-465-2204	equipment
Mat Inc.	http://www.soilguard.com	1-888-477-3028	HECPs
Mulch & Seed Innovations	http://www.mulchandseedinnovations.com	1-256-927-8823	HECPs
North American Green	www.nagreen.com	1-800-772-2040	HECPs
Profile Products	www.profileproducts.com	1-800-508-8681	HECPs
Southwest Environment Services, Inc.	http://www.southwestenvironment.com	1-903-531-2211	HECPs
Terra Novo	http://www.earthguard.com	1-888-843-1029	HECPs

Appendix E: Acronyms and Terms

Acronyms

Term	Spellout
AR	Army Regulation
ASTM	American Society for Testing and Materials
BFM	bonded fiber matrix
BMP	Best Management Practice
CEERD	U.S. Army Corps of Engineers, Engineer Research and Development Center
CEMML	Center for the Environmental Management of Military Lands
CONUS	Continental United States
DA	Department of the Army
ECB	Erosion Control Blanket
ECTC	Erosion Control Technology Council
FRM	Fiber-Reinforced Matrix
HECP	Hydraulic Erosion Control Product
HM	Hydraulic Mulch
HQUSACE	Headquarters, U.S. Army Corps of Engineers
NRCS	National Resource Conservation Service
PAM	Polyacrylamide
PDF	Portable Document Format
PE	Program Element
POC	point of contact
PWTB	Public Works Technical Bulletin
PWTB	Public Works Technical Bulletin
RECP	Rolled Erosion Control Product
RUSLE	Revised Universal Soil Loss Equation
SFM	Stabilized Fiber Matrix
SMM	Stabilized Mulch Matrix
URL	Universal Resource Locator
USACE	U.S. Army Corps of Engineers
USDA	U.S. Department of Agriculture
USDA	U.S. Department of Agriculture
USEPA	U.S. Environmental Protection Agency
USEPA	U.S. Environmental Protection Agency
WWW	World Wide Web

Explanation of Terms (Glossary)

Term	Definition
Alkaline	Having a pH above 7, or being basic.
Berm	A mound or wall of earth or sand.
Biodegradable	Broken down by organisms found in the environment.
Germinate	To develop from a seed into a sprouted plant.
Hydrocolloid	A mixture in which one substance is distributed evenly throughout another; in a hydrocolloid, the dispersing substance is water.
Hydrophobic	Resistant to the absorption of water.
Infiltration	The process by which water enters into a soil matrix.
Photodegradable	Decomposed by exposure to light.
Polyacrylamide (PAM)	A highly water-absorbent gel that can be used as a thickening or suspending agent, formed from cross-linked acrylamide units.
Soil Structure	The shape soil particles take when they form an aggregate.
Soil Texture	One of 12 classifications based on percent compositions of sand, silt, and clay.
Slurry	A mixture of insoluble substances in water.

Appendix F:
References

ASTM D6459-07. 2008. *Standard Test Method for Determination of Rolled Erosion Control Product (RECP) Performance in Protecting Hillslopes from Rainfall-Induced Erosion*. ASTM International, West Conshohocken, PA.

Amaranthus, Mike, and Dave Russell. 2004. "Revegetating After a Wildfire." *Erosion Control*. November.

American Chemical Society. 2007. "What are the Health Effects of Acrylamide and How Can it Be Reduced in Food?" *Science Daily*. August.

Anderson, Neil. 2002. "Secrets of the Underground Network." *Land and Water* 46(2).

Baxter, Roberta. 2007. "Hydroseeding: An Industry Evolving." *Erosion Control.* February.

CEMML. 2007. *Applications of Bailey's Ecoregions to military lands. Center Environmental Management of Military Lands (CEMML)*, Colorado State University, Fort Collins, CO. Accessed online on May 11, 2009, http://www.cemml.colostate.edu/bailey_ecoregion.htm.

Cilimburg, Amy, and Karen Short. 2005. *Effects of Forest Fires*, http://northernrockiesfire.org/effects.htm

Cole, Jason. 1999. "Factoring in the Elements: Tips on Choosing the Best Materials and Application Methods for your Projects." *Erosion Control*. November.

Cooke, R.A., T.A. Dillaha, T.M. Gidley, and S. Mostaghimi. 1994. "Effectiveness of Different Approaches for Controlling Sediment and Nutrient Losses from Eroded Land." *Journal of Soil and Water Conservation* 49(6):615-616.

Clean Washington Center (CWC). 1999. *Evaluation of Hydroseeding with Compost Additives.* February 1999.

Faucette, Brit. 2004. *Evaluation of Environmental Benefits and Impacts of Compost and Industry Standard Erosion and Sediment Control Measures Used in Construction Activities.* University of Georgia.

Hayes, S.A., R.A. McLaughlin, and D.L. Osmond. 2005. "PAM Use for Erosion and Turbidity Control on Construction Sites." *Journal of Soil and Water Conservation* 60(4):193-197.

Howard, Heidi R., and Brandy S. Koch. 2004. *Current Technologies for Erosion Control on Army Training Lands*, Public Works Technical Bulletin 200-3-30. U.S. Army Corps of Engineers, Washington, DC, http://www.wbdg.org/ccb/ARMYCOE/PWTB/pwtb_200_3_30.pdf

Kegley, S., B. Hill, and S. Orme. 2007. *PAN Pesticides Database.* Pesticide Action Network, http://www.pesticideinfo.org

Lauro, Frank J., and Marc S. Theisen. 2007. "Finding the Right Erosion Control Solution." *Land and Water* 50(6).

Leman, Robert G., Mark L. McFarland, and Charles Stichler. 1998. *Non-Traditional Soil Additives: Can They Improve Crop Production?* Texas Agricultural Extension Service.

Leyva, George, and Hossain Kazemi. 2002. *Erosion and Sediment Control Field Manual*, 4th ed. California Regional Water Quality Control Board.

Lu, Jianhang, and Laosheng Wu. 2003. "PAM Distribution in Columns of Organic Matter-Removed Soils Following Surface Application." *Journal of Environmental Quality.*

MacDonald, L.G., D.T. Rough, and K. Schaffrath. 2007. "Post Fire Erosion: Long Term Recovery and Effectiveness of Rehabilitation Techniques." *EOS Trans. AGU*, 88(52) Fall Meeting Supplement, Abstract H43F-1697.

McFarland, M.L., C.R. Stichler, and R.G. Lemon. 1998. *Non-Traditional Soil Additives: Can They Improve Crop Production?* L-5202. Texas Cooperative Extension, College Station, TX.

Nadler, A., J. Letey, and M. Malik. 1991. "Mobility of Polyacrylamide and Polysaccharide Polymers Through Soil Materials." *Soil Technology* 4:255-263.

Nadler, A., J. Letey, and M. Malik. 1992. "Desorption of Polyacrylamide and Polysaccharide Polymers from Soil Materials." *Soil Technology* 5.

Northcutt, Greg. 2004. "Improve Hydroseeding Success by Breathing New Life into Barren Soils." *Land and Water* 48(2).

Smith, Eldon A., Frederick W. Oehme, and Susan L. Prues. 1997. "Environmental Degradation of Polyacrylamides II: Effects of Environmental (Outdoor) Exposure." *Ecotoxicology and Environmental Safety* 37(1).

Steinbacher, John. 2000. "Revegetating with Native Plants at Drastically Disturbed Sites." *Erosion Control.* March.

U.S. Environmental Protection Agency (USEPA). 1997. *Innovative Uses of Compost: Erosion Control, Turf Remediation, Landscaping.* EPA530-F-97-043. October 1997.

Wohlgemuth, Peter M., Jan L. Beyers, Ken R. Hubbert, and Peter R. Robichaud. 2006. *Evaluating the Effectiveness of Mulching as a Post-Fire Erosion Control Treatment.*