ALTERNATIVES TO SILT FENCE FOR TEMPORARY SEDIMENT CONTROL AT HIGHWAY CONSTRUCTION SITES: GUIDELINES FOR TxDOT

by

Harlow C. Landphair
Research Scientist
Texas Transportation Institute

Jett A. McFalls
Research Associate
Texas Transportation Institute

Beth E. Peterson
Graduate Research Assistant
Texas Transportation Institute

and

Ming-Han Li
Graduate Research Assistant
Texas Transportation Institute

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16. Abstract

Since the implementing of the NPDES, TxDOT has spent an average of approximately $4.5 million on the installation and maintenance of silt fence. This project identified three promising alternatives to the use of silt fence for temporary sediment control on construction sites. The report provides an analysis of the cost effectiveness of the alternatives compared to silt fence and makes several recommendations for selecting an appropriate alternative to silt fence. Based on the research, the report recommends that the use of silt filter fence as an in-channel silt dam should be discontinued in favor of a more suitable option. The report appendix provides suggested special specifications and alternative materials.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

PROBLEM OF SEDIMENTATION

It is estimated that 3.5 billion metric tons of sediment are washed into U.S. streams and rivers annually (Mitchell, Sargand, & Masada 1991). The sedimentation problem is serious enough that it is considered by some to be one of the top environmental issues in the world today (Dallaire 1996). Sediment washed into a river or stream due to sheet erosion can quickly overload the waterways in a drainage basin. Sedimentation results in aggradation of the stream bed, change of the channel pattern, and sedimentation of rivers, lakes, and reservoirs. This results in increased flood elevations and increased down-stream flooding (Mitchell 1993; Smith 1994). Sediment-laden runoff also impacts aquatic habitats and reduces productivity by decreasing water clarity, increasing toxic and nutrient content, and causing deoxygenation of the water (Connelly & Lin 1996; Fennessey & Jarrett 1994). The consequences of these problems lead to quantifiable economic losses such as increased utility costs and increased flood damage. There are also less quantifiable intangible consequences, such as reduced water quality (Goldman, Jackson, & Bursztynsky 1986). One estimated annual cost of damage from water-based soil erosion in the U.S. was $6.1 billion (in 1980 dollars) (Fennessey & Jarrett 1994).

GOVERNING LEGISLATION

The Federal Water Pollution Control Act of 1972, or "Clean Water Act" (CWA), is the primary legislation governing the protection and improvement of water quality in the U.S. Because erosion and sedimentation are an integral part of the water quality equation, the CWA is the basis for provisions that require erosion and sediment control. As a result of this legislation, many states were prompted to strengthen existing, or pass for the first time, stormwater management and sediment control legislation. The CWA also addressed soildisturbing activities other than agricultural and rural land management practices to include housing developments, highway construction, shopping centers, and other urban development (Peterson 1997).

When considered as a percentage of the annual total, erosion associated with general construction activities constitutes only a small portion of the total annual loss. However, the concentrated nature of construction activities becomes a major source of pollution to the lakes and streams that drain urbanizing watersheds (Goldman, Jackson, & Bursztynsky 1986:1.2). Highway construction projects in particular also have a significant impact. One study in the mid-1960s found that sediment from highway construction contributed 85% of the total sediment yield from overland runoff in one drainage basin (Vice, Guy, & Ferguson 1969). Furthermore, because excavation and filling activities for highways may extend for several miles, the projects may cross the boundaries of several watersheds (Mitchell 1993:1). This subsequently led the U.S. Environmental Protection Agency (EPA) to identify highway construction as a potential source of significant sediment pollution.

Pursuant to the provisions of the Clean Water Act as amended, the EPA was charged with promulgating rules to implement a "National Pollutant Discharge Elimination System" (NPDES). The NPDES rules and permitting requirements for managing stormwater discharges from construction activities became effective in 1992.

TxDOT ACTIVITIES

Texas is one of 11 states which currently does not have the NPDES permitting authority as part of a state-based regulatory program. For this reason, the state and TxDOT use the federal guidelines as the basis of its stormwater management and permitting process. The federal program requires submitting a Notice of Intent (NOI) for each construction project. The NOI "is a certification that a storm water pollution prevention plan has been prepared for the site and that the plan is in compliance with all federal, state, and local requirements for erosion control and storm water management" (Roberts 1995:9). The NOI is based on a Stormwater Pollution Prevention Plan (SW3P) which outlines the construction sequence, describes the erosion and sedimentation control measures and the procedures for inspection maintenance and repair. The process is completed with the filing of the Notice of Termination (NOT).

TxDOT responded to the implementation of the NPDES program with a pro-active, comprehensive stormwater management program for its construction projects. The program is outlined in the 1993 TxDOT publication *Stormwater Management Guidelines for Construction Activities*. TxDOT's program is based on three stormwater management objectives for construction projects:

1) preventing degradation of receiving waters;
2) facilitating project construction and minimizing overall costs; and
3) complying with federal, state, and local regulations.

Compliance with the NPDES requirements has resulted in a substantial increase in the costs associated with temporary erosion and sediment control on TxDOT construction projects. A major component of the increased cost is the use of geosynthetic silt fence. Nationally, geotextile silt fence is the most popular means of temporary sediment control on construction projects. The primary applications include preventing sediment migration beyond the construction site perimeters, in-channel silt traps, and drain inlet protection.

During the past three years, TxDOT's total expenditures for temporary erosion and sediment control on highway construction projects have ranged from $9.3 million to slightly less than $6 million per year. Of these amounts, costs for the installation, maintenance, and removal of silt fence for temporary sediment control have ranged from $6.2 million to $4.1 million per year and between 60 to 69% of the total annual expenditure for temporary erosion control.

Because these costs are significant, TxDOT has undertaken efforts to determine the mechanical effectiveness of silt fence, the cost effectiveness of the material, and what alternatives might exist which could reduce the annual costs. This study is one part of the overall effort and has two objectives:

1) to identify alternative methods or technologies which can be used for temporary sediment control measures during construction; and
2) to evaluate the cost effectiveness of alternative measures.

DEFINITION OF SILT FENCE

INTRODUCTION

In reviewing the literature, there appears to be no standard definition associated with the term *silt fence*. The majority of sources use *silt fence* as a generic term to mean a sediment control structure made of a geotextile fabric and used for a variety of applications. Other sources refer to this type of generic, geotextile fence as a *filter fabric fence*. Some sources define *silt fence* as a geotextile material reinforced by wire mesh, while other sources define this type of reinforced fencing as a *filter fabric fence*. Throughout this report, *silt fence* is a generic term for a geosynthetic fabric used as a sediment control structure, and a *filter fabric fence* is a silt fence reinforced with wire mesh.

GEOTEXTILE SILT FENCE

The geotextile materials commonly used to make silt fences are polyester or polypropylene. For sediment control purposes, there are three main categories of geotextiles: 1) woven slit-film fabrics; 2) woven monofilament fabrics; and 3) non-woven fabrics. The two purposes of the silt fence are to optimize the passage of water and to retain solids in runoff (Horner, Guedry, & Kortenhof 1990). Theisen (1992) cites Richardson and Koerner (1990) in their description of a silt fence (pp. 4-36):

> "A well designed silt fence must initially screen silt and sand particles from runoff. A soil filter is formed adjacent to the silt fence and reduces the ability of water to flow through the fence. This leads to the creation of a pond behind the fence which serves as a sedimentation basin to collect suspended soils from runoff water. To meet such needs, the geotextile must have properly sized openings to

form the soil filter and the storage capacity of the fence must be adequate to contain the volume of water and sediment anticipated during a major storm."

These materials should be selected according to the fabric strength and permeability. While tests of fabric strength are standardized in the industry, permeability is not consistently defined. Subsequently, Horner, Guedry, and Kortenhof (1990) state, "selection of characteristics to optimize both passage of water (to prevent pooling) and retention of solids in a given application is not entirely clear" (p. 8). To prevent the fence from sagging and allowing the release of sediment-laden runoff, the supporting fence posts also need to be placed close enough together to support the sediment load and water pressure behind the fence (Horner, Guedry & Kortenhof 1990).

APPLICATIONS OF SILT FENCE

Silt fence can be grouped into three types based on the application. These are:

- Perimeter control. This is the most common application of silt fence. The fence is placed around the limit of construction to prevent sediment from migrating off the site. The fabric is healed in at the base and supported by posts at regular intervals.

- Protection of storm drain. This application is intended to trap sediment before it enters a storm drain. The fabric is healed in at the base surrounding a drainage inlet or culvert entrance and is supported by posts at regular intervals. Straw or hay bales or wire mesh may also be placed on the downstream side of the fabric to reinforce the fence material.

- In-channel applications for minor swales or ditches. This application utilizes a filter fabric fence to form a sediment trap in a drainage channel. The fence is constructed with the wire mesh reinforcement placed on the downstream side of the fabric. The fabric is healed in at the base and is supported by posts at regular intervals.

LITERATURE REVIEW AND CURRENT PRACTICE

PROCESS

TxDOT has sponsored six projects that examine recent literature in erosion control measures. These are:

1) No. 1379-1, Temporary Erosion Control Measures Design Guidelines for TxDOT;
2) No. 0-1475, Evaluation of the Impacts, Performance and Costs of Storm Water Pollution Prevention Plans (SW3P) as Applied to Highway Construction;
3) No. 1425, Evaluation of the Impacts, Performance and Costs of Stormwater Pollution Prevention Plans (SW3P), as Applied to Highway Construction;
4) No. 7-1934, Water Quantity and Quality Impacts Assessment of Highway Construction in Austin, Texas, Area;
5) No. 7-2954, Determination of the Performance Efficiency of Permanent Runoff Control Systems;
6) NCHRP 15-13, Long-term Performance of Geosynthetics in Drainage Applications;
7) NCHRP 25-1, Wet Detention Pond Design for Highway Runoff Pollution Control; and
8) P/F HPR-2(168), Management of the Discharge and Quality of Highway Runoff in Karst Areas to Control Impacts to Ground Water.

The primary objectives of this project were to expand the understanding of options for sediment control and determine the cost effectiveness of alternatives to silt fence. This was done by exploring the international literature and research in related areas of inquiry such as mining and agriculture as well as the transportation and erosion control industries. The process included a broad-based literature search relating to erosion and sediment control, with the emphasis on temporary sediment control measures and alternatives to silt fence. In addition, personal contacts and interviews were used in selected TxDOT districts and with other state departments of transportation to determine the current state of practice in the field.

LITERATURE REVIEW

Introduction

While the primary focus of this project was temporary sediment control during highway construction, a broad-based literature search was undertaken that included erosion and sediment control. These two areas of inquiry and practice are so closely related that a great deal of significant content would have been overlooked by attempting to narrow the focus to temporary sediment control measures and alternatives to silt fences. The literature search included national and international sources in the subject areas of agriculture, mined land reclamation, transportation, and the erosion control industry. In addition to regularly cataloged publications, erosion and sediment control manuals from several state transportation agencies were reviewed.

Historical Perspective

Early interest in the subject of sediment and sedimentation centered primarily on the theory and problems of sedimentation as related to settling basins for public water-works projects such as sewage treatment and water purification facilities. One of the earliest articles on the issue of the settlement of suspended sediment was by Seddon (1889). While theories about the law or laws pertaining to the settlement of sediment existed at this time, Seddon states that he was probably the first to conduct actual research on the "phenomena of settlement" and report his findings.[1] Hazen (1904) notes that little was published on the theory of sediment settlement since Seddon's (1889) article, but since then, "the practice of building and operating sedimentation basins [for public water-works projects] has advanced materially" (Hazen 1904:45).

Brown (1965) states,Between 1850 and the early 1940s, that less than 150 literature references, including domestic and foreign, were found on the subject of reservoir silting. As of 1935, only a few records existed on the sediment loads of streams and many of these were of highly questionable value due to a lack of understanding of the principles of sediment transport and the crude sampling equipment (Brown 1965). Most of the pioneering research in the field of sediment transport was done in European universities and institutes. Prior to 1935, very few research studies on sedimentation were done in the U.S. (Brown 1965).

In 1935, the U.S. Congress passed the Soil Conservation Act to address the serious loss of soil from croplands caused by water and wind erosion. This legislation established the U.S. Department of Agriculture (USDA) Soil Conservation Service (SCS), which was renamed in 1995 to the Natural Resources Conservation Service (NRCS). By 1946, there were over 3,000 papers, articles, and reports published on the topic of sedimentation and related subjects (Gottschalk 1965). In 1947, the first national conference on sedimentation was held in Denver (Brown 1965). During the 1950s, research and field work on sediment transport and sedimentation continued to increase dramatically (Brown 1965). The second national conference on sedimentation was held in 1963 in Jackson, Mississippi. In the 15 years since the first such conference, a great deal of field research and laboratory studies had been done, resulting in significant advancements in the knowledge of sedimentation conditions and processes (Brown 1965; Vanoni 1965).

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[1] Pearsons [, 1904 #93], in his discussion of Hazen's [, 1904 #92] article, mentions that he received input from the late Col. Henry Flad and T. J. Whitman of St. Louis, and the late Birdsill Holly of Lockport, New York, when designing the settling basins for Kansas City in 1874. According to Pearsons, these men "had made careful experiments on both sedimentation and filtration" (p. 72), as had he himself. However, no mention is made of these experiments being reported in writing.

Between 1937 and 1965, the vast majority of the research studies done on erosion and sediment control related to agricultural, range, and forest lands (Israelsen et al. 1980). By the mid-1960s, research was beginning to address erosion problems related to construction and transportation. Early research on sediment problems resulting from urban construction activities include the study by Guy (1965), which focused on the problem of sediment-laden runoff resulting from changes in land use, i.e., from rural to residential.

While organized efforts towards erosion problems and control along highways began in the early 1930s with activities of the American Association of State Highway Officials (AASHO) and the Highway Research Board (HRB),[2] such efforts concentrated on engineering and design aspects of highways for the overall reduction of erosion (Johnson 1961). In 1965, Bullard was one of the first to discuss erosion problems associated with highway construction. Some of the early, notable research on erosion and sediment problems related to highway construction activities was conducted by Vice, Guy, and Ferguson (1969), Swerdon and Kountz (1973), and Reed (1978). As of 1980, however, quantitative data from research on erosion and sediment problems relating specifically to highway construction activities was still "practically nonexistent" (Israelsen et al. 1980:4). In 1993, Barrett et al. arrived at a similar conclusion from their thorough review and evaluation of literature on highway runoff and construction. The Barrett report concluded that "there is an abundance of literature on erosion control methods, but only a handful of reports that focus on the control of erosion from highway runoff. Furthermore, only a fraction of these reports contain quantitative analysis of control methods" (p. 41). The literature review for this report further supports this finding.

[2] The American Association of State Highway Officials later changed to its current name—American Association of State Highway and Transportation Officials (AASHTO). The Highway Research Board later changed its name to the Transportation Research Board (TRB).

OVERVIEW OF THE SEDIMENT CONTROL LITERATURE

Introduction

Most of the current research and other literature related to sediment control is devoted to the broad scope of erosion control and associated management practices. There is an abundance of literature dealing with sediment control methods and collection practices. However, these issues are usually addressed as a subset of the overall strategy for erosion control. Silt fence is most often referenced as part of a discussion of sediment management and drainage control.

Performance of Geotextile Silt Fence

The use of silt fence for temporary sediment control has become a de facto standard as the primary means of sediment control for construction sites for the following applications:

- Perimeter control,
- Protection of storm drain, and
- In-channel applications for minor swales or ditches.

Popularity of Silt Fence

Geotextile silt fence has gained popularity over other temporary sediment control measures because of several factors including longevity, durability, ease of installation, portability, and maintenance. The primary disadvantage of silt fence is frequent failure, with the causes usually being related to improper installation and maintenance. The most common failure is undercutting, in which the fabric pulls out of the check slot and allows sediment-laden flow to undercut the fencing. The results are erosion problems and sediment-laden runoff bypassing the ditch flow and entering receiving waters.

The NPDES mandates have resulted in significantly increased expenditures on sediment control, and silt fence in particular. There is little published research which provides quantitative performance measures of silt fence materials. Kouwen's (1990) report for the Ontario Ministry of Transportation provides a detailed characterization of the laboratory performance of burlap, straw bales, and synthetic fabric. In an unpublished study, McCoy (1993) presents data collected from field observation studies of silt fence in Austin, Texas. The data from the field studies suggest that the filtration rates obtained in the laboratory are considerably higher than the values observed in the field. Data from other work in progress seem to confirm this observation. Clearly, more research is needed if performance becomes a consideration in the regulatory rule. At this point, no quantitative methods or measures are associated with regulatory programs.

Some publications have attempted to develop cost effectiveness measures for a variety of Best Management Practices (BMPs). These include reports by Mayo et al. (1993) for the EPA, and by Horner, Guedry, and Kortenhof (1990 #81) for the Washington State Department of Transportation. In addition, Harding (1994) has developed an Erosion Control Benefit Matrix (ECBM) which could be used to evaluate and select appropriate BMPs. Most of these methods use a performance measure as a variable in the cost effectiveness equation. However, given the lack of reproducibility of performance measures, these methods must be viewed with a degree of suspicion.

Performance of Traditional Alternatives to Silt Fence

Temporary sediment control measures in construction that predate the use of geotextile silt fence include hay and straw bales, sandbags, rock check dams, and diversion dikes. These seem to have evolved as part of traditional agricultural and engineering practices. References were noted in the USDA, Soil Conservation Service, Field Engineering Manual and the National Handbook of Conservation Practices based on SCS research that has antecedents which date back to the early- to mid-1900s. Many current field manuals describe the appropriate applications and provide installation details. It is believed that most of the existing erosion control literature and manuals can be traced back to this early work in erosion control. The reasons for the decline in the use of these traditional methods in favor of geotextile silt fences can be attributed to issues of longevity, reliability, durability, portability, and maintainability.

Hay and Straw Bales

Before the wide availability of geosynthetic fabrics, hay and straw bales were commonly used for both perimeter and in-channel sediment control. When used for in-channel sediment control and installed properly, hay or straw bale sediment checks can reduce channel degradation by capturing sediment and reducing water velocities (Fifield 1993). From his field research study, Reed (1978) estimated the sediment trap efficiency of straw bales (based on the sediment yield from the construction area and the amount of sediment trapped behind the bale structures) to be 5%. Fifield (1993) believes that their trap efficiency is up to 20%, but he acknowledges that the sediment removal rate is usually lower due to failure of the hay/straw bale check structure. Kouwen (1990) states that "straw bales are as effective as geotextiles or gravel berms" (p. iv). He also points out, however, that compared to silt fence, hay and straw bales are much more difficult to install properly and have a much shorter effective life. Hay/straw bales can also contain viable seeds of nonnative plants and weeds which can germinate and grow, thus creating additional problems at the site (O'Malley 1996).

In a joint study for the Ohio Department of Transportation and the Federal Highway Administration (FHWA), Mitchell (1993) conducted a survey of temporary erosion and sediment control guidelines and practices used in other states. Survey responses were received from personnel in 49 states. The results of the survey found that the most routinely altered type of erosion and sediment control measure, as specified in construction drawings, is the replacement of hay or straw bales during construction. He found that in "roughly 36%

of the situations" hay or straw bales were routinely replaced with filter fabric fence. Specific reasons for the replacements were not cited in the report.

According to the literature, the major problem with the use of hay and straw bales for sediment checks is the tendency of the bales to degrade quickly (Fifield 1993; Mitchell 1993; O'Malley 1996; Roberts 1994). Depending on the type of binding and vegetation, as well as climatic factors, hay and straw bales have an effective life of three months (Roberts 1995) to 12 months (Fifield 1993). Sediment bale checks are therefore recommended only for applications of short duration.

Furthermore, runoff can undercut the bales if not properly installed. This results in erosion problems and bypassing of the ditch flow (Mitchell 1993). Undercutting also causes the bales to break up and migrate to other areas, including off the construction site. This creates litter problems which can act as dams for debris and causing flooding (O'Malley 1996). Measures which can be taken to reduce these problems include embedding the bales at sufficient depth and staking them securely in a trench (Fifield 1993; Mitchell 1993). In addition, an adequate number of bales needs to be installed upslope in the ditch or swale and sufficient checks in the series need to be provided (Mitchell 1993).

Mitchell's (1993) study results found that, due to the difference between sheet flow and concentrated flow, bale sediment checks had longer service life when installed along the toe of the embankment than when installed in ditches. However, Roberts (1995) states that straw bales "may be used in swales with very low flows to filter runoff" (p. 43). Mitchell's (1993) report also notes that hay bales were not effective for preventing sediment from entering culverts. He suggests alternative sediment control measures for this situation, "such as providing a standpipe sediment control on the culvert inlet, or rock check dams" (p. 126).

Rice Straw Bales

One potential alternative for straw/hay bales is the use of rice straw bales. O'Malley (1996) states that, according to John Haynes, transportation erosion specialist for the California Department of Transportation (CalTrans), "rice straw has a higher silicate content, and the bales are [therefore] less prone to breaking up when they get wet. Additionally, rice straw contains few viable seeds, and therefore minimizes the problem of introducing nonnative plants and weeds" (O'Malley 1996:35).

Sandbags

The life of a sandbag depends in part on the material used for the bag. The traditional burlap material had a life of six to twelve months depending on the climate. A new 1,200-hour bag on the market reportedly "lasts twice as long as ordinary bags and is good for the entire erosion control season" (O'Malley 1996:26). Since lesser bags, such as 400- or 600-hour bags, may need to be replaced well before the completion of a job, 1,200-hour bags may be more cost effective to use (O'Malley 1996). The availability of UV-resistant synthetic fabrics has also increased the field life span of bags to as much as five years.

In order to ensure that sandbags will be effective, it is necessary to use a bag large enough so it will not be easily displaced. One recommendation is a minimum bag size of 22.7 kg (50 lb). It is also important to use a good granular sand in the bags so the water will actually filter through (O'Malley 1996). However, because these bags are filled with sand, they represent a potential source of sediment if the bag is damaged or fails.

Rock Check Dams

Rock check dams or berms are another sediment control measure used for in-channel, silt-trap applications. In their study of TxDOT construction sites, Barrett et al. (1996) found that silt fences and rock berms were the most commonly used in-channel sediment and erosion controls on TxDOT construction projects. In his *Best Management Practices for Erosion and Sediment Control* developed for the Federal Highway Administration, Roberts (1995) defines a check dam as "a small, temporary obstruction in a ditch or waterway used to prevent erosion by reducing the velocity of flow" (p. 43). From the results of his research study, Reed (1978) calculated the sediment trap efficiency of rock dams at 5%, based on the sediment yield from the construction area and the amount of sediment trapped behind the dam. Barrett et al. (1996) performed a field evaluation of one rock berm made of rock gabions and found a "negligible" removal efficiency of total suspended solids (TSS). Roberts (1995) states that check dams are not and should not be used as sediment trapping devices because their function is not for the control of sediment.

Diversion Dikes

Diversions are a tool to reduce sheet erosion on steep slopes. They have also been employed as a means of perimeter silt control. Their primary disadvantage is that sediment is often washed from the diversion dikes during peak flows. The cost of stabilizing diversion dikes used for temporary erosion control is not generally cost effective.

Sediment Basins and Sediment Traps

The use of sediment basins and traps are forms of in-channel and end-of-channel sediment control, especially from sites larger than 0.2 hectares (0.5 acre) and in watershed drainage areas which contain soils high in clay and silt. They remove sediment from runoff by detaining the runoff for a time period sufficient to allow the suspended solids to settle out of suspension. *Sediment traps* are considered in-channel sediment control measures and are generally used for sites with a drainage area of up to two hectares. *Sediment basins* are end-of-channel solutions and are used for larger areas up to 40 hectares (Roberts 1995). A more in-depth discussion of sediment basins and traps is contained later in this report.

Best Management Practices

A primary objective of this report was to identify sediment control practices used in the field as well as cost effective alternatives to silt fence. As previously mentioned, Mitchell (1993) conducted a joint FHWA and Ohio Department of Transportation study which surveyed and compared temporary erosion and sediment control guidelines used in other states. There were 62 responses from 49 states. Thirteen of the responding states included personnel from two departments, generally the design and construction departments, within the state agency.

Figure 1 shows the number of responses in each category of sediment control practices. The use of filter fabric fence combined with hay/straw bales was the most common practice, followed by filter fabric fence only. Kouwen (1990) states that the combination of silt fence and bales is the most effective since "it compensates for the shortcomings of each material" (p. 7). He also notes that using these materials together is more expensive than using either one separately. Furthermore, Mitchell's study found that geographic location and the availability of natural and synthetic materials was a significant influence in the selection of a management practice.

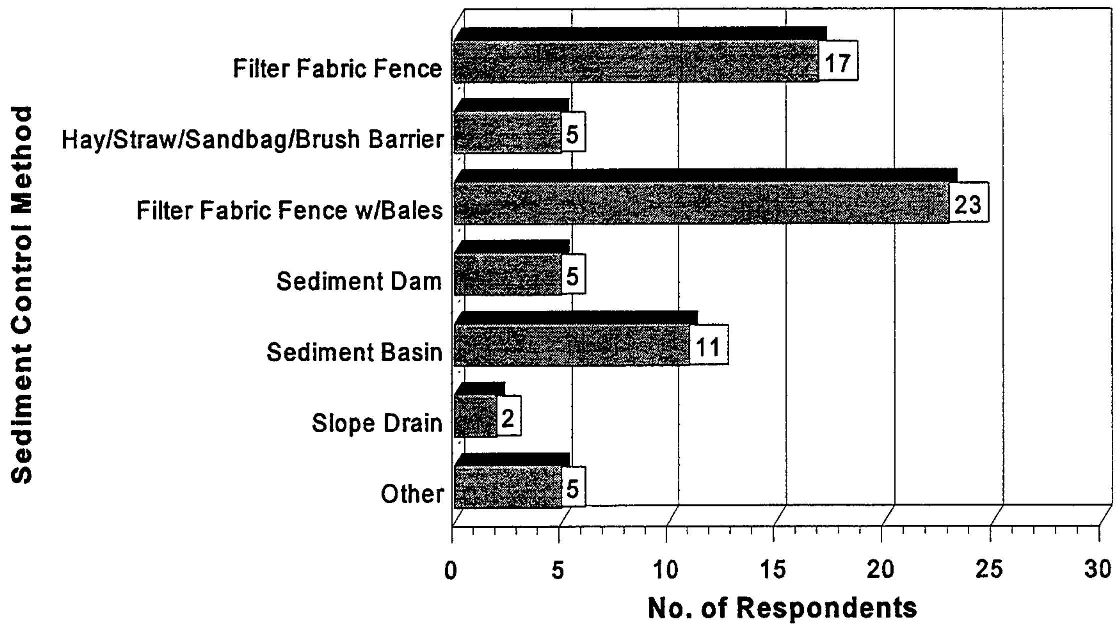

Figure 1. Temporary Sediment Control Method Ranked as the Most Important
Source: Mitchell, 1993. *Assessment of Erosion/Sediment Control in Highway Construction Projects,* p. 24

According to Mitchell's (1993) survey, the most common management practices for which states had specifications were filter fabric fence, bale checks, and sediment basins. These are consistent with TxDOT practices. The BMPs recommended in TxDOT's 1993 *Storm Water Management Guidelines for Construction Activities,* Section 5.0, are diversion, interceptor, and perimeter dikes; interceptor and perimeter swales; rock, brush, and sandbag filter dams; sediment control fence; sediment traps; and sediment basins.

In addition, TxDOT sediment control guidelines specify that measures such as hay bales, triangular sediment filter dikes, etc. may also be used, but they "are only recommended after consideration of the devices listed above has been given" (p. 36).

Mitchell's (1993) study also addressed major problems encountered by the various states in implementing erosion/sediment control measures. The survey results found that the most important problem was weather condition. The second most important problem was lack of contractor cooperation, and the third was lack of state personnel/time. The latter problem was also ranked by the majority as being the second most important problem.

CURRENT PRACTICE

Introduction

Because research literature tends to lag behind field practice in some situations, a survey was made of selected states and TxDOT districts. Only individuals responsible for field management of erosion control activities were interviewed. Fifteen state transportation agencies and eight TxDOT districts were contacted.

Since the purpose of the survey was informational, a subject matter outline was used rather than a formal survey instrument. The topics explored were: 1) application of geotextile silt fence for perimeter, inlet protection, and in-channel sediment control; 2) problems they encountered with the use of silt fence; and 3) their knowledge of, or use of, alternatives to silt fence. The information obtained from these interviews proved to be extremely valuable for this report.

Review of the States

The 15 state transportation agencies contacted and surveyed include Arizona, California, Florida, Georgia, Indiana, Maine, Minnesota, New York, North Carolina, Ohio, Pennsylvania, Virginia, Washington, Wyoming, and Wisconsin. The interviews confirmed that silt fence is the product of choice for temporary sediment control for the perimeters of construction sites. With few exceptions, the use of hay/straw bales and sandbags has been almost completely replaced with geotextile silt fence. The exceptions to the use of silt fence were usually related to high velocity, in-channel applications or where biodegradable applications are desirable or required.

Of the states contacted, only California (CalTrans), Washington (WSDOT), and Wyoming (WYDOT) indicated that they were evaluating alternatives to fabric silt fence. CalTrans has used the Continuous Berm™, an extruded sand dike, and is experimenting with the use of burlap fabric as a biodegradable option to geotextile fabric (Fifield, 1997 #115). WSDOT and WYDOT have begun to experiment with the use of the Triangular Silt Dike™ as a replacement for straw bales and/or sandbags. WYDOT recently started a pilot field trial program on the Silt Dike™.

Since their experience with the product was still new, data or specific information on its performance was not available (Samson 1997). WSDOT first performed new product evaluation tests on the Triangular Silt Dike™ and immediately began using them as replacements for straw bales and sandbags in the field. WSDOT has found the product to be extremely successful (Jenkins 1997; O'Malley 1997), and is considering using the Silt Dike™ as a replacement for silt fence in certain applications, such as minor in-channel applications (Jenkins 1997).

TxDOT Districts

Personnel in eight TxDOT districts were interviewed. No one in these districts was experimenting with alternatives to silt fence and they generally agreed that silt fence is a good solution to on-site sediment control. They felt that most of the problems with silt fence are due to abuse, improper installation, or inadequate maintenance, which can result in failure of the structure. One field manager in the Austin District felt that silt fence was also a good public relations tool. He said people seem to like the visual separation it provides, and they tend to complain when silt fence is not in place on a construction site.

The Austin District also indicated that they had some experience with Triangular Silt Dike™. The product seemed to perform as advertised, but no one felt they had sufficient experience with the material to make any firm conclusions.

ALTERNATIVES TO SILT FENCE FOR SEDIMENT REDUCTION

EROSION CONTROL STRATEGIES

While the focus of this project is on alternatives to silt fence for sediment control, it is important to place the discussion of sediment control in the broad context of erosion control. Numerous authorities in the literature sources point out the importance of preventing erosion as part of the equation, and generally relate the severity of sediment problems to the failure to control erosion. In fact, erosion control measures are the first line of defense in preventing off-site sediment movement from construction sites (Dallaire 1996; Horner, Guedry, & Kortenhof 1990; Israelsen et al. 1980; Lee 1995; Mayo et al. 1993; Northcutt 1997; O'Malley 1996; Roberts 1994; Roberts 1995; Schueler & Lugbill 1990; Smith 1994). Roberts (1994) states that sediment "controls based on the principles of filtering and trapping have limited efficiency and are used primarily as backup measures" (p. 38). Northcutt (1997) suggests, "Good erosion

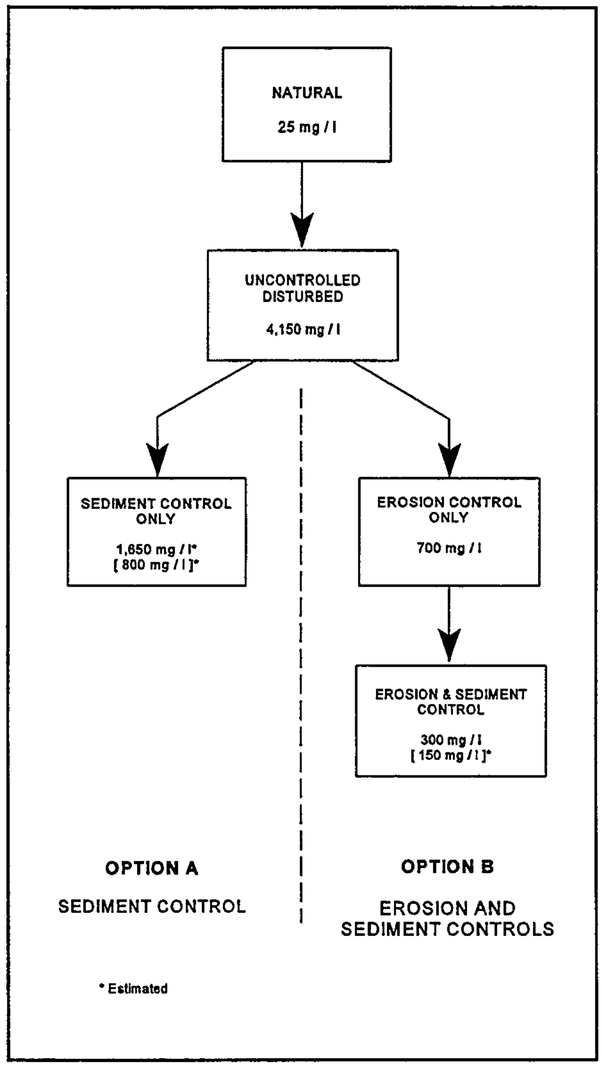

Figure 2. Relationship of Total Suspended Sediment Concentrations (TSS) in Sediment Control and Erosion Control Practices
Source: Schueler and Lugbill, 1990, as diagramed in Mayo et al., 1993

control takes care of sediment problems" (p. 10). As shown in Figure 2, Schueler and Lugbill (1990) found that erosion controls can be 85% effective in reducing suspended sediment loss from construction sites, while sediment controls have reported effective rates of 60-80%. When erosion controls and sediment controls are utilized together, the effectiveness level can be as high as 95% in reducing offsite suspended sediment loss, which approaches natural erosion levels (Schueler & Lugbill 1990, Mayo et al. 1993).

To ensure effective performance, sediment control and removal measures require continuous maintenance, which is often a costly process. Erosion control, on the other hand, requires less maintenance and is therefore generally less expensive (Mayo et al. 1993; Northcutt 1997). Mayo et al. (1993) further state that the costs associated with sediment control, including materials, labor, and maintenance costs, can be reduced by employing effective erosion control measures throughout the construction process. Moreover, as Horner, Guedry, and Kortenhof (1990) point out, these financial analyses do not include the costs associated with restoring slopes that have been eroded in the construction process. Erosion control is, therefore, much more effective and economical than simply relying on sediment control.

The issue of erosion control for sediment control is addressed in TxDOT's 1993 *Storm Water Management Guidelines for Construction Activities*. "Temporary structural controls . . . are the last means of defense to prevent erosion and sediment problems associated with construction activities. Consideration should first be given to minimizing the erosion potential" (Section 2.8, p. 15).

PHASED CONSTRUCTION PROCESS

Numerous literature sources discussed the advantage of staging the construction process to reduce the need for sediment control (Goldman, Jackson, & Bursztynsky 1986; Mayo et al. 1993; Northcutt 1997; Northcutt 1994; Roberts 1995; Schueler & Lugbill 1990).

Northcutt (1997) acknowledges that this is a relatively new concept in the U.S. construction industry. He cites the U.S. agriculture industry as good example of how a major shift in management practices, such as developing and encouraging new tilling practices, can reduce erosion and sediment production and decrease overall costs.

In his seven-year field study involving highway construction activity in five adjacent drainage basins in Pennsylvania, Reed (1978) divided the construction activities into seven phases. These were: 1) clearing and grubbing; 2) culvert construction; 3) bridge construction; 4) early earthmoving; 5) winter; 6) final earthmoving and drainage operations; and 7) automatic grading. The study evaluated both the effects of highway construction on suspended-sediment discharges and concentrations in streams, and the effectiveness of different erosion control measures in reducing sediment discharge during highway construction activities. In the final analysis relating to sediment yield, the study results found that the amount of potential sediment depends on the stage of construction. Specifically, his data found that sediment discharge increased:

- about 200% during the clearing and grubbing phase and during periods with little construction activity, such as winter and early spring;

- about 700% during the construction phases involving active earthmoving; and

- about 4,000% during the periods when the construction area was being fine graded and prepared for paving.

Schueler and Lugbill (1990) suggest that erosion potential can be related to six stages of construction. The stages they identify are: 1) pre-construction; 2) clearing and grading for access; 3) full clearing and grading; 4) installation of storm drainage systems; 5) active construction of structures; and 6) site stabilization.

A staged construction process is also advocated in *Best Management Practices for Erosion and Sediment Control,* developed by Roberts in 1995 for the Eastern Federal Lands Highway Design of the Federal Highway Administration. The three construction phases identified are: 1) the initial clearing phase; 2) the intermediate grading phase; and 3) the final stabilization of the site. Roberts suggests that addressing these three phases of construction in erosion control plans will aid in the selection of erosion control materials, especially on larger, more complicated projects.

When surface erosion control measures are employed during the different stages of a construction project, they "appear to provide at least a six-fold reduction in downstream suspended sediment levels" (Schueler & Lugbill 1990:x). It is, therefore, critical to implement erosion control measures quickly and to properly maintain them over the entire course of the construction project. Their study also points out that sediment controls are most effective during the early stages of construction and the most ineffective during later stages. In discussing stage five, Schueler and Lugbill (1990) state (p. 16):

> "Storm runoff volumes reach their maximum as the watershed reaches its ultimate imperviousness and remaining disturbed areas become heavily compacted. Storm drain systems efficiently convey runoff and sediments to the sediment controls. Disturbed areas subject to erosion are sharply reduced; however, erosion rates in the remaining disturbed areas are very high due to the declining effectiveness of temporary stabilization techniques. In addition, washoff of sediment tracked onto impervious areas becomes an important source of sediment. Effective capacity of sediment controls reach their lowest levels."

The reduction of erosion during the various stages of construction can be accomplished through the use of two strategies: 1) limit the amount of time that a site remains in an advanced stage of construction; and 2) reduce the total area of a construction site which can be disturbed at any given time (Goldman, Jackson, & Bursztynsky 1986; Roberts 1994; Roberts 1995; Schueler & Lugbill 1990; Smith 1994). In his study, Mitchell (1993) found that 28 of the 49 responding states contain a guideline in their document dealing with the maximum erodible area which should be exposed at any one location. These maximum erodible areas range from 1,625.8 m^2 to 101,170.6 m^2 (17,500 ft^2 to 1,089,000 ft^2), with over half (15) of these states citing 69,676.7 m^2 (750,000 ft^2) as the maximum area to be exposed, and about one-fifth (six states) citing 68,796 m^2 (740,520 ft^2) as the maximum area. TxDOT's guidelines do not specify a definite maximum area which can be exposed. Rather, the guidelines list "some items to consider when planning the sequence and phasing of highway construction operations," including "sustain a manageable area of construction activities, i.e., ensure that the contractor limits the area of erodible soil exposed at any given time such that erosion can be effectively controlled" (TxDOT *Storm Water Management Guidelines for Construction Activities*, 1993 #17, Section 2.3).

Finally, it is critical to develop an overall erosion control strategy, or a Best Management Practice (BMP), prior to the beginning of construction. The purposes of the BMP are to minimize the amount of exposed soil at any one time and to ensure that appropriate erosion and sediment controls are implemented for each phase of construction (Dallaire 1996; Roberts 1995).

In summary, the employment of phased construction practices can be of tremendous benefit in highway construction projects. Utilizing such measures can greatly reduce erosion and subsequent sediment control problems, which results in the overall reduction of necessary erosion and sediment control measures. The end result can be a substantial cost savings.

ALTERNATIVES TO SILT FENCE

INTRODUCTION

No matter how comprehensive an erosion control strategy or a BMP is, it is inevitable that some sediments will be produced at construction sites. Therefore, some sediment control measures will always be necessary to contain the sediment on the construction site. The main focus of this report was to identify cost effective alternatives to silt fence for sediment control. Researchers found and investigated, several alternatives including:

- Sediment basins;
- Extruded sand dike;
- Semi-rigid geosynthetic dike;
- Hay/straw bale; and
- Rock/log check dam.

Based on the cost, ease of installation, adaptability to different situations and reuse potential, researchers identified three promising alternatives:

- Sediment basins;
- Extruded sand dike; and
- Semi-rigid geosynthetic dike.

Sediment basins are traditional alternatives and have been discussed briefly. They are considered to be potentially viable alternatives to silt fence in certain situations and will be discussed further in this section. The extruded sand dike and semi-rigid geosynthetic dike are the two alternatives which appear to be the most promising. Hay/straw bales and rock check dams are considered to be traditional alternatives and, as previously discussed in this report, have some inherent problems as sediment control devices. As a result, they are not considered to be feasible alternatives to silt fence for most situations. Other methods and materials studied were not considered practical alternatives primarily due to high installation and maintenance costs. Short longevity and poor portability are also reasons why other alternatives are dismissed.

SEDIMENT BASINS AND TRAPS

Description and Applications

Sediment basins and traps are impoundment structures constructed below the construction site which are designed to capture sediment-laden runoff and detain the runoff for a time period sufficient to allow the suspended solids to settle out of suspension. Sediment basins and traps have commonly been used for controlling boundary erosion, especially from sites larger than 0.2 hectares (0.5 acre) and in watershed drainage areas which contain soils high in clay and silt. Sediment traps are in-channel sediment control measures and are generally used for sites with a drainage area of 0.2 to 2 hectares. Sediment basins are end-of-channel solutions and are used for larger areas up to 40 hectares (Roberts 1995). Basins and traps are currently used for two reasons: 1) to remove the suspended soil from the runoff leaving a site; and 2) to store the sediment (Fennessey & Jarrett 1994).

Usage Requirements

In *Best Management Practices for Erosion and Sediment Control,* Roberts (1995) discusses the NPDES regulations and the Notice of Intent (NOI) covered under a general NPDES permit. Current requirements for an NOI include standards for sediment basins or traps as follows:

> Sites with common drainage locations that serve 10 or more disturbed acres must have a sediment basin installed where it is attainable (where a basin is not attainable, sediment traps, silt fence or other equivalent measures must be installed). Sediment basins must provide 250 m^3/ha (3600 cubic feet of storage per acre) drained. Drainage locations which serve less than 10 disturbed acres must have installed either a sediment basin, sediment trap, or as a minimum, silt fence along the down slope and side slope perimeter (Roberts 1995:11).

Some states have stricter sediment control requirements for the use of sediment basins. For example, the state of Virginia requires the use of sediment basins for disturbed areas with drainage areas of 1.2 or more hectares (three or more acres). Areas involving less than 1.2 hectares of drainage may be controlled by a sediment trap (Connelly & Lin 1996). The state of Pennsylvania requires 140 m^3 (5,000 ft^3) of water storage capacity and 57 m^3 (2,000 ft^3) of sediment storage capacity per acre of construction area drainage (Fennessey & Jarrett 1994).

Limitations for Application in Highway Construction

Sediment basins and traps have limited use in highway construction projects. These types of projects are plagued by the problem of insufficient right-of-ways for adequate erosion and sediment control practices. This problem is especially true for the use of sediment basins or traps as a sediment control measure due to the enormous area required for these impoundment structures (Mitchell 1993; Roberts 1995). Because of the lack of right-of-way space or an area of sufficient size, Mitchell (1993) found that basins are often relocated farther down the drainage slope than was initially specified in the construction specifications, which then causes the basins to frequently be underdesigned for the increased drainage area. Sediment then accumulates much more rapidly in the basins, which results in the need for more frequent cleaning. The use of sediment basins is also limited in highway construction due to their application for large drainage areas (Roberts 1995).

Design and Performance Considerations

There are two major considerations for the specific design of sediment retention basins: 1) providing sufficient storage for the sediment that is produced; and 2) providing the proper hydraulic environment so that sediment is trapped in the structure (Haan & Ward 1978). Storage is a function of the relative erosiveness of the soil. The basin and outlet should be designed to ensure that the removal of sediment is a function of sediment load and particle size distribution. Much of this involves specific engineering design issues and is, therefore, beyond the scope of this report. Further information can be found in literature on the subject.

In a 1993 study, Mitchell found that states used different design criteria for sediment basins, ranging from two-year design storm frequency to 50-year storm frequency. The two-year design storm return frequency was the most common, followed by the 10-year return frequency.[3]

Other sediment basin research and design issues are explored in the literature. Fennessey and Jarrett (1994) are of the opinion that the principal problem with sediment basins used in construction projects is a lack of understanding of design requirements for such basins. Inadequate basin designs result in poor sediment retention and removal, with a high percentage of the total suspended solids being washed from the basin during the next runoff event. It becomes questionable whether sediment basins are the best technology to use in urban and construction environments.

Haan (1978) found that adequate design procedures were not available for basins with rapidly changing flow rates, such as those produced by stormwater runoff. Goldman et al. (1986:8.2) state that "it is impossible to construct an ideal sediment basin" for

[3] Mitchell's report noted that the respondents who indicated that very large design storm events were used for sediment basins in their states "could have misinterpreted the survey question" (p. 34).

construction activities due to inherent problems such as cost, space limitations on construction sites, and other practical problems. Fennessey and Jarrett (1994) point out that the studies done over the previous 30 years centered primarily on improving the performance of sediment basins in the mining industry, which utilizes basins with permanent water pools. The majority of sediment basins used at construction and highway construction sites do not have permanent water pools, however. Recent research in the highway and construction industry has studied the use of sediment basins with permanent water pools in urban and highway construction projects. The results have shown that "wet" basins are more effective than basins without pools, or "dry" basins, when used in these construction activities (Schueler & Lugbill 1990; Horner, Guedry, & Kortenhof 1990).

Schueler and Lugbill (1990) performed a study in 1988 involving both field and laboratory sampling "to evaluate the performance of current designs of sediment basins and rip-rap outlet traps" (p. ix) at suburban construction sites in Maryland. The design criteria for sediment basins and traps existing in the state of Maryland in 1990 include:

- Sediment basins - 135 m^3/hectare (1800 cf/acre) of storage capacity, usually wet, with a maximum drainage area of 40 hectares (100 acres).

- Sediment traps - 135 m^3/hectare (1800 cf/acre) of storage capacity, with a maximum drainage area of 6 hectares (15 acres); six variations of trap designs available.

Their study included performing tests to determine the settling characteristics of suspended sediment in sediment basins/traps from construction site runoff. Included in their findings were the following (Schueler & Lugbill 1990: ix):

- Incoming levels of TSS tended to increase sharply under the following conditions: 1) when the sites were in advanced stages of construction; 2) when sites received rainfall volumes in excess of 0.75 inches; and 3) at sites with storm drain inlets or eroded gully inlets.

- Sediment removal within traps and basins was significant; however, outflows still contained high levels of sediment, with a median TSS concentration of 283 mg/1 and a median turbidity of 200 NTUs. A significant decrease in the efficiency of traps and basins was found when storm events produced greater than 1.0 inches of rainfall at sites in an advanced stage of construction and with sediment basins which had standing water.

- Sediment controls (sediment basins and rip-rap outlet traps) were more effective in the earlier stages of construction and for storm events which produced less than 0.75 inches of rainfall. It also appeared that sediment basins are more effective than sediment traps; however, this finding is considered provisional due to the small number of sediment trap samples collected in this study.

- An analysis of sediment settling data for both field and laboratory samples generally indicated that the settling of sediment was fairly rapid initially, with as much as 60% removal within six hours. In most cases, natural flocculation behavior appeared to accelerate initial settling velocities.

In summary, their results suggest that the sediment basins were overtaxed. Consequently, inflows tended to mix and hold the sediment in suspension and increased TSS levels were released in the outflows.

Effectiveness

The estimated effectiveness of sediment basins and traps varies in the literature. Roberts (1995) states that it can be as high as 80% for both types of structures when they are properly designed, located, and constructed. He adds, however, that the key to effective performance of the structures is adequate storage volume. Mayo et al. (1993) rate the average effectiveness of sediment basins at 70% and of sediment traps at 60%. Goldman et al. (1986) state that sediment basins have a removal efficiency rate of 50-75%.

In their study, Schueler and Lugbill (1990) determined the overall effectiveness of the performance of sediment basins and traps by analyzing the instantaneous removal efficiency (IRE). It was estimated that the overall performance of sediment basins was 65% for all storm events, but only 46% for storm events that produced measurable outflow runoff. "The 46% removal rate should be considered to be a reasonably representative estimate of the effectiveness of existing sediment control designs within the state of Maryland" (Schueler & Lugbill 1990:ix). Their results also found that basins with deep permanent pools of water performed better during large storm events than those without pools. This was apparently due to the pools reducing resuspension of previously deposited sediments.

Mayo et al. (1993) note that the overall effectiveness of sediment basins is dependent, in part, upon the following factors: 1) the geometry of the sediment basins, including the length to width ratio, which is recommended to be a 2:1 ratio; 2) volume of the basins; and, 3) the amount of time the runoff is detained.

Horner, Guedry, and Kortenhof (1990) performed laboratory model-scale testing of various basin design configurations and field monitoring of ponds to determine their effectiveness in the removal of pollutants. In the study, they included designed ponds, or ponds utilizing design features that provide a sufficient detention time for the runoff which would allow sediment and other particles to settle. Overall, their results found a mean total suspended sediment (TSS) reduction rate of 92% and the designed ponds performing slightly better in other pollutant removal than the non-designed ponds. Furthermore, the designed ponds were substantially more economical than the non-designed ponds. The study also found, however, that sediment ponds "were the least economical option" of the various erosion and sediment control measures studied (Horner, Guedry, & Kortenhof 1990:40).[4]

General Recommendations

Because the conclusions and recommendations regarding sediment basins varies considerably in the literature, no definitive conclusions could be drawn for this report. However, it appears that, when a highway right-of-way permits, sediment basins can be effective and should be considered. When sediment basins are used in concert with good upstream erosion control measures, their effectiveness is increased and the necessary size and periodic maintenance is often reduced (Mayo et al. 1993).

Detention time, which is directly related to the design, size, and storage volume of the basin, seems to be one of the most important considerations for the effectiveness of the basin. Research has shown that detention time is increased when the basin length is increased compared to the width (Horner, Guedry, & Kortenhof 1990). Furthermore, research results have found that a permanent wet pool in a basin helps reduce resuspension of previously trapped sediment (Schueler & Lugbill 1990; Horner, Guedry, & Kortenhof 1990). In evaluating the economics of increasing sediment basin capacity, however, it is important to weigh it against erosion hazards.

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[4] Slope treatments evaluated in their study "included straw mulches at three application rates and with and without manure mulching, fertilizing, and seeding; jute, excelsior, woven straw, and synthetic fiber mats; wood fiber mulch with fertilization and seeding, with various amounts of tackifier and without tackifier; a chemical agent; and a filter fabric fence" (Horner, Guedry, and Kortenhof 1990: vi).

THE EXTRUDED SAND DIKE

Introduction

The extruded sand dike is a temporary sediment control device consisting of a geosynthetic fabric tube filled with sand, rock, or soil, which is placed along perimeter line, or stacked in-channel as a placement for check dams, hay bales, and other devices. The dike is extruded by a machine and laid on the project site without staking, trenching, and ground stapling. One example in market, the Continuous Berm™, is introduced as follows:

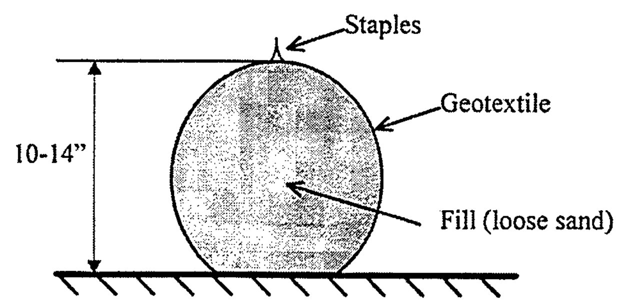

Figure 3. Schematic Drawing of Extruded Sand Dike

Continuous Berm™

The Continuous Berm™ is composed of geosynthetic fabric and fill material (sand, rock, or soil), which is extruded together by the Continuous Berm™ machine. The machine can be towed by many kinds of vehicles and lay the berm on the project site. The fabric is stapled together at the top (Figure 3). The height of the berm can be adjusted from

250 to 300 mm (10 to about 14 in). Since the berm weighs approximately 134 g (295 lbs) per meter, it requires no staking to maintain its location. Because of the low permeability of the berm, flow rates through berms are reduced, creating the ponding conditions which allow settling. Advantages of the Continuous Berm™ are:

1. Relatively inexpensive. More inexpensive if on-site fill material is available.
2. The weight of the fill material holds the berms in place so there is no trenching, staking, and stapling into the ground. It can be used on areas where rock or another hard surface prevents the anchoring of the barrier.
3. Since the berms can be cut into lengths or extruded continuously, they could be stacked to make higher structures in channels or laid in perimeter along channels.
4. Repairs are easily made from stockpiled materials.

Disadvantages of the Continuous Berm™ are:

1. The removal of the berms could be a problem in situations where the sand could not be left in place and spread on the surface.
2. If the Continuous Berms™ are damaged or punctured, the fill could contribute increased sediment.
3. The berm is not recommended for the place which requires the berm to stay in place longer than the life of fabric on berms.

SEMI-RIGID GEOSYNTHETIC DIKE

Introduction

Semi-rigid geosynthetic dike is a temporary sediment control device used mainly as a channel barrier placed perpendicular to the flow of runoff, or as a perimeter line barrier at the toe of slope or right-of-way line. The easy installation, high portability, and increased longevity effectively reduce the cost of installation and maintenance. One example in market, the Triangular Silt Dike™, is introduced as follows:

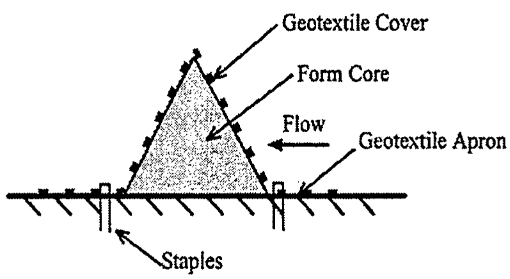

Figure 4. Schematic Drawing of Semi-Rigid Geosynthetic Dike

Triangular Silt Dike™

Triangular Silt Dike™ is a temporary sediment control device used as a perimeter barrier or as an in-channel sediment trap. The standard length of each unit is 2.1 m (7 ft) long and consists of urethane foam covered with woven geotextile fabric. The Triangular Silt Dike™ is shaped approximately 200-250 mm (8-10 in) high in the center and 400-500 mm (16-20 in) base width. The dikes are anchored with wire staples. The schematic drawing is shown in Figure 4. Advantages of the Triangular Silt Dike™ are:

1. No heavy installation, removal and replacement equipment is needed.
2. No machine trenching is required.

3. The dikes are reusable.

Disadvantages of the Triangular Silt Dike™ are:

1. For steeper slopes (10% or higher), it might not be appropriate to use the dikes for sediment control (see Figure 5).
2. Not much information about the sediment control performance is available.

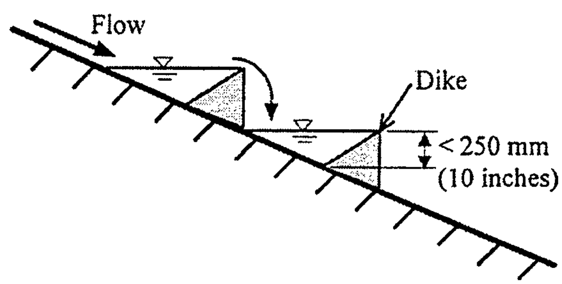

Figure 5. Limited Detained Runoff on Steep Slope (> 10%) by Semi-Rigid Geosynthetic Dike

COST EFFECTIVENESS

INTRODUCTION

The cost of implementing required sediment control measures can vary substantially from one application to another. Costs are dependent upon many factors, including topography, soil conditions, time of year, availability and proximity of materials, prevailing labor rates, etc. For these reasons, it is very difficult to develop a measure of cost effectiveness which can be applied statewide. Particularly in Texas where hydrologic, soil, climatic, and environmental conditions are so varied.

In addition to the environmental variables, it is also desirable to include some measure of material performance in a discussion of cost effectiveness. When researchers reviewed the relevant research literature and information obtained from other state transportation agencies, it became clear that this would not be possible. None of the recent studies have successfully related laboratory performance of silt management materials to field observations. For this reason any attempt to include performance as a measure of cost effectiveness was not deemed possible.

For the purpose of this study, cost effectiveness is based entirely on the life-cycle cost of the material used for temporary erosion and sediment control. The base for comparison of costs is the TxDOT expenditure on silt fence as reported for fiscal years 1995, 1996, and 1997 as of the May posting. The composite costs include the amount of material installed, the cost for removal and replacement of these materials during the construction period, and the cost of removing the materials at the end of construction.

TxDOT records also record costs for silt removal but they do not relate these costs to the associated management practice. That is, the cost for silt removal behind rock dams or silt fence or from in-channel silt traps cannot be distinguished. Further consideration of these costs suggests that silt removal costs are approximately equal regardless of the associated management practice. For this reason no effort was made to include these costs in the measure of cost effectiveness.

BASE LINE COST FOR SILT FENCE

The base line cost for silt fence is the lifetime cost summation of material, installation, and maintenance divided by the initial installed quantity. As shown in Table 1, the cost data summarized from TxDOT Construction Department data, silt fence is represented by "Temp. Sediment Control Fence"; Item "Installation" includes cost of material and installation labor. Item "Remove & Replace" represents the cost of removing damaged silt fences and replacing with new ones. Item "Fence Removal" represents the final removal of silt fences at the end of a project. Hence, Item "Remove & Replace" and "Fence Removal" compose the cost of maintenance. Quantity of Item "Installation" is the initial installed quantity. The average base line cost for silt fence from fiscal year 1995 to 1997 is $14.02 per meter.

The average unit cost for removal and replacement is $7.65 per meter. This averages to 95.5% of the installation cost. The amount of the material that is removed and replaced averages 47% of the originally installed quantity. Item "Remove & Replace" are 95.5 and 47% of initial cost and quantity of Item "Installation," respectively. Therefore, it is assumed that 47% the initial quantity of any sediment control device will need repair and replacement over the course of the project. Similarly, the average unit cost for Item "Fence Removal" is 32.3 % the installation cost. The quantity to be removed averages to about 93% of original installed quantity. Therefore, removal costs are based on 93% of the originally installed quantity.

COST FOR THE EXTRUDED SAND DIKE

In order to estimate the cost reasonably and conservatively, several assumptions have to be made. The assumptions made to estimate the cost are:

1. Woven geotextile is used.
2. Imported sand rather than native material is used for fill.
3. The installation rate is 600 meters per hour (33 ft/min).
4. Fifty percent of the initial installed quantity (base) needs repair and replacement.
5. The unit cost of repair and replacement is 105 % of the initial installation unit cost because the machine is needed and more labor is expected.
6. Ninety three percent of the initial installed quantity (base) will be removed after the completion the project.
7. The unit cost of removal is 35% of the initial installation unit cost.

Based on the above assumptions, the estimated unit cost of the extruded sand dike is $8.11 per meter, which is about 42% less than silt fence (see Table 2).

Table 2. Extruded Sand Dike - Estimated Life-Time Costs

Item	Unit	Unit Cost	Cost per Meter
INSTALLATION			
Fabric	M	$1.10	$1.10
Sand	M3	$45.00	$3.28
Labor and Equipment			

Item	Unit	Unit Cost	Cost per Meter
Pull Truck and Machine	HR	$25.00	
Concrete Truck	HR	$40.00	
Front-End Loader	HR	$38.00	
Conveyor	HR	$27.00	
Labor	HR	$40.00	
Subtotal		$170.00	$0.28*
TOTAL 1	M		$4.66
MAINTENANCE			
Repair and Replacement	M		$2.30
Fabric Removal	M		$1.43
TOTAL 2	M		$3.73
GRAND TOTAL	**M**		**$8.39**

* at 600 M / Hour

COST FOR SEMI-RIGID GEOSYNTHETIC DIKE

The assumptions made to estimate the cost effectiveness of semi-rigid geosynthetic dike are:

1. The average installation rate is 15 meters per hour with two laborers.
3. Forty seven percent of the initial installed quantity will require removal and replacement over the course of the project.
4. Twenty five percent of the initial material quantity will have to be replaced.
5. The average removal and replacement rate is 10 meters per hour.

Based on the above assumptions, the estimated unit cost of the semi-rigid geosynthetic dike is $13.04 per meter, which is 7% less than silt fence (see Table 3).

Table 3. Semi-Rigid Geosynthetic Dike - Estimated Life-Time Costs

Item	Unit	Unit Cost	Cost per Meter
INSTALLATION			
Semi-Rigid Dike &	M	$9.05	$9.05
Labor			
Crew of 2 @	HR	$17.00	
@ 15 m/hr	M		$1.13
TOTAL 1	M		$10.18
MAINTENANCE			
Repair and Replacement			
Crew of 2 @	HR	$17.00	
@ 10 m/hr	M	$1.70	
Material Allowance			
(25% of base)	M	$2.26	
47% of Installed			
Base Affected	M		$1.86
Removal of Dike	M	$1.00	$1.00
TOTAL 2	M		$2.86
GRAND TOTAL	**M**		**$13.04**

COST FOR SEDIMENT BASIN

The size of the sediment basin is dependent on the drainage area. No consistent unit is used to estimate the cost of the sediment basin from the literature. Therefore, an example of comparing the silt filter fence and sediment basin is discussed as follows.

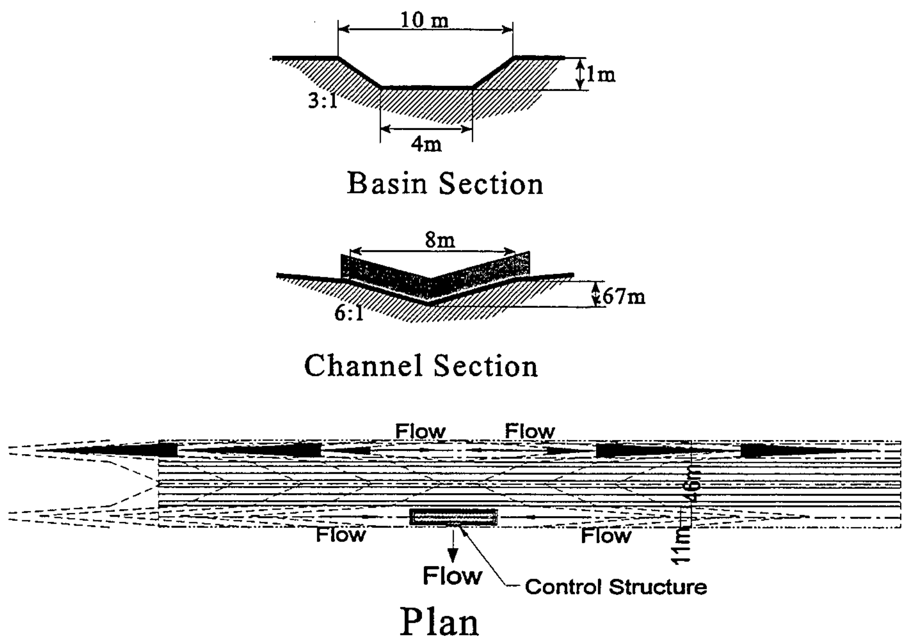

Figure 6. Comparison Example of Silt Filter Fence and Sediment Basin

As shown in Figure 6, silt filter fence is used on one side of a highway and a sediment basin is used on the other side. Both sediment control devices can detain 10 mm-Ha. (one acre-inch) storm runoff along the highway. Based on current equipment and labor averages, the silt filter fence would cost $315.00 per 10 mm-Ha. of retention and the sediment basin would cost $347.50 for the same retention volume. Sediment basin costs $32.5 more than silt filter fence. However, the long-term maintenance and extra labor involved in cleaning several silt filter fences would begin to weigh in favor of the sediment basin solution. The cost of sediment basin with drainage area over 4 Ha. (10 acres) becomes more effective and competitive. Mayo et al. (1993) suggest that impoundment cost decrease as the size of the pond increases. It is also important to note that using sediment basins may not significantly reduce the use of silt fence because as much as 90 percent of the silt fence used is for perimeter silt control. In situation that require perimeter protection, sediment basins are not practical.

CONCLUSIONS AND RECOMMENDATIONS

INTRODUCTION

Three factors which affect the performance of sediment control devices are (1) detention time, (2) runoff velocity, and (3) soil type. Each type of sediment control device is designed to slow the velocity of runoff and detain the water for a period sufficient for suspended solids to settle by gravity. Facilities must also be maintained after installation. Poor maintenance will result in failure. The silt management method should be selected for the soil type on the construction site. Sites that have soils high in clay and silt require larger total storage areas to increase the detention time long enough to remove the suspended solids.

In developing a cost effectiveness index, cost for silt removal was not included because the cost data of silt removal from TxDOT do not relate these costs to the associated management practice. However, the cost of silt removal is usually calculated by silt unit volume, cubic meter, to associated management practice. It appears that the cost of silt removal is uniform among most sediment control devices. For this reason, no effort was made to include these costs in the measure of cost effectiveness.

After some emerging methods and current practices were investigated, alternatives to silt fence exist. Material with low initial costs, allowing easy installation, replacement, and repair is considered to be the most cost effective. Material with low costs but short longevity and poor portability is not considered as a good alternative to silt fence. Although alternatives to silt fence do exist, they still have their own limitations. No single option will replace silt fence as a sediment management tool. The recommended uses and limitations of alternatives to silt fence are described in this section.

ALTERNATIVES

Three promising alternatives were identified that can be used to replace silt fence depending on the specific application. Silt fence can be replaced with the extruded sand dike (the Continuous Berm™), the semi-rigid geosynthetic dike (the Triangular Silt Dike™) or the sediment basins.

Continuous Berm™

The Continuous Berm™ can be used to replace all applications of silt fence, perimeter silt fence, in-channel silt fence, and inlet protection. The Continuous Berm™ is essentially a continuous sandbag that uses rolled geotextile fabric as the container. When the job is completed, the fabric is cut and pulled out and the fill material is spread uniformly over the surface.

The only limitation to the use of the Continuous Berm™ is in situations where the sand fill in the berm could not be spread on the site when the fabric container is removed. Installation requires less labor and time, which makes it significantly less expensive than the silt fence. Since no staking, matting, and pinning are required for installation, the Continuous Berm™ is an excellent solution for sediment control on hard surfaces. Typical of east and east central Texas where sand fill materials are available on site, costs are reduced even further.

The Continuous Berm™ can be used in-channel to substitute for rock check dams. Segments of berms can be stacked in channels as sediment traps. They are especially useful in those channels of more than 10 percent slope where the silt filter fence and semi-rigid geosynthetic dikes cannot be used. The Continuous Berm™ can also be used as an inlet protection.

Semi-Rigid Geosynthetic Dike

With its easy installation and reusability, the semi-rigid geosynthetic dike becomes a cost-effective alternative to silt filter fence. For channel slopes less than 10 percent, the dike is a good substitute for rock check dams. The attached apron or erosion blanket of the dike protects the base of the dike when water is diverted and runs along the dike. The dike can also be used as a replacement of diversion dikes.

Sediment Basins

Sediment basins are cost-effective tools when large drainage areas [greater than 2 hectares (5 acres)] are involved. However, they must be used in conjunction with good upstream surface protection. By minimizing sediment loads, the sediment basins will be more efficient and require less routine maintenance. However, without appropriate upstream surface protection, research clearly demonstrates that sediment basins will be rendered ineffective. Likewise, the cost of maintaining the basin, as well as upstream channels and structures, will quickly negate any savings over other means of sediment control.

SILT FILTER FENCE USED AS AN IN-CHANNEL SEDIMENT TRAP IS UNRELIABLE

In the literature review no research related to installation or field conditions for in-channel applications was found. However, Alberta Ministry of Transportation Report no. 90-03 (Kouwen 1990) noted that silt filter fences fail when sediments accumulate up to the top of the fabric. No explanation of why the failure occurred was offered. In addition, the sediment control handbook from Virginia (1992), Colorado (1995), and Arizona (1995) do not permit the use of silt filter fence in live streams or swales or ditch lines where flows are likely to exceed 0.03 m^3/s (1 cfs) or 0.015 m^3/s (0.5 cfs). Mayo et al. (1993) recommend that silt fences be used only where there is no concentrated flow. A mechanics investigation of typical silt filter fence clearly demonstrates that these structures are likely to fall when the soil becomes saturated. From a mechanics point of view posts would have to be erected in excess of 1.25 mm (4 ft) with spacing of 0.9 to 1.1 m (3 to 3.5 ft). Given these findings and the fact that at least two cost-effective alternatives exist. It is recommended that the use of silt filter fence be discontinued for in-channel applications.

NEW INSTALLATION TECHNOLOGY FOR SILT FENCE

Introduction

Although some cost-effective alternatives to silt fence are available, the alternatives will not likely replace silt fence altogether. There is evidence that the cost of the fabric used for silt fence will decline and advances in technology will reduce the cost of installation and the incidence of failures. One new method appears to promise reduced installation cost and reliability of silt fences -- Tommy® Silt Fence Machine.

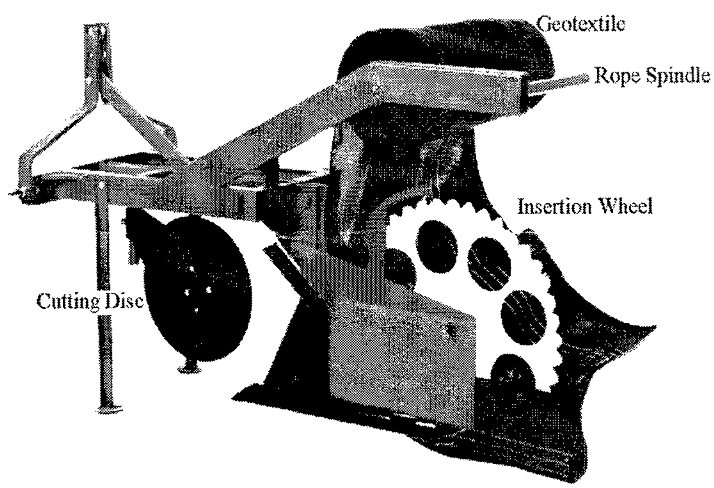

Figure 7. Tommy® Silt Fence Machine
Source: Manufacturer's Brochure

Tommy® Silt Fence Machine

The Tommy® Silt Fence Machine (Figure 7) contains of a circular disk, a plow-shaped blade, upon which a roll of geosynthetic fabric and rope are loaded. During operation the circular disk slices through the soil and inserts geosynthetic fabric with interlock rope into the ground vertically. The rope-lock system will significantly increase the resistance to pull-out. The use of the machine is limited to unconsolidated materials. It would not be effective where soil depths are less than 200 mm (8 in).

RECOMMENDATIONS

The following actions, on the part of TxDOT, are recommended as a result of this study.

1. The Continuous Berm™ is recommended as a cost effective alternative for all current applications of silt fence where the sand can be spread on site after construction.
2. The practice of using silt filter fence as an in-channel silt trap should be discontinued.
3. The Triangular Silt Dike™ should be considered as a primary tool for in-channel silt traps. Based on cost, the Triangular Silt Dike™ competes favorably with rock filter dams and silt filter fence. The primary limitations are slope and high velocity flows. Silt fence will continue to be a tool for temporary silt control.
4. When silt fence is used the specifications should require that installation be by machine only. Hand or mechanical trenching and manual backfilling should not be allowed except in situations inaccessible by machines or when rocky or shallow soils prevent the use of a machine. If much of the site would mitigate against the use of machine installed silt fence, consideration should be given to use the Continuous Berm™.

RECOMMENDED SPECIAL SPECIFICATIONS AND REVISIONS TO SPECIAL SPECIFICATION

This section provides recommendations for the application of alternatives to silt fence along with recommended special specifications.

APPLICATIONS

The Extruded Sand Dike

Definition

The extruded sand dike a temporary sediment control devices consisting of a geosynthetic fabric tube filled with loose friable material, which is placed along perimeter line, or stacked in a channel to form a silt trap, or protect a drain inlet.

Purpose

A continuous berm intercepts and detains sediment while decreasing the velocity of storm runoff. Its major function is to detain the runoff and allow suspended sediment to settle.

Conditions Where Practice Applies

Perimeter Use

- Below disturbed areas where sheet and rill erosion might occur;

- Where the size of the drainage area is no more than 0.4 hectare (1 acre); the maximum slope length behind the berm is 30 m (100 ft); the maximum slope gradient behind the berm is 50 percent (2:1), and
- In small swales or ditches where the maximum contributing drainage area is no greater than 0.4 hectare (1 acre) and flow rate is no greater than 0.028 m^3/s (1 cfs).

In-Channel Use

- In small, open channels which drain 4 hectares (10 acres) or less. They shall not be used in perennial streams.
- Temporary ditches or swales which, due to their short length of service, cannot receive a nonerodible lining but still need some protection to reduce erosion.
- Permanent drainage that for some reason cannot receive a permanent nonerodible lining for an extended period of time.
- Either temporary or permanent swales or waterways which need protection during the establishment of grass linings.

Design Considerations

The following criteria shall be considered:

- Materials (including geosynthetic fabric and fill materials; fill materials could be sand, rock, and soil);
- Drainage area;
- Height;
- Sediment removal;
- Maintenance; and
- Berm removal.

The berm is not recommended for the projects which last longer than the useful life of geosynthetic fabric. The berm must be removed when their useful life has been completed. In temporary ditches and swales, berms shall be removed and the ditch filled in when it is no longer needed. In permanent structures, berms shall be removed when a permanent lining can be installed. In grass-lined ditches, berms shall be removed when the grass has matured sufficiently to protect the ditch or swale. The area beneath the berms shall be seeded and mulched immediately after the berms are removed. If any berms break fabrics and fill materials must be removed as soon as possible and replaced with new berms. The recommended Draft Special Specification is as follows.

Draft Special Specifications

Special SPECIFICATION

ITEM XXXX

EXTRUDED SAND DIKE

1. DESCRIPTION. This item shall govern for the materials to be furnished and for the installation, maintenance, and removal of the extruded sand dike of the dimensions shown on the plans. For the in-channel use, the extruded sand dike shall be constructed at the locations shown on the plans and as directed by the engineer. This Item will be used during construction to control erosion and sedimentation.

2. MATERIALS.

   (1) Fabric. Fabric materials shall meet the requirements of Departmental Materials Specification D-9-6230. Geosynthetic fabric shall be a pervious sheet of synthetic polymer composed of at least 85 percent by weight ethylene, propylene, amide, ester, or vinylidene yarn, woven. It shall contain stabilizers and/or inhibitors to resist deterioration by heat,

water, and ultra-violet light. The equivalent opening size of the fabric shall be within the range 70-100. The tensile strength (ASTM D1682G) shall be at least 54 kg.

(2) Fill. Sand is recommended for the fill material. Non-angular rock of 25-50 mm diameter or sandy soil can be used if sand is not available.

3. CONSTRUCTION METHODS.

(1) Perimeter Use.

On slope, the dike line shall maintain positive contact with the surface. A 0.65 m overlap at the joint of two separate dikes is required. The fabric of the dike shall be folded and stapled at intervals not to exceed 150 mm. Dike shall be 275-300 mm high.

(2) In-Channel Use.

For in-channel use dikes shall be extruded in 2-3 m lengths. Length shall be stacked perpendicular to flow direction in channel. Base shall be one bag greater than the number of bags stacked vertically. The maximum height of the stacked dikes shall be 0.9 m. The center of the stacked dikes must be at least 150 mm lower than the outer edges. For flow velocities greater than 2 m/s, the base of the stacked dikes can be keyed into the soil about 150 mm. The maximum spacing between the dikes shall be such that the toe of the upstream dike is at the same elevation as the top of the downstream dike.

4. MAINTENANCE. The extruded sand dike shall be maintained in good condition (including stapling and placement) by the Contractor. All necessary work and materials to maintain the integrity of the dike, including keeping fabric free of accumulated silt, debris, etc., shall be provided until earth work construction and permanent erosion control features are in place, and/or the disturbed area has been adequately stabilized. When the Special Specification,

"Temporary Erosion, Sedimentation, and Water Pollution Prevention and Control," is in the contract, stabilization shall be as described in Subarticle 4.C. of that specification. The areas damaged by the removal process shall be stabilized by the contractor using appropriate methods as approved by the Engineer.

Damaged or punctured dikes shall be repaired by the replacement of a new segment. At least a 0.6 m overlap is required for the perimeter use. For the in-channel use, regular inspections shall be made to insure that the center of the dam is lower than the edges. Erosion caused by high flow around the edges of the dikes shall be corrected immediately.

When the accumulated sediment deposit reaches a depth of approximately 150 mm, it shall be removed and disposed of at approved sites in a manner that will not contribute to additional siltation. If the structure ceases to function as intended, the engineer may direct that the dike or portions thereof be replaced. Such replacement will be measured for payment.

5. MEASUREMENT. Extruded sand dike will be measured by the linear length of the dike in m, complete in place, measurement being made along the centerline of the top of the dike.

Each time the engineer directs that the extruded sand dike (or portions thereof) be removed or removed and replaced, it will be measured for payment.

6. PAYMENT. The work performed and materials furnished in accordance with this Item and measured as provided under "Measurement," will be paid for at the unit price bid for "Extruded Sand Dike," of the type specified. This price shall be full compensation for furnishing all materials; stapling; and for all tools,

equipment, labor, and incidentals necessary for the construction and maintenance (except as shown below) of the dikes.

When the engineer directs that the extruded sand dike installation (or portions thereof) be replaced, payment will be made at the unit price bid for "Extruded Sand Dike (Remove and Replace)," of the type specified. This price shall be full compensation for the removal and replacement of the extruded sand dike and for all manipulations, labor, tools, equipment and, incidents necessary to complete the work.

The removal of accumulated sediment deposits, as described under "Maintenance," will be measured and paid for under the pertinent bid items of the Special Specification, "Earthwork for Erosion Control."

The work performed in the final removal of the extruded sand dike installation as described under "Maintenance" and measured as provided above will be paid for at the unit price bid for "Extruded Sand Dike (Removal)" of the type specified. This price shall be full compensation for removing the dike from the existing location and properly disposing of it and for all manipulations, labor, tools, equipment, and incidentals necessary to complete the work.

Stabilization (as described under "Maintenance") will be measured and paid for under the various pertinent bid items.

Semi-Rigid Geosynthetic Dike

Definition

The semi-rigid geosynthetic dike is a temporary sediment control device used mainly as a channel barrier placed perpendicular to the flow of runoff, or as a perimeter line barrier at the toe of slope or right-of-way line.

Purpose

A dike intercepts and detains small amounts of sediment from disturbed areas during construction. The dike reduces water velocities and allows sediment to settle behind the dike.

Conditions Where Practice Applies

- Below disturbed areas subject to sheet and rill erosions.
- Where the size of the drainage area is no more than 0.4 hectare (1 acre); the maximum slope length behind the dike is 30 m (100 ft); the maximum slope gradient behind the dike is 50 percent (2:1).
- In small swales or ditches where the maximum contributing drainage area is no greater than 0.4 hectare (1 acre) and flow rate is no greater than 0.028 m^3/s (1 cfs).
- Semi-rigid geosynthetic dikes shall not be used on areas where rock or another hard surface prevents the anchoring of the dike.
- For in-channel use, semi-rigid geosynthetic dikes shall not be used on channel bed slope steeper than 10 percent and where water level is routinely expected to reach 200 mm.

Design Considerations

The following criteria shall be considered:

- Materials (including dike, and protective apron);
- Drainage area;
- Height;
- Sediment removal;
- Maintenance; and
- Dike removal.

The dike must be removed when their useful life has been completed. Dikes shall be removed and the channel surface shall be repaired. The area beneath the dikes shall be seeded and mulched immediately after the dikes are removed. The recommended Draft Special Specification is as follows.

Draft Special Specifications

SPECIAL SPECIFICATION

ITEM XXXX

SEMI-RIGID GEOSYNTHETIC DIKE

1. DESCRIPTION. This Item shall govern for the materials to be furnished and for the installation, maintenance, and removal of the semi-rigid geosynthetic dike of the dimension shown on the plans. This Item will be used in-channel or inlet protection temporarily during construction to control erosion and sedimentation.

2. MATERIALS.

   (1) Dikes. The dike shall be triangular shaped having a height of at least 200-250 mm in the center with equal sides and a 400-500 mm base. Length shall be 2.1 m unless otherwise indicated on the plans. The

material shall be urethane foam or other synthetics approved by the engineer.

(2) Protective apron. The vertical portion of the dike shall be protected from undercutting by an approved geosynthetic material. The apron shall extend a minimum of 0.9 m on sides of the vertical dike.

(3) Staples. The dikes shall be anchored to the ground with wire staples. The staples shall be No.11 gauge wire and be at least 150-200 mm long.

3. CONSTRUCTION METHODS.

(1) Dike segments shall be placed beginning at the center of the channel working toward the outside edges. Sufficient segments shall be placed to extend past the limit of flow when the water level reaches the elevation of the middle segment.

(2) The upstream apron shall be placed in a check slot of at least 200 x 200 mm wide in clay soils and a minimum of 300 x 200 mm wide in sandy soils. The fabric shall be placed in the check slot then the slot will be backfilled and compacted.

(3) The dikes shall be stapled to ensure positive contact is maintained with the bottom of the channel along its full length as called for in the manufacture literature.

4. MAINTENANCE. The semi-rigid geosynthetic dike shall be maintained in good condition (including stapling and placement) by the contractor. All necessary work and materials to maintain the integrity of the dike, including keeping the dike free of accumulated silt, debris, etc., shall be provided until earth work construction and permanent erosion control features are in place and/or the disturbed area has been adequately stabilized. When the Special

Specification, "Temporary Erosion, Sedimentation, and Water Pollution Prevention and Control," is in the contract, stabilization shall be as described in Subarticle 4.C. of that specification. The areas damaged by the removal process shall be stabilized by the contractor using appropriate methods as approved by the Engineer.

Damaged dikes shall be repaired by the replacement of a new segment. At least a 0.6 m (2 ft) overlap and stapling is required. For the in-channel use, regular inspections shall be made to insure that the center of the dam is lower than the edges. Erosion caused by high flow around the edges of the dikes shall be corrected immediately.

The dike shall be inspected immediately after each rainfall to ensure that the blanket/protective apron is secure and that edges have not been breaking. Any required repairs shall be made immediately.

When the accumulated sediment deposit reaches a depth of approximately 150 mm (6 in), it shall be removed and disposed of at approved sites in a manner that will not contribute to additional siltation. If the structure ceases to function as intended, the engineer may direct that the dike or portions thereof be replaced. Such replacement will be measured for payment.

5. MEASUREMENT. The semi-rigid geosynthetic dike will be measured by the linear length of the dike in meters, complete in place, measurement being made along the centerline of the top of the dike.

Each time the engineer directs that the semi-rigid geosynthetic dike (or portions thereof) be removed or removed and replaced, it will be measured for payment.

6. PAYMENT. The work performed and materials furnished in accordance with this item and measured as provided under "Measurement," will be paid for at the unit price bid for "Semi-rigid Geosynthetic Dike," of the type specified. This price shall be full compensation for furnishing all materials; stapling; and for all tools, equipment, labor, and incidentals necessary for the construction and maintenance (except as shown below) of the dikes.

When the engineer directs that the semi-rigid geosynthetic dike installation (or portions thereof) be replaced, payment will be made at the unit price bid for "Semi-rigid Geosynthetic Dike (Remove and Replace)," of the type specified. This price shall be full compensation for the removal and replacement of the semi-rigid geosynthetic dike and for all manipulations, labor, tools, equipment and incidents necessary to complete the work.

The removal of accumulated sediment deposits, as described under "Maintenance," will be measured and paid for under the pertinent bid items of the Special Specification, "Earthwork for Erosion Control".

The work performed in the final removal of the semi-rigid geosynthetic dike installation as described under "Maintenance" and measured as provided above will be paid for at the unit price bid for "Semi-rigid Geosynthetic Dike (Removal)" of the type specified. This price shall be full compensation for removing the dike from the existing location and properly disposing of it and for all manipulations, labor, tools, equipment, and incidentals necessary to complete the work.

Stabilization (as described under "Maintenance") will be measured and paid for under the various pertinent bid items.

REVISIONS TO SILT FENCE INSTALLATION

SPECIAL SPECIFICATION

ITEM XXXX

TEMPORARY SEDIMENT CONTROL FENCE

1. DESCRIPTION. This item shall govern for the materials to be furnished and for the installation, maintenance, and removal of temporary sediment control fence of the dimensions shown on the plans. This item will be used temporarily during construction to control erosion and sedimentation.

2. MATERIALS.

(1) Fence Description. The fence shall be constructed using woven geotextile fabric.

(2) Fabric. Fabric materials shall meet the requirements of Departmental Materials Specification D-9-6230, "Temporary Sediment Control Fence Fabric."

(3) Posts. Posts shall be a minimum of 1.2 m long, essentially straight, and shall be wood or steel, unless otherwise shown on the plans. Soft wood posts shall be at least 75 mm in diameter or nominal 50 x 100 mm. Hardwood posts shall have a minimum cross-section of 40 x 40 mm. Steel posts shall be "T" of "L" shaped with a minimum weight of 1.9 kg per meter.

(4) Net Reinforcement. If reinforcing is deemed necessary, a different method, dike, berm, or dam should be used. Net reinforcement shall be galvanized welded wire mesh of a minimum 12.5-gauge wire or equal as approved by the engineer with a maximum opening size of 50 x 100 mm and shall be at least 600 mm wide unless otherwise shown on the plans.

(5) Staples. Staples used to secure reinforcement and fabric to wood posts shall have a crown at least 19 mm wide and legs 9.5 mm long.

(6) Rope. The rope diameter shall be at least 19 mm wide for anchoring.

(7) Used Materials. Previously used materials from other TxDOT projects, meeting the above requirements and when approved by the engineer, may be used. Previously used materials from within the project shall be used whenever possible.

3. CONSTRUCTION METHODS. The temporary sediment control fence shall be used during construction near the downstream perimeter of a disturbed area to intercept sediment from sheer flow. A temporary sediment control fence shall not be used to control sedimentation in areas of concentrated flow. The fence installation methods shall be as specified below unless otherwise shown on the plans. The physical alignment and location of the fence shall be as shown on the plans or as directed by the Engineer.

(1) Installation of posts. Posts shall be embedded to 450 mm deep, or adequately anchored if in rock, with a spacing of 1.8 to 2.4 m, and installed on a slight angle toward the anticipated run-off source.

(2) Fabric installation. Fabric shall be machine installed. The machine shall set the fabric at a minimum depth of 300 mm wrapped over a 19 mm rope anchor.

(3) Fabric anchoring. When tight soils prevent closing of the fabric slot, the check slot shall be compacted using a tractor or other vehicle acceptable to the cut. Compaction will be required when a space of 50 mm or greater is visible between the edge of the cut and fabric.

(4) Fabric attachment. The reinforcement shall be attached to the end posts, if wood, by staples, or if steel, by T-clips or sewn vertical pockets at a minimum of four (4) locations. The reinforcement shall be attached to each succeeding post as approved by the Engineer. The ends of

successive reinforcement sheets or rolls shall be connected at a fence post at least six (6) times with hog rings.

The fabric shall be fastened to the top strand of reinforcement by hog rings or cord at a maximum spacing of 380 mm.

(5) Fabric splices. Splices shall occur at a fence post and shall have a minimum lap of 150 mm attached in at least six (6) places. Splices in concentrated flow areas will not be permitted.

When removing a temporary sediment control fence that is suitable for relocation, the Contractor shall take all necessary measures to maintain the fabric in the best condition.

Requirements for the installation of a used temporary sediment control fence shall include:

(1) Minimal or no visible signs of biodegradation (weak fibers);

(2) No excessive patching every 4.6 to 6.1 m; and

(3) Posts must not be bent and backing must not have holes.

4. MAINTENANCE. The temporary sediment control fence shall be maintained in good condition (including staking, anchoring, tension adjustments, etc.) by the Contractor. All necessary work and materials to maintain the integrity of the fence, including keeping fabric free of accumulated silt, debris, etc., shall be provided until earth work construction and permanent erosion control features are in place, and/or the disturbed area has been adequately stabilized. When the Special Specification, "Temporary Erosion, Sedimentation, and Water Pollution Prevention and Control," is in the contract, stabilization shall be as described in Subarticle 4.C. of that specification. The areas damaged by the removal process

shall be stabilized by the Contractor using appropriate methods as approved by the Engineer.

Torn or punctured fabric shall be repaired by the replacement of a patch consisting of an additional layer of fabric over the damaged area. The patch shall have a minimum overlap of 450 mm in all directions and be securely attached to the repaired fabric.

Fence shall be inspected immediately after each rainfall to ensure that the soil rope-lock system is secure and that fence fabrics have not been pulled out. Any required repairs shall be made immediately.

When the accumulated sediment deposit reaches a depth of approximately 150 mm, it shall be removed and disposed of at approved sites in a manner that will not contribute to additional siltation. If the structure ceases to function as intended, the Engineer may direct that the fence or portions thereof be replaced. Such requirement will be measured for payment.

5. MEASUREMENT. The temporary sediment control fence will be measured by the linear length of the fence in meters, complete in place, measurement being made along the centerline of the top of the fence.

Each time the Engineer directs that the temporary sediment control fence (or portions thereof) be removed or removed and replaced, it will be measured by the meter for payment.

6. PAYMENT. The work performed and materials furnished in accordance with this Item and measured as provided under "Measurement," will be paid for at the unit price bid for "Temporary Sediment Control Fence," This price shall be

full compensation for furnishing, placing, and maintaining the fence (except as shown below); for all required trenching, fence posts, fabric, and backfill; and for all labor, tools, equipment, and incidentals necessary to complete the work.

When the Engineer directs that the temporary sedimentation control fence installation (or portions thereof) be replaced, payment will be made at the unit price, bid for "Temporary Sediment Control Fence (Remove and Replace)." This price shall be full compensation for the removal and replacement of the fence installation and for all manipulations, labor, tools, equipment, and incidentals necessary to complete the work.

No non-damaged material will be removed from the project until such time that no new installations or replacements will be required. All sound materials removed from project installations will be placed or stockpiled for project placement or replacement. No new material will be accepted when stockpiled material is available for use. The Contractor retains ownership of the stockpiled material.

The removal of accumulated sediment deposits, as described under "Maintenance," will be measured and paid for under the pertinent bid items of the Special Specification, "Earthwork for Erosion Control."

The work performed in the final removal of the temporary sediment control fence installation as described under "Maintenance" and measured under "Measurement" will be paid for at the unit price bid for "Temporary Sediment Control Fence (Remove)." This price shall be full compensation for removing the fence from the existing location, for stockpiling for future use, for proper disposal of damaged material, and for all manipulations, labor, tools, equipment, and incidentals necessary to complete the work.

Stabilization (as described under "Maintenance") will be measured and paid for under the various pertinent bid items.

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APPENDIX A

QUANTITIES AND EXPENDITURES FOR EROSION AND SEDIMENT CONTROL FOR TxDOT 1995-1997

TxDOT Total Quantities and Expenditures for Erosion and Sediment Control

Item	Unit	FY 1995 Quantity	FY 1995 Total Cost	FY 1995 Avg. Unit Cost	FY 1996 Quantity	FY 1996 Total Cost	FY 1996 Avg. Unit Cost	FY 1997* Quantity	FY 1997* Total Cost	FY 1997* Avg. Unit Cost	Overall Avg. Unit Cost
ROCK FILTER DAMS											
TY 1	M3	815.70	$44,144.00	$54.12	1,165.51	$37,761.00	$32.40	1,146.97	$46,205.99	$40.29	$40.95
TY 1	M	24,074.67	$963,314.84	$40.01	19,804.15	$889,167.24	$44.90	23,486.25	$844,757.22	$35.97	$40.04
TY 2	M3	32.08	$1,785.00	$55.64	308.94	$19,502.50	$63.13	0.00	$0.00	$0.00	$62.42
TY 2	M	15,211.06	$754,497.05	$49.60	14,620.31	$801,578.80	$54.83	10,342.59	$413,648.12	$39.99	$49.03
TY 3	M3	151.99	$8,225.00	$54.12	0.00	$0.00	$0.00	0.00	$0.00	$0.00	$54.12
TY 3	M	5,824.14	$465,767.60	$79.97	8,656.77	$580,717.78	$67.08	3,758.01	$251,788.33	$67.00	$71.18
TY 4	M3	9.16	$2,880.00	$314.41	9.62	$1,134.00	$117.88	0.00	$0.00	$0.00	$213.74
TY 4	M	2,308.44	$161,736.25	$70.06	857.53	$92,835.05	$108.26	212.87	$8,937.00	$41.98	$77.99
TY 5	M	4,216.40	$136,886.25	$32.47	2,017.07	$261,327.00	$129.56	300.00	$8,200.00	$27.33	$62.20
Subtotal 1	M3	1,008.93	$57,034.00	$56.53	1,484.07	$58,397.50	$39.35	1,146.97	$46,205.99	$40.29	$44.41
Subtotal 2	M	51,634.71	$2,482,201.99	$48.07	45,955.83	$2,625,625.87	$57.13	38,099.72	$1,527,330.67	$40.09	$48.90
SUBTOTAL	All		$2,539,235.99			$2,684,023.37			$1,573,536.66		
% of Total E & S Cntrl Cost			27.24%			36.20%			26.29%		
TEMP SEDMT CNTRL FENCE	M	410,450.47	$6,210,157.78	$15.13	297,308.75	$4,299,513.84	$14.46	329,838.86	$4,038,026.44	$12.24	$14.02
TEMP SEDMT CNTRL FENCE (INLET PROTECTION)	M	2,695.21	$30,840.38	$11.44	6,333.13	$118,551.00	$18.72	4,774.46	$95,708.00	$20.05	$17.76
SUBTOTAL	M	413,145.68	$6,240,998.16	$15.11	303,641.88	$4,418,064.84	$14.55	334,613.32	$4,133,734.44	$12.35	$14.07
% of Total E & S Cntrl Cost			66.95%			59.59%			69.05%		

* Data to June of FY

TxDOT Total Quantities and Expenditures for Erosion and Sediment Control

Item	Unit	FY 1995 Quantity	FY 1995 Total Cost	FY 1995 Avg. Unit Cost	FY 1996 Quantity	FY 1996 Total Cost	FY 1996 Avg. Unit Cost	FY 1997* Quantity	FY 1997* Total Cost	FY 1997* Avg. Unit Cost	Overall Avg. Unit Cost
SANDBAG BERMS/DAMS											
150 mm High	M	0.00	$0.00	$0.00	0.00	$0.00	$0.00	178.00	$1,753.00	$9.85	$9.85
178 mm High	M	0.00	$0.00	$0.00	0.00	$0.00	$0.00	66.00	$1,089.00	$16.50	$16.50
300 mm High	M	0.00	$0.00	$0.00	0.00	$0.00	$0.00	300.00	$3,000.00	$10.00	$10.00
Subtotal 1	M	0.00	$0.00	$0.00	0.00	$0.00	$0.00	544.00	$5,842.00	$10.74	$10.74
SANDBAGS	EA	0.00	$0.00	$0.00	400.00	$4,000.00	$10.00	14,189.00	$78,930.00	$5.56	$5.68
SUBTOTAL	ALL		$0.00			$4,000.00			$84,772.00		
% of Total E & S Cntrl Cost			0.00%			0.05%			1.42%		
PAVED FLUMES (TEMP) & PIPE SLOPE DRAINS	M2	208.89	$18,287.50	$87.55	147.06	$38,720.00	$263.29	0.00	$0.00	$0.00	$160.16
SUBTOTAL	M2	208.89	$18,287.50	$87.55	147.06	$38,720.00	$263.29	0.00	$0.00	$0.00	$160.16
% of Total E & S Cntrl Cost			0.20%			0.52%			0.00%		
BALED HAY	EA	35,830.00	$523,767.34	$14.62	15,914.00	$268,829.55	$16.89	10,322.00	$194,389.68	$18.83	$15.90
SUBTOTAL	M2	35,830.00	$523,767.34	$14.62	15,914.00	$268,829.55	$16.89	10,322.00	$194,389.68	$18.83	$15.90
% of Total E & S Cntrl Cost			5.62%			3.63%			3.25%		
GRAND TOTAL			$9,322,288.99			$7,413,637.76			$5,986,432.78		

* Data to June of FY

TxDOT Total Quantities and Expenditures for Erosion and Sediment Control - Heavy Equipment Work

Item	Unit	FY 1995 Quantity	FY 1995 Total Cost	FY 1995 Avg. Unit Cost	FY 1996 Quantity	FY 1996 Total Cost	FY 1996 Avg. Unit Cost	FY 1997* Quantity	FY 1997* Total Cost	FY 1997* Avg. Unit Cost	Overall Avg. Unit Cost
HEAVY EQUIPMENT WORK											
Earthwork - CL 1	H	0.00	$0.00	$0.00	0.00	$0.00	$0.00	181.00	$16,120.00	$89.06	$89.06
Earthwork - CL 2	M3	49,695.09	$434,196.45	$8.74	13,471.76	$174,371.42	$12.94	3,608.87	$61,497.63	$17.04	$10.03
Earthwork - CL 3	M3	19,338.96	$190,004.90	$9.82	6,272.61	$86,447.10	$13.78	8,486.28	$76,453.37	$9.01	$10.35
Backhoe Work - CL 1	H	4,759.35	$225,213.61	$47.32	3,902.45	$191,492.62	$49.07	3,321.43	$159,054.45	$47.89	$48.05
Backhoe Work - CL 2	M3	11.46	$270.00	$23.56	0.00	$0.00	$0.00	22.64	$1,300.00	$57.42	$46.04
Front-End Ldr Wk - CL 1	H	1,530.00	$73,907.18	$48.31	1,694.50	$86,548.84	$51.08	1,601.00	$73,620.95	$45.98	$48.51
Front-End Ldr Wk - CL 2	M3	1,585.58	$2,325.96	$1.47	9.17	$552.00	$60.20	433.06	$3,555.00	$8.21	$3.17
Bkhoe/Frt-End Ldr - CL 1	H	2,722.00	$139,858.30	$51.38	1,860.80	$80,080.90	$43.04	2,774.65	$96,891.33	$34.92	$43.06
Frt-End Ldr/Blade Wk - CL 2	M3	367.37	$2,645.50	$7.20	0.00	$0.00	$0.00	109.98	$1,440.00	$13.09	$8.56
Blading Work - CL 1	H	1,119.25	$72,073.18	$64.39	935.00	$54,826.29	$58.64	2,278.65	$100,685.33	$44.19	$52.52
Bulldozer Work - CL 1	H	702.00	$36,175.80	$51.53	1,325.00	$67,225.75	$50.74	385.00	$20,250.00	$52.60	$51.27
Excavation Work - CL 1	H	1,751.00	$100,395.15	$57.34	841.00	$46,792.40	$55.64	204.25	$14,327.01	$70.14	$57.76
Dragline Work - CL 1	H	30.00	$2,972.60	$99.09	26.00	$1,300.00	$50.00	20.00	$2,000.00	$100.00	$82.53
Scraper Work - CL 1	H	40.00	$2,400.00	$60.00	0.00	$0.00	$0.00	0.00	$0.00	$0.00	$60.00
Subtotal 1	H	12,653.60	$652,995.82	$51.61	10,584.75	$528,266.80	$49.91	10,765.98	$482,949.07	$44.86	$48.94
Subtotal 2	M3	70,998.46	$629,442.81	$8.87	19,753.54	$261,370.52	$13.23	12,660.83	$144,246.00	$11.39	$10.01
TOTAL	All		$1,282,438.63			$789,637.32			$627,195.07		

* Data to June of FY

APPENDIX B

COSTS FOR SEDIMENT CONTROL MEASURES

Sediment Control Measure	Unit*	Material Cost	Total Cost Per Unit	Annual Maint. Cost (% Capital Cost)	Reference	Notes
Filter Fabric Fence	LF		$3.39	100%	Mayo et al. 1993	Report for EPA
Silt Fence	LF	Geotextile: $0.20 - 0.30	$2.00 - 5.00	Repair: 100% Replace: 150 - 200% Sediment Removal: $5.00 - 10.00/CY	Virginia 1992	
Rock Check Dam	SY		$13.00 - 20.00	Repair: 100% Replace: 150 - 200% Sediment Removal: $5.00 - 10.00/CY	Virginia 1992	
Log Check Dam	EA		$400 - 600			
Triangular Silt Dike™	LF		$4.20	Repair: 0%	WSDOT 1997	
Straw Bales	EA		$7.80 - 10.60		SEWRPC 1991	
Straw Bales	EA	$2.00 - 3.50	$9.00 - 18.00	Repair: 100% Replace: 150 - 200% Sediment Removal: $5.00 - 10.00/CY	Virginia 1992	
Hay Bales	EA		$9.20		Goldman 1986	
Pine Straw Bales	EA	$3.00 - 6.00			Market	
Sand Bags	LF		$5.70		WSDOT 1997	
Inlet Protection	EA		$25 - 100	Repair: 100% Replace: 150 - 200% Sediment Removal: $5.00 - 10.00/CY	Virginia 1992	
Inlet Protection Device	EA		$106 - 154	100%	SEWRPC	

Sediment Control Measure	Unit*	Material Cost	Total Cost Per Unit	Annual Maint. Cost (% Capital Cost)	Reference	Notes
Sediment Trap with Pipe Outlet	EA		$3400 - 6700		Goldman 1986	Lowest cost in range based on 1-acre drainage area. Highest cost based on 5-acre drainage area.
Sediment Trap with Stone Outlet	EA		$675 - 2550			
Sediment Trap	EA		$500 - 700 $1200 - 1400 $1800 - 2100	Repair: 100% Replace: 150 - 200% Sediment Removal: $5.00 - 10.00/CY	Virginia 1992	Lowest cost range based on 1-acre drainage area. Second and highest ranges are for 2- and 3-acre drainage areas.
Sediment Basin (Trap) 3000 CF 250000 CF	CF		$0.20 $0.18	25%	SEWRPC 1991	
Sediment Trap	CF		$0.60	20%	Mayo et al. 1993	
Sediment Basin	EA		$10000 - 15000		Goldman 1986	$15000 is estimated cost for basin with 30-acre drainage area.
Sediment Basin 12500 CF 40750 CF 196000 CF	CF		$0.80 $0.40 $0.30	25%	SEWRPC 1991	
Sediment Basin	CF		$0.40	25%	Mayo et al. 1993	
Diversion Swale (general)			$4.17		Mayo et al. 1993	Including diversion swale, diversion dike, right-of-way diversion, and fill diversion.

* LF = Linear feet, SY = Square yard, CF = Cubic feet, CY = Cubic yard, HR = Hour, EA = Each