Laboratory Evaluation of Geotextile Performance in Silt Fence Applications using a Subsoil of Glacial Origin

by

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Abstract

LABORATORY EVALUATION OF GEOTEXTILE PERFORMANCE IN SILT FENCE APPLICATIONS USING A SUBSOIL OF GLACIAL ORIGIN

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The research tested the filter performance of four different geotextiles. A flume apparatus was constructed and used to simulate a silt fence installation. The apparatus and procedures were based on a previous study performed by the Virginia Highway Transportation and Research Council. Water and sediment was filtered through a fabric sample and the ratio of the sediment concentration in the influent compared to the concentration in the effluent determined and expressed as a percent.

Two physical properties of the fabrics were examined as predictors of fabric filter efficiency. The Apparent Øpening Size was not a reliable predictor of fabric performance for the samples tested. The flow rate through the fabric indicated that fabrics with a lower flow rate will probably exhibit higher filtration efficiencies, but an inadequate number of tests were performed for conclusive evidence.

The effect of sediment particles larger than the U.S. Standard No. 30 sieve on fabric clogging and blinding was briefly examined. These larger particles did not contribute significantly to blinding.

TABLE OF CONTENTS

LIST OF FIGURES

1. Introduction

Construction activities have always bared the subsoil and increased the potential for erosion. Roman and Greek engineers recognized a connection between deforestation and increased deposition of sediment in harbors. Sediment is the major pollutant of streams in terms of weight and volume (ASCE,1975). The problems caused by sediment include the disruption of aquatic ecosystems, degradation of water quality and reduction in the capacity of water conveyance systems (Reed,1977;Foster and Meyer,1977).

Several investigators have attempted to measure the effects of construction activities on the rate of erosion. A Pennsylvania study determined that between 17 and 37 tons of soil per acre were lost on a highway construction project in spite of aggressive erosion control measures being incorporated (Hainly,1978). An investigation into the rate of erosion after the construction of logging roads in western Oregon determined that 130 tons of soil per acre were eroded in the first year (Wilson,1963). A study performed in Virginia included construction projects on which little or no effective erosion control measures were implemented. In the conclusions of that study the author stated, "A lack of erosion and sediment control measures and bad construction techniques cannot be tolerated" (Wyant,1982).

Concern about accelerated erosion due to construction activities and the effects of the resulting sediment on the environment has increased significantly in recent years. The passage of the Federal Clean

Water Act (33 U.S.C. 1251-1376) in 1977 resulted in increased emphasis being placed on preventing soil from migrating from construction sites to watercourses. State and local laws, regulations and policies relating to sediment control have also proliferated as concern about water quality has mounted (Amimoto,1978;Boysen,1977;King County,1987;Sherwood,1978).

Improvements have been made in the methods used to control erosion and sediment as a result of increased regulation and technological advances. Greater understanding of the sediment transport process and incorporation of textiles in sediment control structures have contributed significantly to this process.

Silt fences are useful for preventing material which has been dislodged by erosion from being transported off of the construction site by water. Two fundamental methods are employed in controlling sediment transport: prevent the material from moving or capture the material once it is in transit. Sediment capture, which is the function of a silt fence, can be further subdivided into the processes of settling and filtering. Both settling and filtering are achieved by silt fences in order to separate sediment from the transport agent. Settling is well understood to be a function of(Gilbreath,1979):

a. particle size and shape

b. specific gravity of the particle

c. fluid viscosity

d. acceleration due to gravity

e. turbulence

Equations have been developed and refined to determine the requirements of a basin intended to settle a particular particle of given size and properties. These equations have proven useful in the laboratory and in the field (TRB,1980). The process of filtering by silt fences has not been so extensively investigated, nor has a method for the measurement of silt fence fabric performance been widely adopted.

Purpose and Scope of this Investigation

The purpose of this investigation was to examine the sediment removal performance of silt fence fabrics. Several other areas of fabric performance were briefly examined, including flow rate variation over time and the effect of blinding on fabric performance. A laboratory investigation was undertaken in which procedures designed to test the effectiveness of geotextiles in removing sediment from water were used. The soil used in this investigation is typical of the subsoils found in the western part of the State of Washington. In addition, four fabrics with different physical characteristics were tested and correlations between fabric properties and performance were examined.

A discussion of the theories pertaining to sediment transport and deposition are beyond the scope of this paper. While a detailed discussion of the processes by which geotextiles prevent the passage of sediment will not be attempted, some general conclusions may be stated with regard to trends observed in the data for the various geotextiles.

2. Performance of Silt Fences

A silt fence is a barrier which allows the passage of water, but retards or prevents the passage of accompanying sediment. The use of silt fences is appropriate where low flows are expected or the drainage area is small. The maximum recommended drainage basin area for a single silt fence installation is approximately 5 acres (Boysen,1977). The area served by a silt fence can vary widely, however, because a single fence can be hundreds of feet long. Typical silt fence applications include the toe of slopes, intermittent stream channels, storm water inlets, and inlets to sedimentation basins (Horz,1986).

Prior to the development of synthetic geotextiles suitable for use as silt fences the predominant materials used to check the movement of sediment in small applications were straw bales. The two primary advantages that synthetic fabrics may have when compared to straw bales are lower costs and improved performance. It is difficult to make a general conclusion with regard to cost due to labor and the variable costs associated with each particular application. Silt fences constructed using geotextiles generally have a higher material cost, but lower installation and maintenance costs, compared to straw bales (Wyant,1976; Mirafi,1987).

The performance of silt fences has only recently been rigorously investigated. At present there is no standard method of determining the efficiency of silt fence materials which is widely recognized and used.

The Virginia Highway and Transportation Research Council developed a procedure for evaluating what is referred to as the "filter efficiency" of geotextiles used in silt fence applications (Wyant,1980). This method filtered water with a known concentration of suspended sediment through a sample of geotextile. The sediment concentration of the filtrate was then measured and compared to the initial concentration. The ratio of the final sediment concentration to the initial concentration was expressed as a percent. The resulting percent was termed the "filter efficiency" of the fabric. Although the procedure appears widely applicable, it was only applied to soils typically found in the Commonwealth of Virginia in the initial study.

2.1 Factors Affecting Performance

Factors which affect the performance of silt fences include;

a. fabric characteristics

b. installation

c. sediment characteristics

d. site specific variables which affect the volume of influent to the structure or the concentration of sediment in the influent.

A discussion of each of these factors is presented below.

2.1.1 Fabric Characteristics

Several characteristics of geotextiles influence the filter efficiency. The method of fabric construction controls the size and tortuousity of openings and also determines the final fabric thickness. Nonwoven, and woven fabrics have both been marketed by geotextile manufacturers for use in silt fence applications. Nonwoven fabrics exhibit longer and more tortuous pores than woven fabrics and as a result the probability of clogging is increased (Bell and Hicks,1980). Nonwoven fabrics also stretch more readily than woven fabrics, therefore nonwovens used in silt fence applications generally require that wire fence or geogrid reinforcing be provided. The majority of fabrics presently marketed for silt fence application are of woven construction. Only woven fabrics were available for this investigation, therefore the performance of fabrics constructed by other manufacturing methods were not examined.

Bell and Hicks, et. al. (1980) identified several fabric characteristics that may influence the fabric performance. The important characteristics which might influence the performance of silt fences are identified as:

Pore Size Distribution. Larger pores will increase the rate of flow and also will allow larger particles to pass through the fabric.

Percentage Open Area. The percentage of open area is a function of the number and size of pores. In fabrics having similar pore size distributions the fabric with a higher percent open area will have a larger number of pores per unit area and will exhibit a higher flow rate. Clogging should also be less of a problem in the fabric with a higher percentage of open area due to the higher number of pores.

Thickness. Thicker fabrics have longer and more tortuous flow paths, resulting in greater opportunity for particles to clog openings. This is particularly true for nonwoven fabrics.

Fiber Diameter. For two fibers with identical percentages of open area, the fabric with larger fibers will have fewer and larger openings than the fabric with smaller fibers.

Two important fabric characteristics can be quantified using standard procedures specified by the American Society for Testing and Materials (ASTM). The test most applicable to silt fence performance is ASTM D 4751-87, Standard Test Method for Determining Apparent Opening Size of a Geotextile (ASTM,1988a). The AOS test specified by ASTM is very similar to an Army Corps of Engineers test designated COE CW-02215. The COE test is cited by some geotextile manufacturers when providing a value of the AOS of their products.

The results of the ASTM AOS test provide the largest particle which will effectively pass through a geotextile determined by sieving glass beads through a dry fabric sample. Beads of a known size are sieved, with increasingly large beads being sieved until at least 95% by weight of a given size are retained on the geotextile. The AOS reported is the average value determined from at least 5 specimens and is usually expressed as the U.S. standard sieve number on which 95% of the beads of the final size would be retained. This procedure does not provide adequate information to determine the performance of a particular fabric in a silt fence application because it does not account for the possibility that sediment particles will behave differently when being transported by water, but it does provide information for one of the fabric characteristics which contributes to fabric performance.

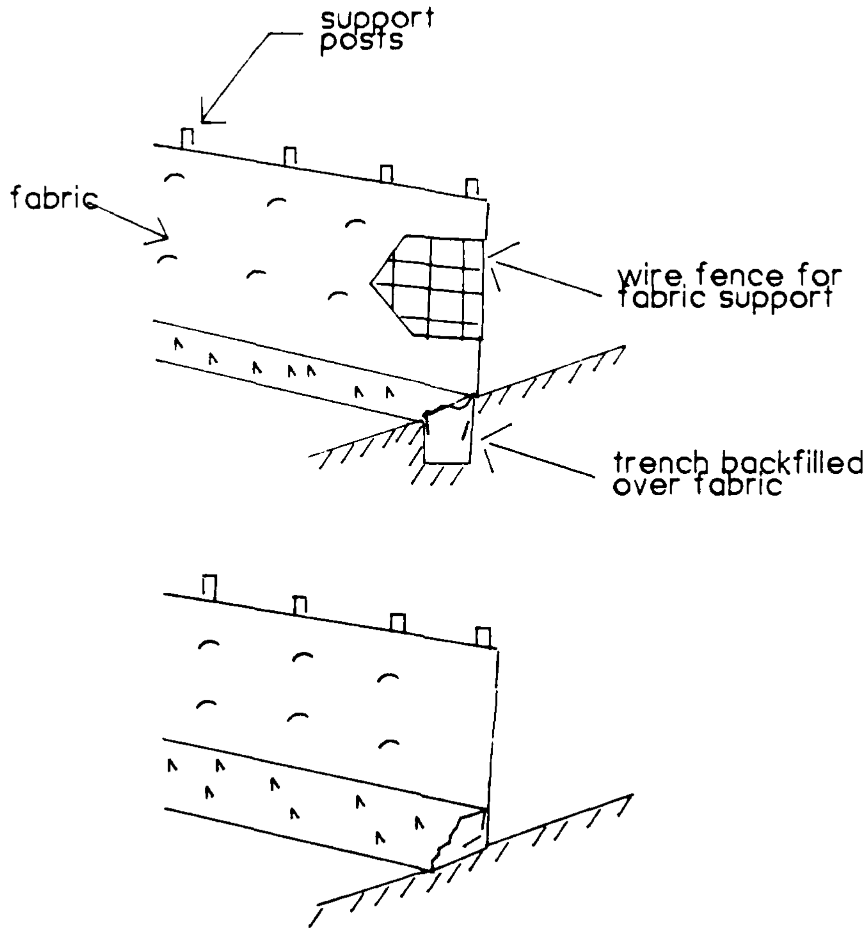
Another standard test which provides valuable information relating to fabric characteristics is ASTM D 4491-85, Standard Test Methods for Water Permeability of Geotextiles by Permittivity (ASTM,1988b). This procedure provides the rate of flow through a fabric independent of fabric thickness. There are two variants of this procedure; the constant head test and the falling head test. Both variations require that the fabric sample be mounted in a vertical cylinder and the flow of water through the fabric measured. The permittivity test does not account for the effect of sediment on permittivity, nor does it evaluate the effects of clogging or blinding. This test in combination with the ASTM AOS determination provides an indirect indication of the percentage of open area of the fabric.

Several other ASTM tests have been established which are applicable to geotextiles intended for use as silt fences, but most provide information which applies to fabric durability, not performance. The two ASTM tests previously mentioned measure fabric characteristics which are often related to performance, but neither provides a direct measurement of the ability of a fabric to prevent the passage of sediment.

The fabric texture may also affect the performance of a silt fence, although this property has not been rigorously investigated. Texture as used herein refers to the roughness, tightness of spinning, and number and thickness of loose fibers for each strand of yarn. Casual observation is adequate to ascertain that fabrics differ markedly in these respects. Some are manufactured with slick, flat, plastic-like yarns while others exhibit a rough texture similar to burlap. The rough texture and small, loose individual fibers of the latter fabrics should capture more sediment particles due to higher friction and by entanglement. Therefore, fabrics woven from rougher yarns should exhibit a higher filter efficiency if all other fabric characteristics are equal.

2.1.2 Installation of Silt Fences

The performance of a geotextile fabric will have little impact on the filtration efficiency of a silt fence if the fence is not properly installed. Several investigators have examined silt fence installation and all recommend very similar designs (Bell and Hicks,1980; Minnitti, 1983; Sherwood,1978). Manufacturers have accepted these recommendations and often provide schematics of the standard design with product literature for silt fence fabrics (Mirafi,1987; Amoco,1988; Webtec,1987). Figure 2.A. is a diagram of the recommended method for installing silt fences as well as an accepted alternate method. National Cooperative Highway Research Program Report 220 noted that; "Erosion control measures are of no value if they are not installed properly in the right places at the appropriate times, and then adequately maintained" (Israelson,1980). Proper installation of silt fences is particularly crucial



Alternate Toe-in Method

Figure 2.A. Recommended Silt Fence Installation

because little sediment will be captured if water is allowed to pass under or around the fabric.

Maintenance of a properly installed silt fence is also very important. Although the literature provides varied recommendations, the common concensus is that the structure should be inspected after each storm and that accumulated sediment should be removed from behind the fabric when the potential sediment volume is 1/3 to 1/2 full (Sherwood,1978; SCS,1983). One alternative which has been recommended is that a new structure be erected to intercept the flow previously captured by a silt fence which is nearing capacity (Bell and Hicks,1980).

An equation has been developed to predict how high the water will rise behind a silt fence (Bell and Hicks,1984). This equation can be used to in the formulation of a design. A simplified version of the equation is given as:

$$X = H + h_1 + h_2 \qquad \text{(Eq. 2-1)}$$

Where:
- X = total height of material behind fence (in.)
- H = height of impermeable soil cake clogging fabric (in.)
- h_1 = height through which flow occurs (in.)
- h_2 = head required to initiate flow through fabric (in.)

The relationships between the variables in equation 2-1 are shown in Figure 2.B.

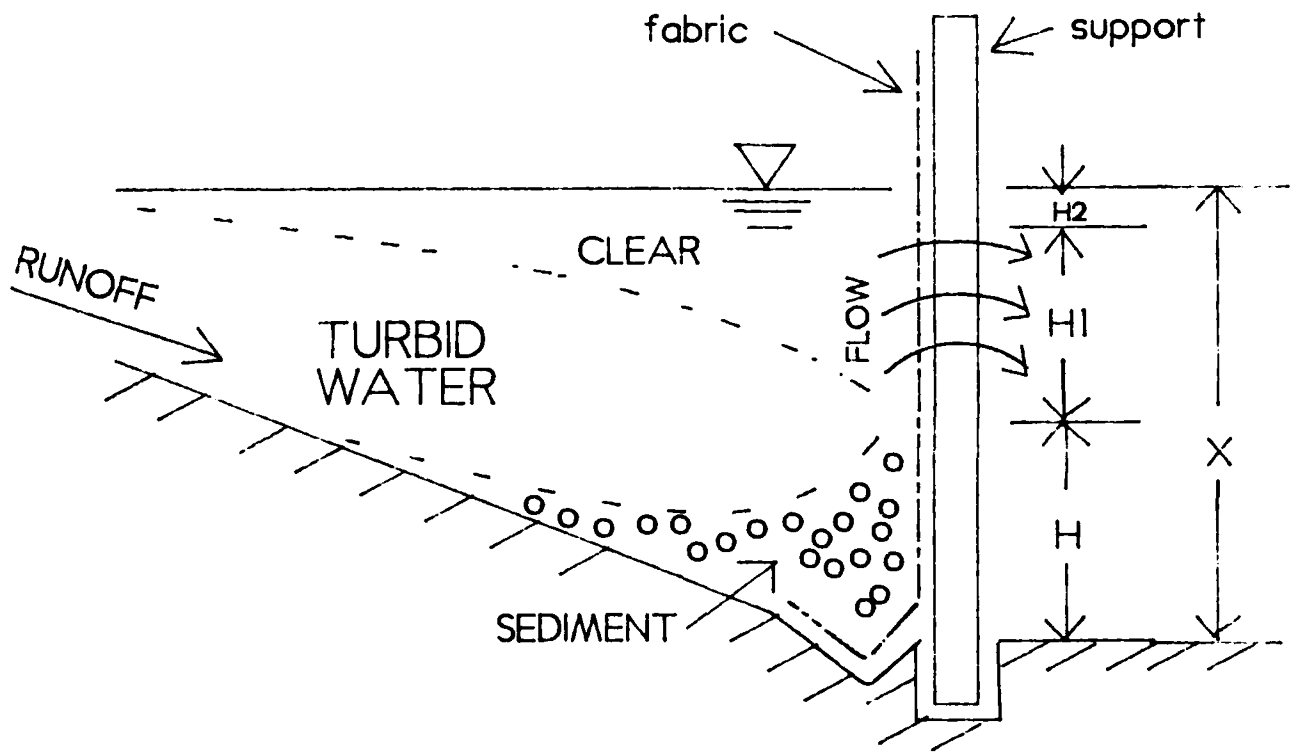


Figure 2.B. Silt Fence Function

2.1.3 Sediment Characteristics

Sediment is transported by water either as bed load or in suspension (ASCE,1975). The bed load will settle as soon as the dynamic energy of the water is converted to potential energy, and this occurs behind the silt fence as the fabric retards the flow. Sediment carried as bed load does not affect fabric performance provided that it is not allowed to accumulate to the point where the material is deposited against the fabric and causes blinding.

A portion of the larger suspended particles will also settle behind the silt fence due to the decreased stream velocity. The exact fraction which will settle is dependent on numerous variables. In erosion control structure design the settling velocity of particles is generally determined by Stoke's Law (Gilbreath,1979). Stoke's Law is only applicable for a flow regime in which the Reynold's number is less than 1. The Reynold's number is expressed as:

$$R_e = (V_s * D) / kv \qquad \text{(Eq. 2-2)}$$

Where: R_e = Reynold's number

V_s = settling velocity, cm/sec

D = diameter of spherical particle, cm

kv = kinematic viscosity of water, cm^2/sec

For $R_e < 1$, the equation for determining the settling velocity from Stokes' Law is:

$$V_s = (g / (18 * kv)) * ((S_s - 1) * D^2) \qquad \text{(Eq. 2-3)}$$

Where: g = acceleration due to gravity, cm/sec^2

S_s = specific gravity of the particle

The remaining terms are the same as defined for equation (1-2).

Stoke's Law includes simplifying assumptions that skew the results of equation 2-3 (Gilbreath,1979). One assumption is that the particles are spherical. This is not often the case in nature. Rod and disc shaped particles have been found to have settling velocities ranging from 73 to 78% of that predicted using Stoke's Law (Fair,1971). Another assumption commonly incorporated in equation 2-3 is that all of the particles under consideration have the same specific gravity (Gilbreath, 1979). The settling velocity of particles with a specific gravity less than that assumed be lower than predicted by Stoke's Law. Water quality and sediment concentration may also affect settling velocity and are outside of the parameters considered in the equation.

The size of sediment particles is the principal soil characteristic which will affect the performance of silt fence fabric. If the particles of sediment are smaller than the fabric pores, some may pass through. No particles larger than the fabric pores will be passed. Although this is true for uniform particle sizes, the problem is somewhat more complex when the sediment suspended in the water to be filtered is graded and has a wide range of particle sizes. Bell and Hicks, et. al.(1980), hypothesized that blinding of the influent side of the fabric tends to constrict the fabric pores, not only reducing fabric permittivity, but causing progressively smaller sediment particles to be trapped by the fabric. Grain size distribution also becomes an important characteristic of sediment which affects fabric performance if the blinding effect actually occurs.

2.1.4 Site Specific Variables

The Universal Soil Loss Equation (USLE) is typically used to estimate the amount of erosion which will occur on a construction site (TRB,1980). The Musgrave equation is sometimes used to estimate sheet erosion on very steep slopes, but it is much less popular than the USLE (Bedner and Fluke,1980). One of the variables used in the USLE is the Soil Erodibility Factor (K). The K-value represents the ability of a soil to resist erosion by rain, and for a particular soil is dependent on a combination of soil properties. A higher K-value indicates a more erodible soil, so for soils with a high K it may be anticipated that more sediment will be carried away by runoff in a given storm. The concentration of sediment in the influent to a silt fence may affect fabric performance, although no investigation in this area has been noted.

The other variables in the USLE also impact the efficiency of silt fences. The USLE is used to predict the gross soil loss per year, and the equation is represented as (Gilbreath,1979):

$$A = R * K * LS * CP \quad \text{(Eq. 2-4)}$$

Where: A = soil loss, tons/acre

R = rainfall factor

K = soil erodibility factor

LS = length-slope factor

CP = control practice factor

The effect of the soil erodibility factor (K) was discussed in section 2.1.4. The remaining 3 factors are site specific. The USLE is useful in estimating the concentration of sediment in the runoff which will reach the silt fence installation. It should be noted that the control practice factor (CP) should only include control practices in place upstream from the silt fence when predicting sediment concentration at the fence. The USLE must be applied with caution because it was initially formulated for predicting erosion from agricultural land. It also does not account for sediment deposition on the site, such as that which might occur in depressions (Wischmeier, 1976).

2.2 Measures of Filtration Performance

There is no universally accepted standard method for determining the filtration performance of silt fence geotextiles at the present time. The Virginia Highway and Transportation Research Council developed the procedure on which VTM-51 is based (Wyant,1980). This official standard of the Virginia Highway and Transportation Department is gaining acceptance outside of the Commonwealth of Virginia, but the acceptance is not yet universal.

The apparatus used in the Virginia test is a box-like flume. Three sides of the flume are enclosed and a sample of the fabric to be tested is placed over the open end. Water containing sediment is then introduced into the flume and passes out through the fabric. The amount of sediment residue by weight remaining in the filtered water is compared to the amount introduced with the inflow. The filter efficiency of the fabric is the ratio of the residues expressed as a percent.

One aspect of the Virginia test which limits applicability is that the soil to be used in the procedure is not rigidly specified. The test method recommends a silty soil with a particular gradation be used. It also suggests that either another available silty soil or soil from the construction site may be substituted. The results of the tests are not meaningful unless the soil used is completely specified with the results. The soil used is rarely included with filter efficiency data provided by geotextile manufacturers.

The New York Department of Transportation has also designed and constructed a flume-type apparatus for testing geotextiles under consideration for use as silt fences (Minnitti,1983). The dimensions of the flume used by this agency were 37 inches in length and 6 inches wide. Both ends of the device were closed with a pipe protruding from the downstream end to collect effluent. The fabric sample was clamped in a frame at approximately the center of the flume forming two cells. Dirty water was poured into one of the rectangular cells and the downstream cell was filled with clean water in the initial stage of the test. Flow was allowed to take place with the dirty water upstream, thus filtering it through the fabric. The outflow was analyzed to determine how much soil passed through the fabric.

The New York method is very similar to the Virginia method, but the equipment is more difficult to construct and work with. Also, results for the procedure have not been reported in a form from which the test can be reproduced as is the case for the Virginia method.

Another procedure has been developed to measure geotextile filtration performance using an apparatus in which the fabric was mounted in the horizontal plane and water flow was vertical (Atmatzidis, et. al., 1982). The device incorporated a pump, piezometers, a flow meter, and considerable plumbing. The effectiveness of several geotextiles in filtering suspended clays was determined. The results noted that the device was not particularly well suited for evaluating woven fabrics due to the rapid clogging of these fabrics under the test conditions. One sample tested was a woven fabric with an Apparent Opening Size of approximately 50. The test determined that the fabric removed 8 to 12% of the suspended material by weight. None of the other woven fabrics tested could be properly evaluated due to clogging.

A researcher at the California Department of Transportation developed a test in which a fabric sample was mounted in a horizontal pipe and ballotinni introduced in the flow through the fabric (Hoover,1982). The procedure appears reliable, but the construction of the apparatus was somewhat complicated.

Several other experiments have been carried out with the intent to determine the filtration capabilities of geotextiles. The vast majority of these experiments were not designed to evaluate the performance geotextiles used in silt fence applications.

3. Equipment Used in Testing

One of the primary goals of this investigation was to obtain results comparable to those obtained by the Virginia Highway and Transportation Research Council in determining the filter efficiency of geotextiles used in silt fence applications (Wyant, 1980). The procedure used by the Research Council has been designated as Virginia Test Method 51 (VTM-51) by the Virginia Department of Highways and Transportation. The flume box was constructed to the same dimensions as that used by the VHRTC and the methodologies used in performing the tests were very similar. The major difference between the two investigations were the soils used. Soils typical of the Commonwealth of Virginia were used in the Virginia tests. VTM-51 recommends the gradation and characteristics of the soil to be used in the procedure. The specified soil is a silt typical of Virginia, although the test method allows an available silty soil or the design soil to be used as an alternative. The results of the test using the specified soil are not necessarily applicable to soils for other regions of the United States. This investigation examined silt fence fabric performance using a highly erodible soil of glacial origins typical of many of the subsoils in Western Washington. The gradation curves of the two soils are compared in Figure 3.A.

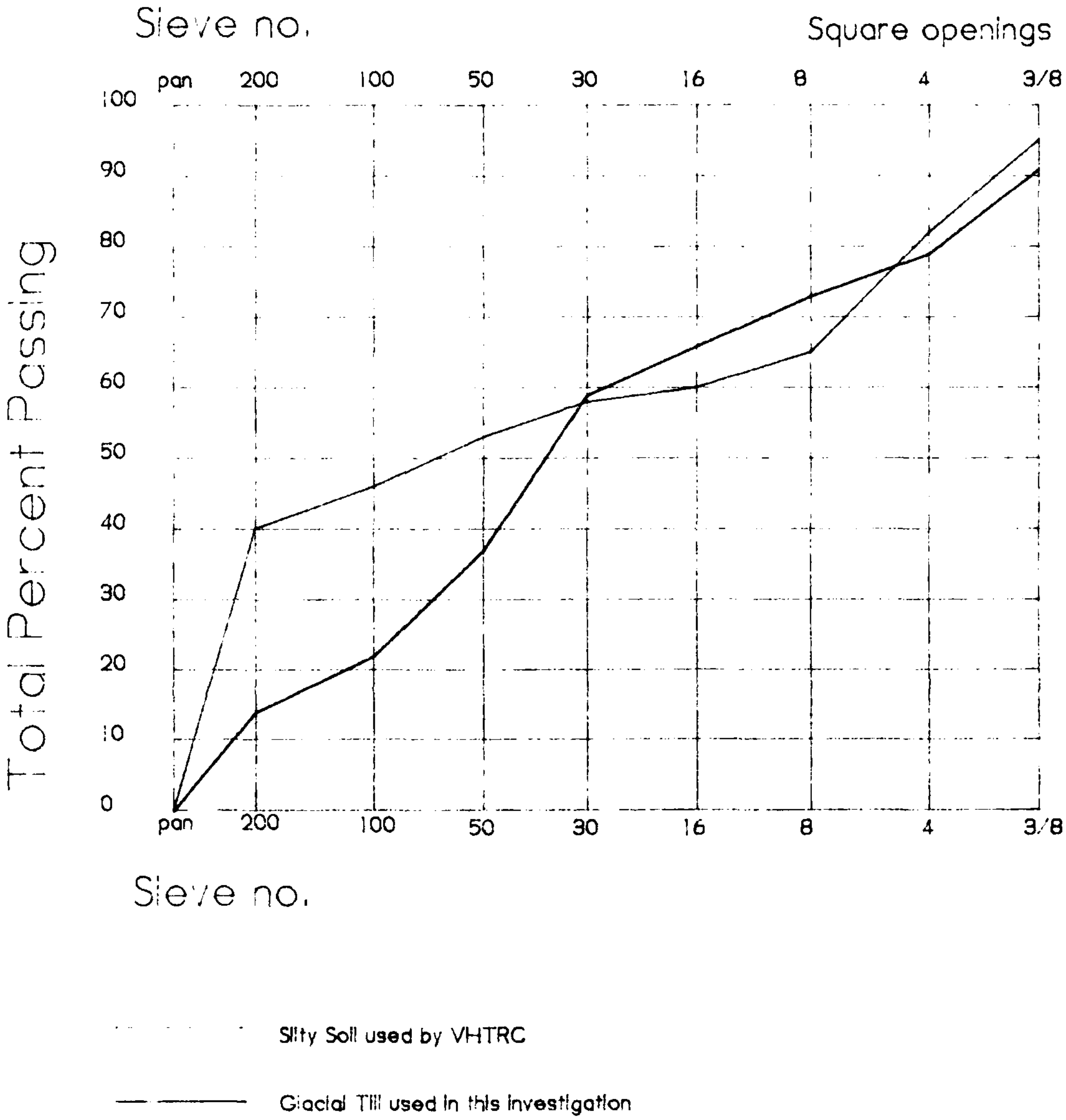


Figure 3.A. Aggregate Gradation Curves

3.1 Sediment

The sediment used in the primary series of investigations was a Brown Glacial Till. The material was obtained at a construction site located on the University of Washington campus in Seattle, Washington. The soil properties are listed in the table below.

Table 3.1. Soil Properties for Brown Glacial Till (UW,1986)

Description:

Light tan, gravelly, silty sand

Classification:

A-1-b(0) AASHTO

SM Unified Soil Classification

Atterberg Limits:

Liquid Limit = 14%

Plastic Limit = NP

Plasticity Index = NA

Specific Gravity:

S.G. of solids = 2.78 (approx.)

Gradation:

Uniformity coefficient = 350

Coefficient of gradation = 35

Material passing the No. 10 sieve was used in the initial series of fabric tests. This corresponds to the soil preparation performed by the Virginia Highway and Transportation Research Council study which this investigation parallels.

The material was divided into the fractions shown in Table 3.2. Note that a large proportion of the soil was retained on the No. 80 sieve. This is not unusual in soils with glacial origins because these soils are typically poorly sorted (SCS,1983). The soil also contained gravel and cobbles larger than 3 inches in diameter, although the fraction larger than the No. 10 sieve was not quantified because the larger particles will settle prior to reaching the fabric in a normal silt fence installation.

Table 3.2. Mixing Proportions for Brown Glacial Till to be used as Sediment

Sieve Retained on (Std. No.)	Total Wt. Retained (g)	% of Total	Wt. for each 50 g sample (g)
16	616.3	6.06	3.0
30	1406.6	13.84	6.9
80	6000.3	59.05	29.5
200	1373.3	13.51	6.8
pan	765.1	7.53	3.8

3.2 Flume Design and Construction

The basis for the design of the flume apparatus was the report for the Virginia Highway and Transportation Research Council which used a similar apparatus and procedure (Wyant,1980). The flume dimensions are shown in Figure 3.B.

The flume box was constructed of 3/4 inch plywood and was assembled using 1 inch screws spaced 3 inches apart. The members were also glued for additional strength. The box was then lined with plastic sheeting in order to prevent leaks and to create channel friction characteristics which could be readily reproduced. The plastic sheeting was fastened to the outer perimeter of the flume using 1/2 inch tacks closely spaced. Wedge-shaped vinyl gasket material was attached to the flume box around the inner perimeter of the open end using 1/2 inch tacks. The gasket material was installed with the narrow edge facing the interior of the flume.

A rectangular frame was constructed of 1/2 inch by 1/2 inch wooden members. The manner in which the frame was attached to the flume was the only marked difference between the flume box constructed for this investigation and the box prescribed by the Virginia test method. The frame was installed such that the top of the frame was flush with the bottom of the flume in the Virginia test. In this investigation the frame was installed inside the flume as shown in Figure 3.C. This resulted in the frame blocking flow through the lower 1/2 inch of fabric.

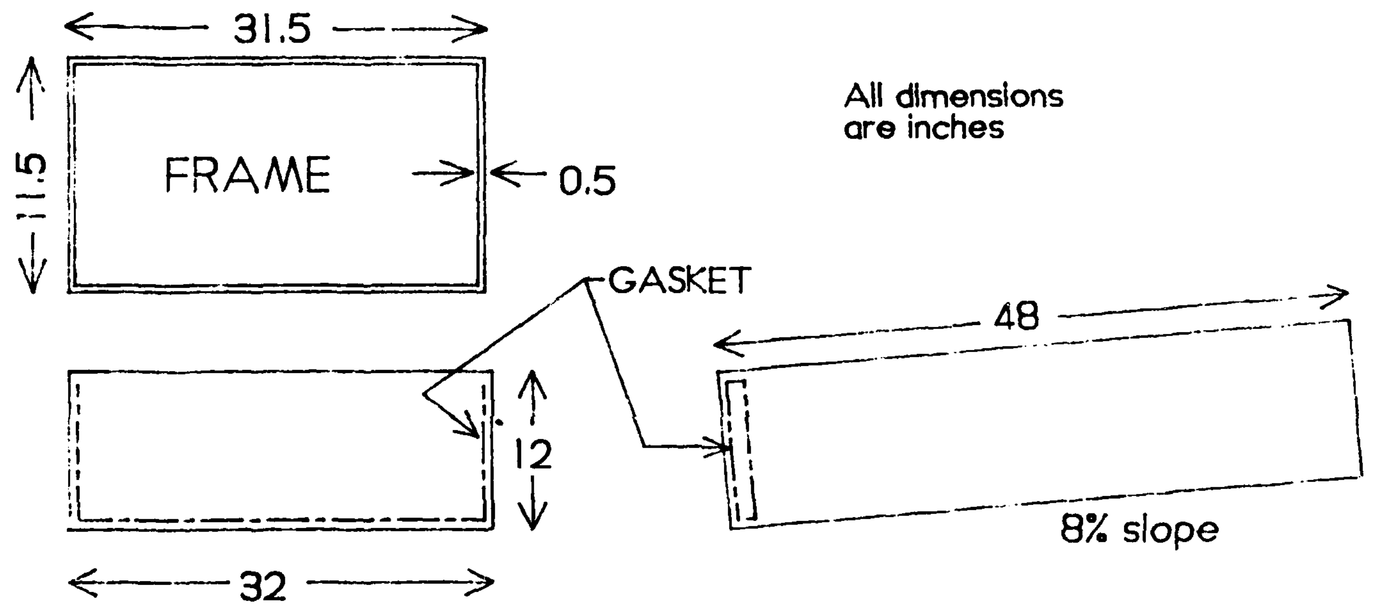


Figure 3.B. Flume Box Schematic Diagram

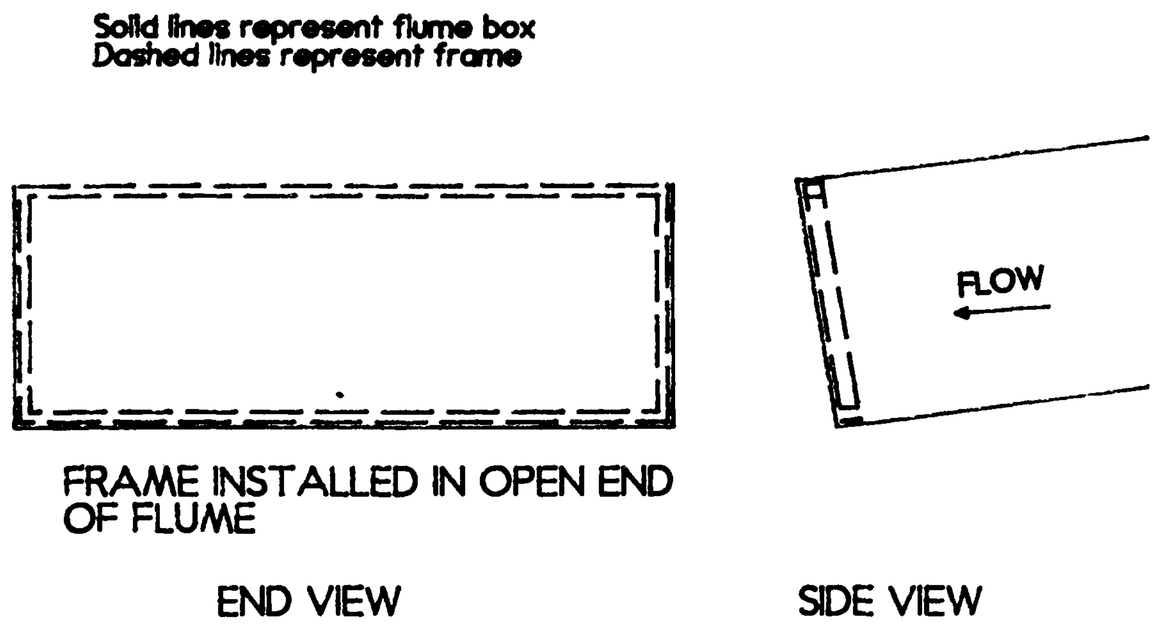


Figure 3.C. Frame Installed in the Flume Box

The frame members were connected by glue and 3/4 inch screws. The dimensions of the frame were 1/8 inch smaller than the inside dimensions of the open end of the flume to allow for easy installation. The bottom and sides of the frame fit snugly against the gasket material attached to the inside perimeter of the open end of the flume box.

A 5-gallon plastic bucket was supported over the flume in order to serve as an inflow regulator. Three 1/2 inch holes spaced 1/2 inch apart were drilled in the bottom of the bucket in a triangular pattern. The influent entered the flume through these holes during the test. This ensured that the sediment-laden water was introduced into the flume at a similar rate and with similar turbulence for each test. No. 0 rubber stoppers were placed in the holes to prevent inflow prior to the commencement of each test. This allowed for the filling of the bucket with 1/3 of the influent prior to starting the timer.

A length of plastic gutter was installed below the open end of the flume in order to capture the effluent and transport it to a container. The gutter was installed such that the edge of the flume overhung the gutter by approximately 1 inch. A 20-gallon plastic container was placed below the lower end of the gutter to receive the filtered water.

The closed end of the flume was elevated to create an 8% slope from the closed end to the open end. This slope was specified by VTM-51.

3.3 Fabrics Tested

All of the fabrics provided by manufacturers for testing were of woven construction and were recommended for use as silt fences. Table 3.3. is a tabulation of the fabric properties as provided by the manufacturers. None of the properties indicated were independently verified in this investigation.

Obvious differences between the fabrics tested were discernible by visual observation. The Mirafi 100X appeared black and shiny. It folded stiffly and felt like plastic. The yarn was flat and twisted yarns within the weave created pores larger than those in areas where the weave was tight and uniform. These larger pores were irregularly spaced.

The Mirafi 600X appeared very similar to the 100X, but it was much stiffer. The weave was tight and uniform, with no twisted yarns or uneven pore distributions that could be identified by visual observation. A complete testing of the Mirafi 600X fabric was not possible due to the small size of the sample provided.

The Amoco 1380 Silt Stop fabric was also shiny and plastic-like. It was woven using two colors of yarn; black and green. The yarn was flat and twisted strands created larger, irregularly distributed pores very similar to those observed in the Mirafi 100X.

The Amoco 2125 fabric was very different from the other fabrics tested. It was composed of black and green yarns, with each color running in perpendicular directions. The green yarn was flat and plastic-like, similar to the yarns used in the other three fabrics. The black yarn was round with many loose fibers, similar to wool yarn. This gave the fabric a soft, burlap-like texture. The weave was tight and uniform throughout.

A standard method for obtaining representative fabric samples from large lots has been developed by ASTM (ASTM,1988c). The procedure is designated ASTM D4354-84, Standard Practice for Sampling of Geotextiles for Testing. The fabric samples made available for this investigation were not large enough to employ the standard sampling method. The largest sample provided was 4 feet wide and 10 feet long, while the ASTM sampling method recommends sampling from 600 square yard lots.

TABLE 3.3. Geotextile Physical Properties provided by Manufacturers

	Properties (units)				
	Thick-ness (mils)	Weight (oz/sy)	AOS (Std. Sieve)	Filter Efficien. (%)	Permit-tivity (*)
Test Method	ASTM D-1777 -64	ASTM D-3776-79	COE CW02215-77	VA DOH VTM-51	ASTM 4491-85
Fabric					
Mirafi 100X	17	2.5	20-35	75	.01[1] 40
Mirafi 600X	30	6.0	30-50	--	.01[1] 50
Amoco 1380	--	--	30-50	75	.4[2] 30
Amoco 2125	--	--	20-30	--	.2[2] 15

Properties which do not affect the filtration performance of the fabrics, such as strength and durability, are not shown.

-- Indicates that a value for this property was not provided in product literature.

* The units for the first value of each fabric in the permittivity column are cm/sec for the Mirafi fabrics and sec^{-1} for the Amoco fabrics. The units of the second value shown for each fabric are gal/min/sf for all fabrics.

1 *Falling Head Test Method*

4. Methodology used in Measuring Performance of Silt Fences in the Laboratory

The procedures described in this section are based on the methodology used by the Virginia Highway and Transportation Research Council and standard procedures specified in Standard Methods for the Examination of Water and Wastewater (Wyant,1980; APHA,1985). It was not possible to adhere to each specified procedure exactly as written. This discussion includes alternatives employed, although such alternatives were minor deviations and would not be expected to affect the final results substantially.

4.1 Flume Operating Procedures

The filtering efficiency tests were setup and performed using the procedures outlined in the following sections. The procedures were performed in exactly the same order and in the same manner for each test.

4.1.1 Preparations for Testing

Each geotextile sample was trimmed to extend beyond the outer edges of the wooden frame by approximately two inches. After trimming, the fabric was laid flat on a table and the frame placed on top of it. Then the top edge of the fabric was folded over twice, creating a triple thickness of fabric one inch wide. This triple thick section was then placed against the back side of the frame, which was facing up as the frame lay on the table. A one-half inch tack was then used to fasten the fabric at the center of the top frame member. The fabric was then pulled tight and another tack placed approximately two inches from the first one fastening the fabric to the top member of the frame. The next tack was placed about two inches on the opposite side of the first tack after pulling the fabric tight. The tacks were alternately placed in this fashion, tightening the fabric from the center, until the material was securely fastened to the top member of the wooden frame. The process was repeated for the bottom member of the frame. On the bottom member the tacks were placed only one inch apart to facilitate caulking between the edge of the fabric and the wooden frame. The corners of the fabric were then tightly folded and tacked to the side members of the frame, again using a double fold to create a triple thickness along the edge of the fabric. The tacks were placed at intervals of two inches on the side members. Figure 4.A. is a schematic diagram of the attachment of a fabric sample to the frame.

A waterproof caulk was used to seal the edge of the fabric to the bottom member of the wooden frame on the effluent side of the frame. This seal was placed to ensure that any sediment which passed through the fabric was not trapped between the wood member and the fabric.

The flume box and fabric frame were constructed such that the frame fit snugly into the open end of the flume. Once the fabric was attached the frame was lowered into the box and a hammer used to

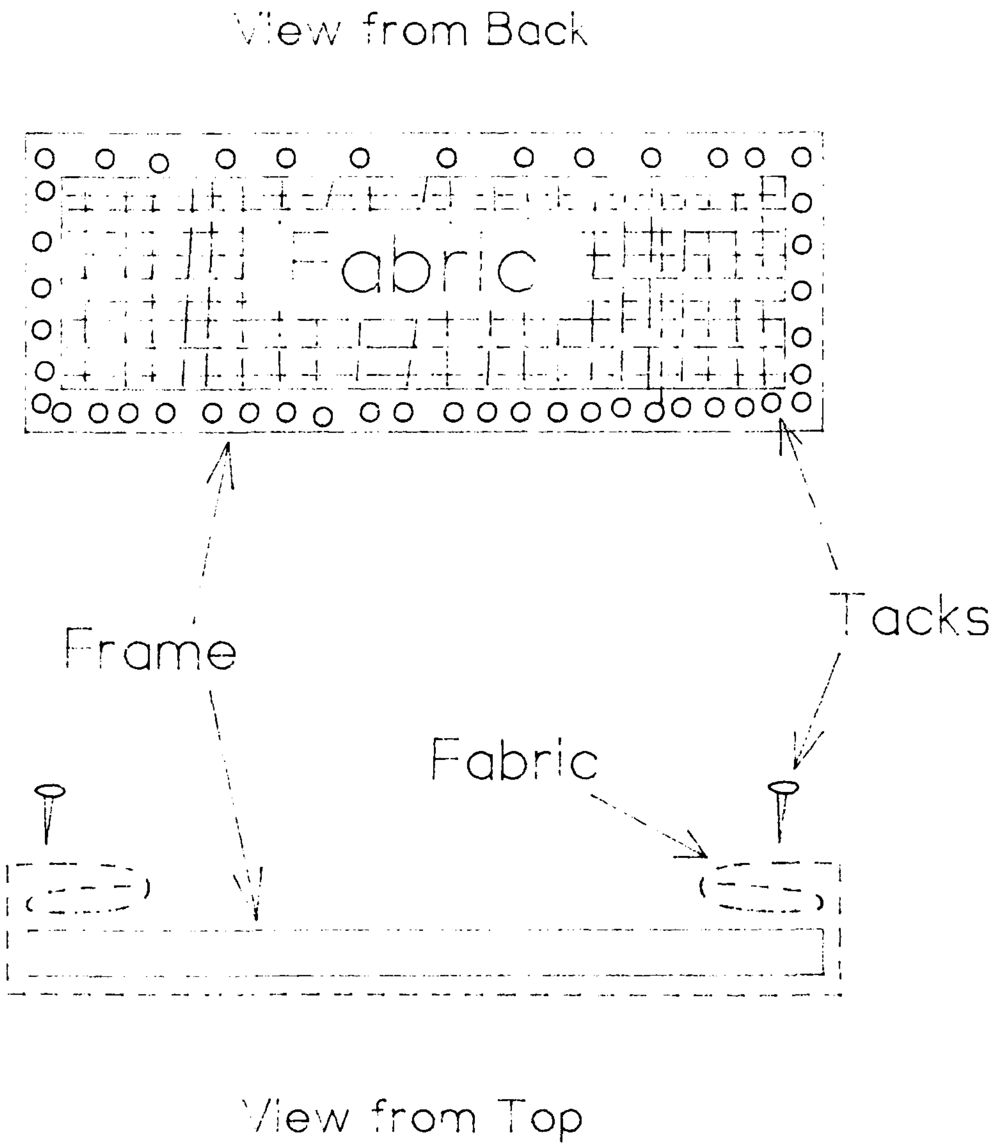


Figure 4.A. Attachment of Fabric to Frame

lightly tap the frame into place against the gasket material. A wooden wedge was then pounded between the frame and the side of the flume box from the inflow side to ensure that the frame would not move during testing.

Waterproof caulk material was also placed between the frame and the flume box after the frame was installed. This ensured that all of the sediment-laden water passed through the silt fence material.

A total of 13.2 gallons of water with 150 grams of soil added was used for each run of the flume test. These quantities were the same as used by the Virginia Highway and Transportation Research Council.

The water was divided into 3 equal parts contained in separate 5-gallon buckets so that it could be lifted and dumped into the inflow apparatus. The soil was prepared in 50 gram lots, each lot containing the same fraction of material retained on each sieve as shown in Table 3.2. One 50 gram lot was added to each bucket.

Two fabric samples were tested using sediment which differed from the aforementioned procedure. The samples of the Mirafi 100X geotextile designated D and E were evaluated using only that portion of the standard sediment sample which passed the No. 30 sieve.

4.1.2 Performing the Filtering Efficiency Test

The inflow was regulated by a 5-gallon bucket with 3 holes drilled into the bottom as described in the section concerning flume design. This bucket was mounted at the side of the flume such that the holes extended

1 inch over the inside edge of the flume and the inflow entered the box 12 inches from the open end. The first bucket of influent was thoroughly agitated using a propeller mixer mounted on a drill. The contents of the first bucket were quickly dumped into the inflow regulating bucket. The stoppers were then removed from the inflow regulator and water began flowing into the flume. A stop watch was started as the stoppers were removed. Water containing sediment from one of the remaining buckets was then used to rinse any sediment remaining in the first bucket into the inflow regulator.

The contents of the second and third buckets were agitated and dumped into the inflow regulator in a similar manner. The buckets were emptied into the inflow regulator in quick succession, resulting in the inflow proceeding at a near uniform rate until the contents of the last bucket began to drain out of the inflow regulator. The inflow regulator was then rinsed with approximately one pint of filtered outflow. The rinse water was dumped into the flume at the same point as the inflow from the inflow regulator entered.

The gutter was rinsed with filtrate from the effluent container prior to obtaining a sample from the effluent.

4.2 Sampling and Analysis of Sediment Residue

Water samples were obtained from the influent and effluent using a 20-inch long clear, flexible plastic tube which was 1/2 inch in diameter. A mark was placed on the tube to indicate the 167- milliliter level. The water and sediment in one of the three buckets containing the influent were vigorously agitated using a drill mounted propeller, ensuring that the constituents were well mixed. The sampling tube with both ends open was rapidly lowered into a bucket to the 167-milliliter mark immediately after agitation, then the exposed end of the tube was covered and the tube quickly withdrawn. The tube was then drained into a 1 quart jar. This process was repeated for each of the 2 remaining buckets which contained influent. All 3 samples were placed in the same jar, forming a 500-milliliter sample of the influent.

The effluent from the flume drained into a single large container. The contents of this container were agitated with the propeller prior to removing each of 3 samples with the sampling tube. The 3 167-milliliter samples were removed and combined in a 1-quart jar to form a 500-milliliter sample of effluent.

4.2.1 Processing of Samples

The water samples collected were analyzed as described in <u>Standard Methods for the Examination of Water and Wastewater</u> (APHA,1985) section 209C, Total Suspended Solids Dried at 103-105 ^{O}C, except for minor deviations which are included in this description of procedures.

The glass fiber filter disks were prepared by placing the disks one at a time in a membrane filter apparatus and washing 3 times with 20 milliliters of deionized water while applying vacuum. The filtered water was discarded after each washing. The washed filters were then placed in aluminum support pans and dried in an oven between 103^{o} and 105^{o} C for one hour. After removal from the oven the filters were placed in a dessicator with their support pans and allowed to cool.

The filters with the support pans were removed from the dessicator and weighed immediately prior to use. The resulting weight is designated as A in equation 4-1, which was the equation used to determine filtering efficiency. One filter was placed in the membrane filter apparatus and the vacuum applied. Approximately 10 milliliters of clean deionized was then passed through the filter in order to ensure that the seal was complete and that none of the sample could bypass the filter material. The 500-milliliter sample containing suspended sediment was then poured into the membrane filter apparatus, with a vacuum maintained until all of the water had passed through the filter. The jar which contained the sample was rinsed with approximately 50 milliliters of deionized water to ensure that all particles were washed into the filter apparatus. The sides of the membrane filter apparatus were also rinsed with deionized water to wash any particles of sediment adhered to the side of the filter holder onto the filter.

The filter was then removed from the membrane filter apparatus, with due care taken to ensure that no loose material was lost. It was then returned to the aluminum support dish and dried in an oven between 103^{o} and 105^{o} C. The filter and support were transferred to a dessicator to cool after drying for one hour. Each filter and support was weighed after approximately 30 minutes in the dessicator. This final weight is designated as B in equation 4-1.

4.2.2 Computation of Filtering Efficiency

The fabric filtering efficiency expressed as a percent was determined using the following equations:

$$RESIDUE_{BEFORE} = B - A_I \qquad \text{(Eq. 4-1a)}$$

Where: B = weight of filter disk and support

A_I = B + weight of residue from influent sample

$$RESIDUE_{AFTER} = B - A_E \qquad \text{(Eq. 4-1b)}$$

Where: A_E = B + weight of residue from filtrate sample

$$FE = \frac{(RESIDUE_{BEFORE} - RESIDUE_{AFTER})}{RESIDUE_{BEFORE}} * 100 \qquad \text{(Eq. 4-2)}$$

Where: FE = Filtration Efficiency (percent)

Equation 4-1 was dictated by Standard Methods for the Examination of Water and Wastewater. The equation used to determine the filtration efficiency is similar to that used by the Virginia Highway and Transportation Research Council (Wyant,1980). The VHTRC used a constant of 3000 milligrams in the equation to account for sediment present in the water prior to adding the specified soil. The series of tests performed in this investigation used a filtered water source in which the initial quantity of sediment was negligible.

4.3 Flow Rate

The flow rate was measured at the discharge end of the gutter which directed the effluent from the flume to the 20-gallon effluent container. The flow was measured periodically until a flow less than 0.25 gallons per minute was measured, or until the flow had decreased to a point at which it was inadequate to fill the measurement container in a reasonable time. The latter case only occurred when the flow was well below 0.25 gallons per minute.

4.3.1 Measurement Procedure

A one-quart jar was held below the outflow from the gutter and a stopwatch used to determine the time required for the jar to fill. This process was repeated periodically during the test. A running clock timed the entire test. The time at which the flow measurement commenced and the time required to fill the jar were recorded.

The first flow measurement was started three minutes after inflow to the flume was initiated for those tests in which the influent contained sediment. This delay was necessary to allow the individual performing the test to adequately rinse all of the influent containers and to inspect the apparatus for leaks. The first flow measurement was started one minute after inflow was initiated for the tests in which no sediment was used. In the initial tests the first two flow measurements were recorded one minute apart and subsequent measurements were taken at two minute intervals. The flow was measured at one minute intervals during the last several tests.

The flow rate was determined using the following equation:

$$FR = 15 / time \qquad \text{(Eq. 4-3)}$$

Where:

FR	=	flow rate (gallons per minute)
time	=	time required to fill 1-quart container (sec)
15	=	factor to convert 1-qt./sec to gpm

The flow rate measurements are tabulated in Appendix B.

5. Analysis of Results

An examination of the measured concentration of sediment in the influent casts suspicion on the accuracy of the plastic tube used to extract residue samples. The soil was carefully weighed into equal batches for each test, but the range of residues measured in the samples from the influent ranged from 0.429 to 1.297 grams. Three separate samples were extracted from the influent for the sample of the Amoco 2125 designated A. The residues measured in this single batch of influent ranged from 0.429 to 0.614 grams. It is possible that the tube sampler was lowered too fast to capture an integrated sample. Another possibility is that the tube was lowered at different rates from one sample to another, resulting in a different fraction of the coarse material near the bottom of the bucket being captured in each sample.

The temperature of the influent was measured for several tests. Stokes Law (equation 2-3) was used to determine the critical particle size for the maximum and minimum temperatures. The assumptions made in applying Stokes Law are discussed in section 5.3. The difference in the critical particle sizes was approximately three percent due to the difference in kinematic viscosity. This indicates that the water temperature differences did not significantly affect the filter efficiencies measured.

5.1 Filter Efficiency

The results from this investigation are compared to the fabric properties most often used to predict filter efficiency in Table 5.1. Note that the filter efficiency expressed in the fourth column was determined from the data as recorded in Appendix A. The normalized filter efficiency was determined using an average value for the concentration of sediment in the influent. The average concentration was determined by averaging the sediment concentration measured in the influent for all of the trials that were run with the normal amount of sediment. The average sediment concentration in the influent for all of the trials for each fabric are tabulated in Appendix C.

Table 5.1 Fabric Properties and Measured Filter Efficiency

Fabric	VTM-51* (%)	AOS (Std. sieve)*	Filter Efficiency (%)	Normalized Filter Efficiency (%)
Mirafi 100X	75	20-35	90.5	89.8
Mirafi 600X	--	30-50	91.0	92.4
Amoco 1380	75	30-50	79.0	81.9
Amoco 2125	--	20-30	87.0	87.6

-- indicates that manufacturer's data was not available for this parameter

* from manufacturers' data (see Table 3.3)

A comparison of the filter efficiencies determined in this investigation with those determined by the fabric manufacturers using the VTM-51 procedures indicates that the results using the latter methodology are conservative for the Brown Glacial Till. Two fabrics, the Mirafi 10CX and the Amoco 1380, had filter efficiencies of 75 percent reported by the manufactures using VTM-51. The results of the tests using the glacial till yielded a filter efficiency of 90.5 percent for the Mirafi 100X and 79.0 percent for the Amoco 1380. Since the soil to be used is not rigorously specified by VTM-51, the observed difference may have been due to the respective manufacturers using different soils in the procedure.

Predicting filter performance using the Apparent Opening Size of the fabrics is not justified based on the results of these experiments. The Amoco 2125 has larger pores than the Amoco 1380, yet it exhibited a markedly higher filter efficiency. This discrepancy may be due to several factors, including the thicker construction and more loose fibers apparent in the 2125. The Mirafi 600X and the Amoco 1380 have the same AOS, yet the filter efficiencies for these two fabrics differed by 12 percent. It would appear from these comparisons that there are many factors in addition to the AOS that determine how effective a geotextile will be in a silt fence installation.

5.2 Flow Rate

Appendix B contains the flow rate data gathered during this series of experiments. Several samples were tested with water that contained no sediment. Three of these samples, two Mirafi 100X and the Mirafi 600X, were tested three consecutive times each using clean water prior to testing with sediment-laden water. The flow rate through the fabric versus time is shown in Figures 5.A, 5.B, and 5.C.

All of the figures demonstrate that the flow pattern for the first run of each experiment differed from the later two runs. The peak of the first run was consistently lower than the peaks of the two runs which followed. The difference between the first and the latter tests was probably due to two factors. The first was the initial wetting of the dry fabric in the initial run for each sample. Subsequent trials were performed immediately after the first run, so no appreciable drying of the fabric occurred between tests. The second factor was the fabric frame which protruded one-half inch from the bottom edge of the flow. This effectively trapped a small quantity of water in the flume which remained during subsequent tests. The quantity of water which could be retained by the bottom member of the frame was less than one-half gallon.

The peak in the flow curve prior to the 3-minute point is also characteristic of all three samples. Approximately 90 seconds was required for all of the influent to enter the flume, and water entered at a higher rate than it was passing out through the fabric during this period of

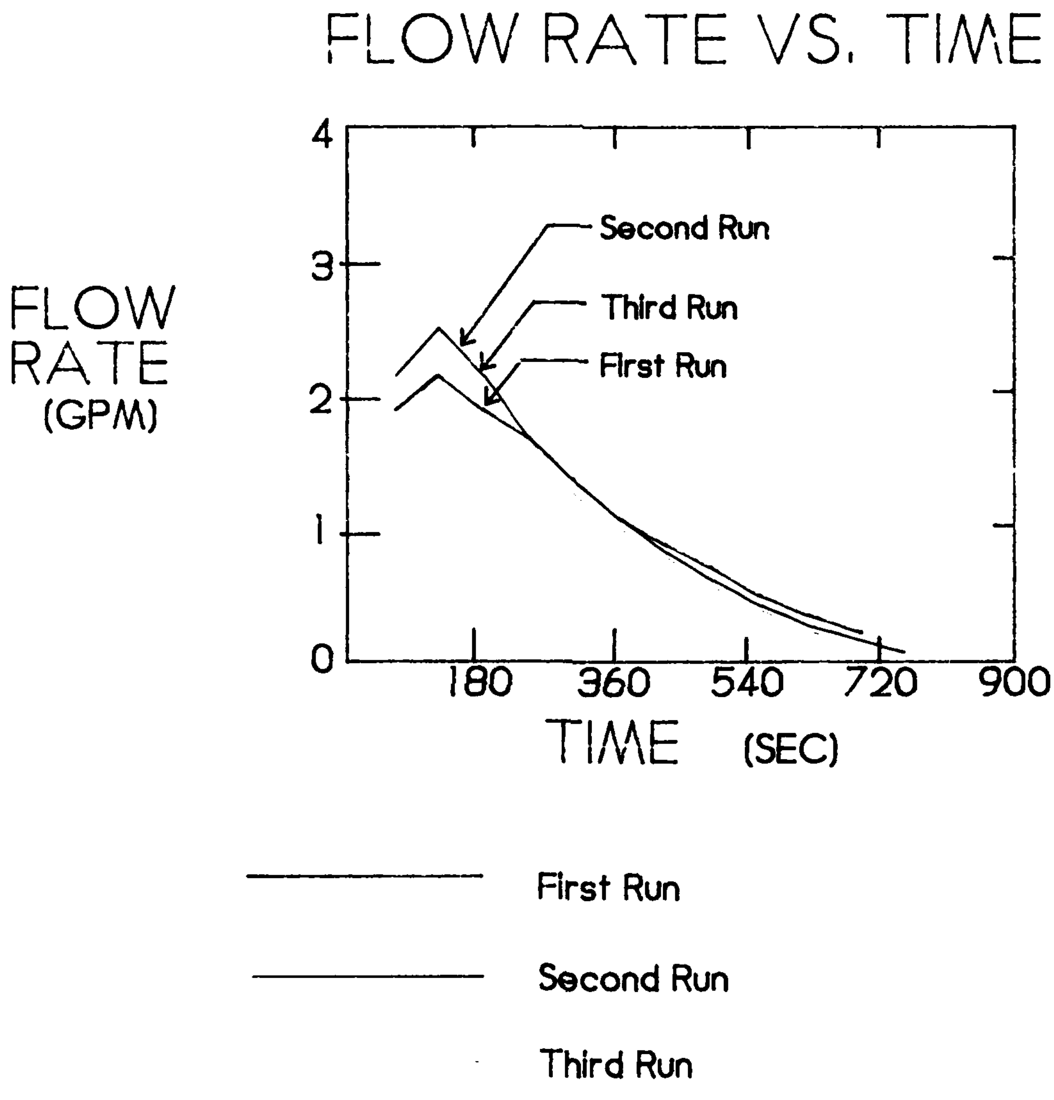


Figure 5.A. Flow Rate through Mirafi 100X Sample D with no Sediment in Influent

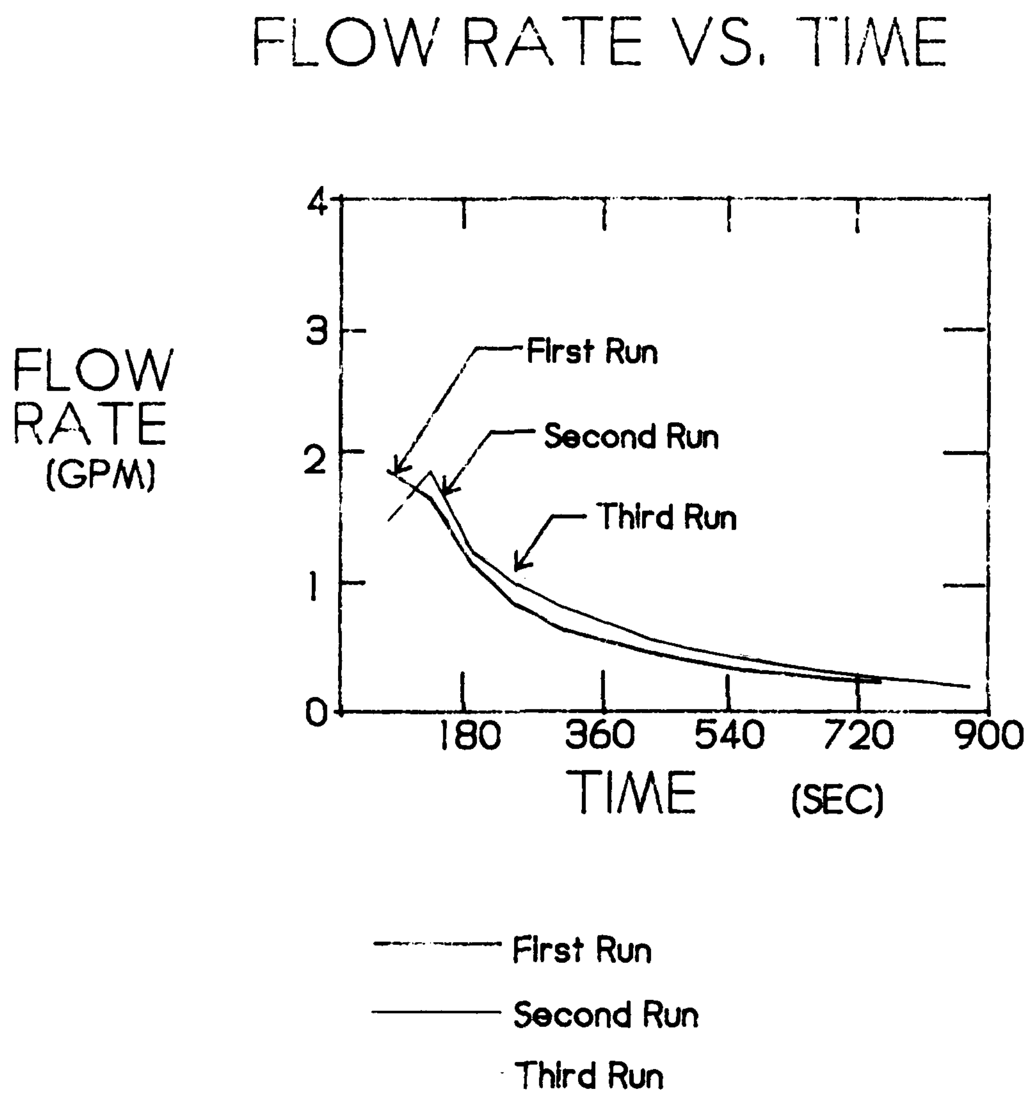


Figure 5.B. Flow Rate through Mirafi 600X Sample A with no sediment in influent

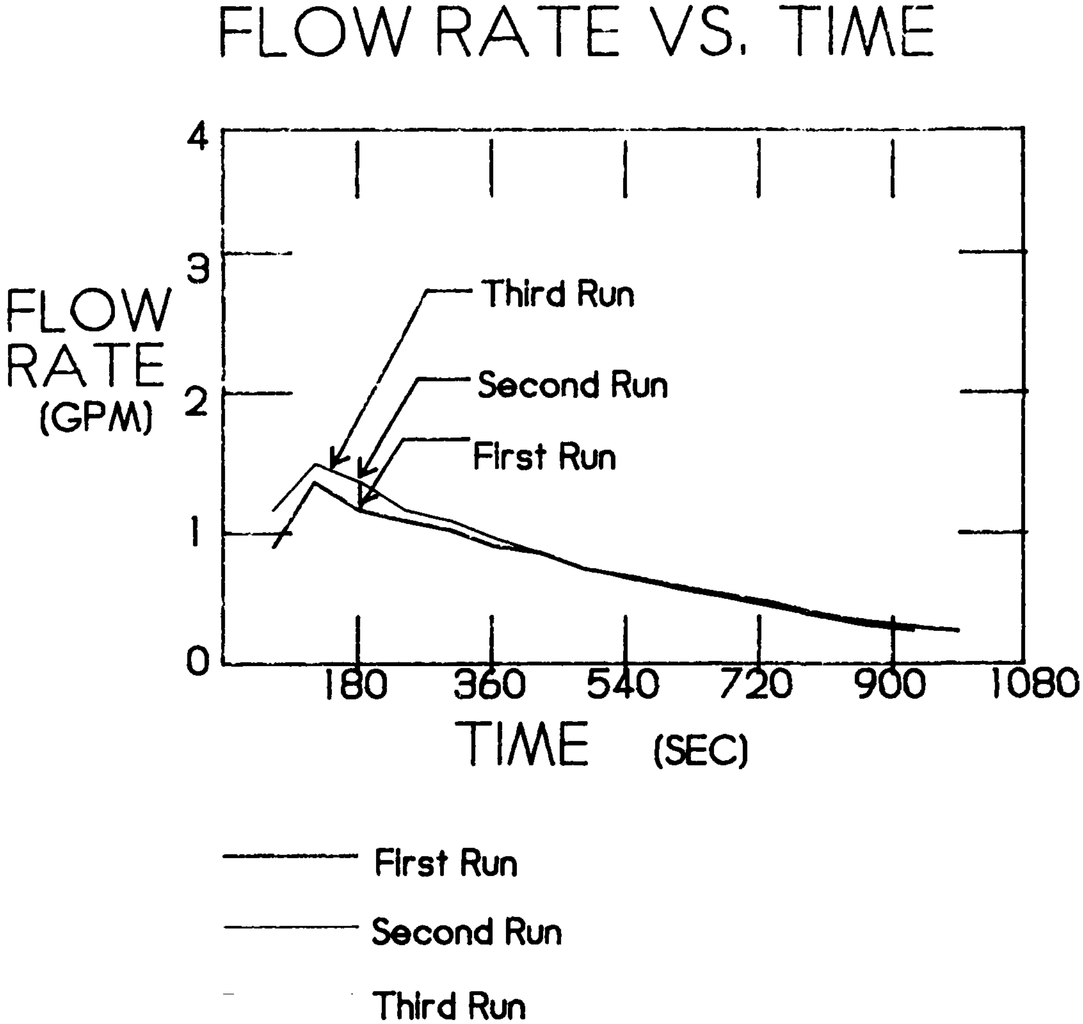


Figure 5.C. Flow Rate through Mirafi 100X Sample E with no Sediment in Influent

inflow. Thus, during the initial 90 seconds the head inside of the flume was increasing and this resulted in the flow rate increase. The head and flow rate began to decrease after the cessation of the inflow. The peaks of the curves are not at or near 90 seconds on the graphs because the flow rate measurements were taken at 60 and 120 seconds.

The first run of clean water through the Mirafi 600X fabric does not exhibit the characteristic peak just discussed, as can be seen in Figure 5.B. The pattern of flow for the initial run indicates that the outflow was more rapid than the inflow during the initial two minutes. The reason for this behavior is not apparent, especially in view of the second and third trials shown on the same figure. Both of the final runs exhibited the characteristic peak as expected.

A comparison of the trials for the Mirafi 100X, shown in Figures 5.A. and 5.C., shows that the pattern of flow for the two samples is similar, but the values of the flow rate are dissimilar. The nonuniformity of the pore openings in this fabric caused by twisted strands may provide a partial explanation for the difference. It is possible that sample D, to which Figure 5.A. corresponds, had more twisted yarns and therefor a much higher proportion of large pores than did sample E. The Mirafi 100X samples D and E were two of the last samples tested, however, and the flume apparatus had noticeably deteriorated, making a reliable seal between between the flume box and fabric frame difficult to maintain. It is likely that an undiscovered leak around the fabric frame resulted in the higher flow rate exhibited by sample D. This possibility is even more probable due to the filter efficiency results shown in Appendix A. Sample

E exhibited a higher filter efficiency than the D sample in each corresponding run. The difference appears small, but it could very well have resulted from a leak in the apparatus when sample D was tested which allowed sediment and water to bypass the fabric.

The maximum flow rate per unit area for each fabric was approximated by dividing the peak flow by the area of flow. The water behind the fabric reached a maximum depth of 3 and 1/2 inches, and this depth corresponded very closely to the instant of peak flow. The area of flow was 31 inches across and 3 inches high due to the fabric frame blocking the flow for 1/2 inch around the perimeter. Flow occurred through a 0.65 square foot area and the maximum head was 3 inches, or about 7.6 centimeters. It should be noted that this is less than the 20 to 80 centimeter head maintained during the ASTM Falling Head Test (ASTM, 1988b). Therefor it was anticipated that the flow rate would be lower than that measured using the falling head procedure.

The actual flow rates measured are compared to those provided by the manufacturers in Table 5.2. Flow rates were computed only for tests in which no sediment was present because the flow rate determinations made by the manufacturers used procedures which did not incorporate sediment.

Table 5.2. Flow Rates provided by Product Literature compared to Flow Rates measured with Flume

Fabric	Sample	Product Lit. Flow Rate (Gal/min/sf)	Flume Flow Rate (Gal/min/sf)
Mirafi 100X	E	40	2.3
Mirafi 600X	A	50	2.9
Amoco 1380	A	30	5.8
	C		11.5
Amoco 2125	C	15	4.6

5.3 Clogging and Blinding

The effects of clogging and blinding are difficult to separate when examining silt fence performance and both terms are used interchangeably here.

The impact of blinding on the performance of silt fence fabrics was investigated in two ways. In the first, the flow rate was measured using clean water prior to performing the tests using sediment-laden water. After the three runs containing sediment were completed an additional trial was performed without sediment in the influent as in the initial run. The flow rates measured during the two trials without sediment were compared to determine if fabric blinding affected the rate of flow through the fabric.

Figure 5.D. is a graph of the flow rate curves using clean water for sample C of the Amoco 1380. Note that the initial flow curve exhibits a much higher flow rate in the early stages, and in fact the flume was emptied in approximately six minutes. The flow curve for the test subsequent to the runs containing sediment has a much lower initial flow and the time required to empty the flume is twice that for the initial run. This indicates that the flow rate through the fabric was reduced substantially. This reduction must be due to the sediment present in the second run because the introduction of sediment to the inflow was the only difference between the two runs.

The second investigation into blinding attempted to establish the effect of the larger particles on the filter efficiency. The diameter of the largest particle expected to remain suspended at the point where the fabric plane intercepted the flow was determined using Stokes Law (equation 2-3), which is reprinted here:

$$V_s = (g / (18 * kv)) * ((S_s - 1) * D^2) \qquad \text{(Eq. 2-3)}$$

The water temperatures measured during the tests were all very near 20° C, so this temperature was used to determine the kinematic viscosity (kv) used in Equation 2-3. The known values for the equation are:

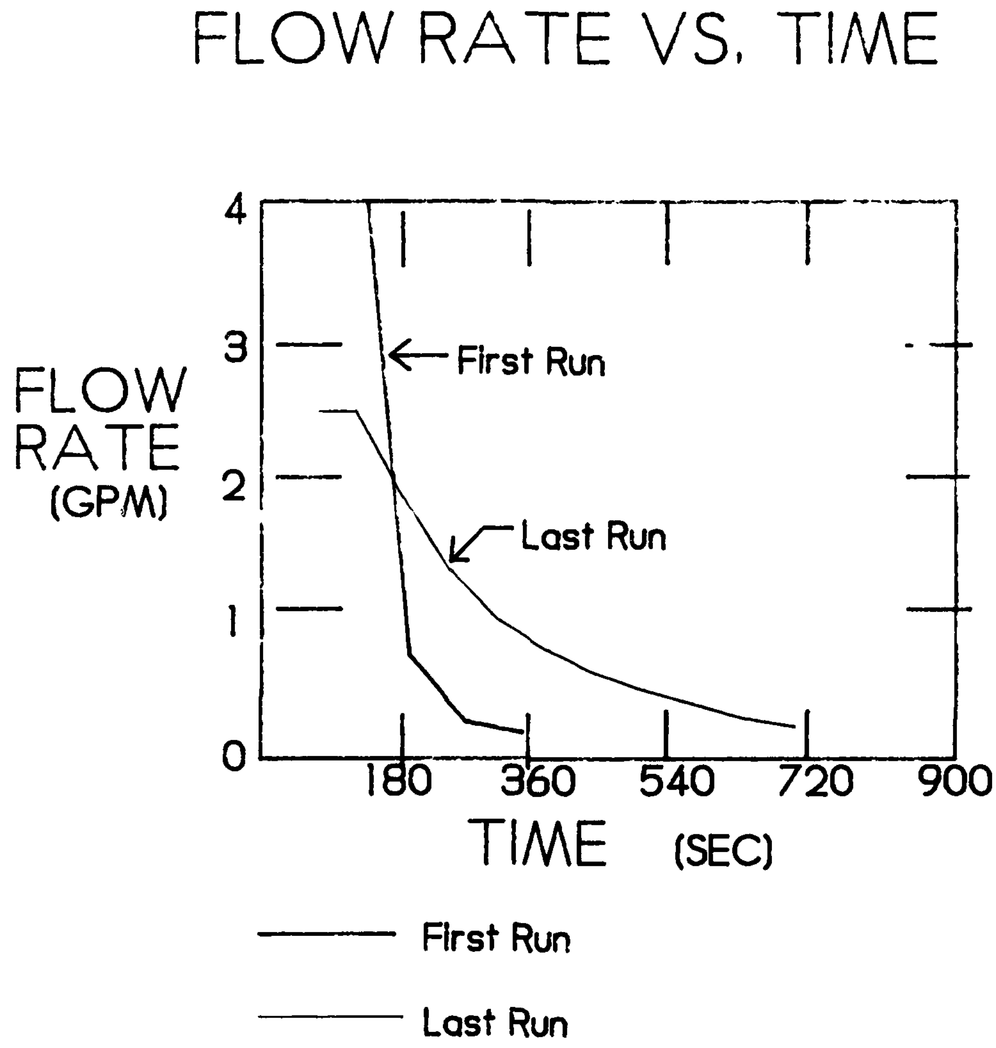


Figure 5.D. Flow Rate through Amoco 1380 Sample C with no Sediment prior to and after Normal Testing

kinematic viscosity (kv) = 0.010087 cm^2/s @ 20^o C (ASCE,1975)

Acceleration of gravity (g) = 981 cm/s^2

Specific gravity of solids (S_s) = 2.78 (see Table 3.1)

The only values which remain unknown are the settling viscosity (V_s) and the particle diameter (D). The time available for particle settling was estimated using other available information, and the fall distance divided by the time available determined the settling velocity used in solving Equation 2-3. Values for the flow area and flow rate were needed to compute the time available for particle settling (t). The flow rate used was 1.9 gallons per minute as this was a common value measured at 180 seconds for runs using the normal sediment sample. It was assumed that the particles entered the flume 12 inches behind the plane of the fabric in order to simplify the solution. Although the particles did in fact enter the flume 12 inches from the fabric, the flow condition upon entry was turbulent. The flow distance was reduced to 6 inches to account for the initial turbulence. The wetted area of the fabric sample was physically measured and determined to be 0.646 square feet. Flow did not take place through the entire sample, however, as it was observed that the top portion of the wetted area did not pass water. The area which did not allow flow differed between fabrics and it was not possible to measure the area accurately, so the area of flow was approximated as 0.6 square feet. All units were converted to SI equivalents because the constant in Stokes' Law applies to SI units. The values thus determined were:

Flow Area = 0.6 ft^2 = 557 cm^2

Flow Rate = 1.9 gpm = 120 cm^3/s

Flow Distance = 6 in = 15 cm

Fall Distance = 3 in = 7.62 cm

Drag on the particle in the horizontal direction and turbulence were neglected. The flow velocity in the flume (v) was determined using the following equation:

$$v = \text{flow rate} / \text{flow area} \qquad \text{(Equation 5-1)}$$

$$v = 0.22 \text{ cm/s}$$

The time required for the flow to proceed from the inflow point to the fabric was computed using the following equation:

$$t = \text{flow distance} / v \qquad \text{(Equation 5-2)}$$

$$t = 68 \text{ s}$$

The settling velocity of the largest particle which would be expected to settle prior to reaching the fabric was determined by the equation below:

V_s = fall distance / t (Equation 5-3)

V_s = 0.112 cm/s

Figure 5.E. is a diagram of the particle fall trajectory in the flume under the given conditions.

The only remaining unknown in Stokes Law is the diameter of the critical particle (D). Equation 2-3 can be rearranged and solved for D as shown below:

$$D = SQRT((18 * kv * V_s) / (g * (S_s - 1)))$$

(Equation 5-4)

D = 0.0034 cm = 0.0013 in

The diameter determined in the above analysis corresponds roughly to the No. 400 sieve. This result indicates that all particles larger than the No. 400 sieve should settle prior to reaching the fabric plane. The results of the residue sampling demonstrated that this was not the case. A portion of the residue from several trials was large enough to be retained on the No. 200 sieve, based on the filter efficiency. It is evident that the manner in which the sediment was introduced into the apparatus created turbulence which interfered with settling. Turbulence may be encountered in a silt fence installation in the field, but probably not to the extent that it was present in the flume apparatus.

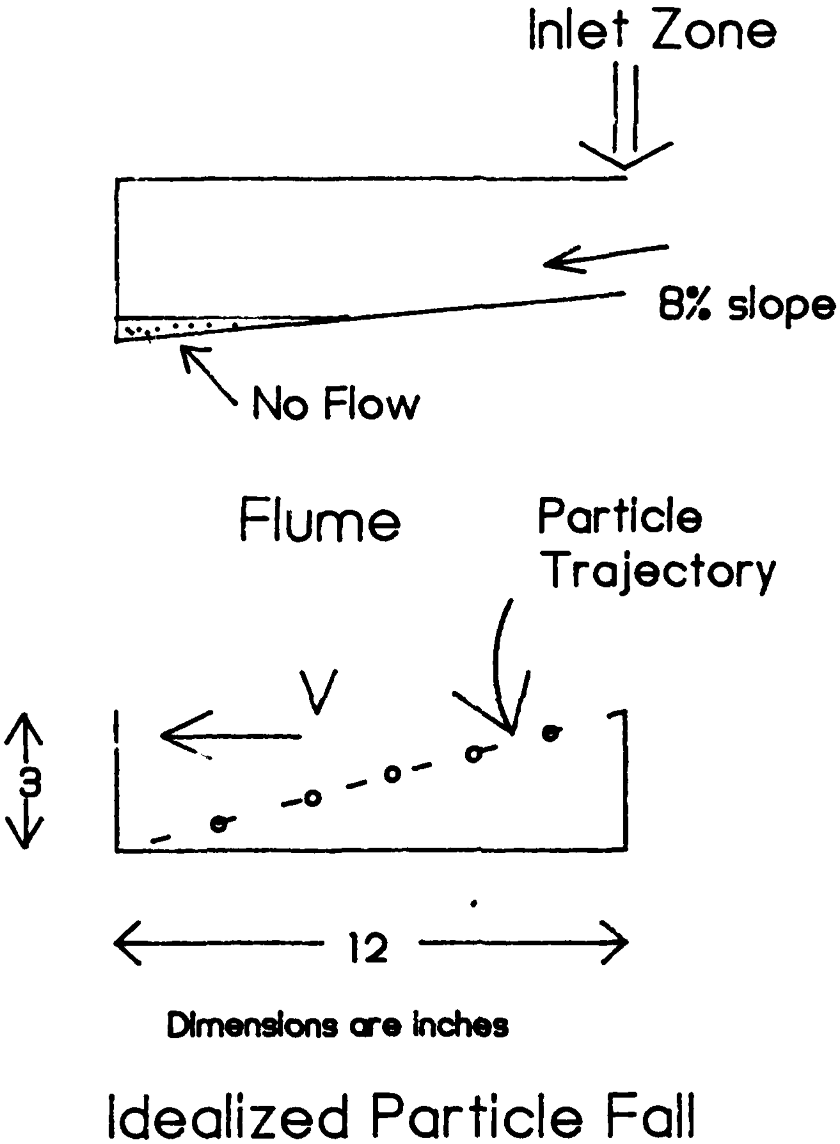


Figure 5.E. Stokes' Law

Because a large fraction of the soil used as the sediment was retained on the No. 80 sieve, it was decided to use the soil passing the No. 30 to test the effects of the larger particles on fabric performance. Table 3.2 lists the fractions of the soil retained on the sieves used to prepare the sediment samples.

Deleting the fraction of sediment larger than the No. 30 sieve was expected to increase the rate of flow through the fabric if the larger fraction did in fact contribute substantially to clogging and blinding. That fraction of the sediment was deleted in the test of Mirafi 100X sample E. The flow rate versus time for sample E is compared to samples B and C of the same fabric in Figure 5.F. The figure demonstrates that the flow rate was actually lower for the test in which the larger particles were absent. This indicates that the larger particles either settle prior to reaching the fabric at the lower end of the flume and do not contribute a great deal to blinding, or contribute to the filter efficiency of the fabric through some unidentified mechanism. An insufficient number of tests were performed to determine whether the flow rates actually differ between the tests using all of the sediment (samples B and C) and that using only the fraction passing the No. 30 sieve (sample E).

Summary and Conclusions

The filter efficiency of two of the fabrics was reported by the manufacturer's using the methodology specified by VTM-51. Both of these fabrics exhibited filter efficiencies 5 to 15 percent higher than

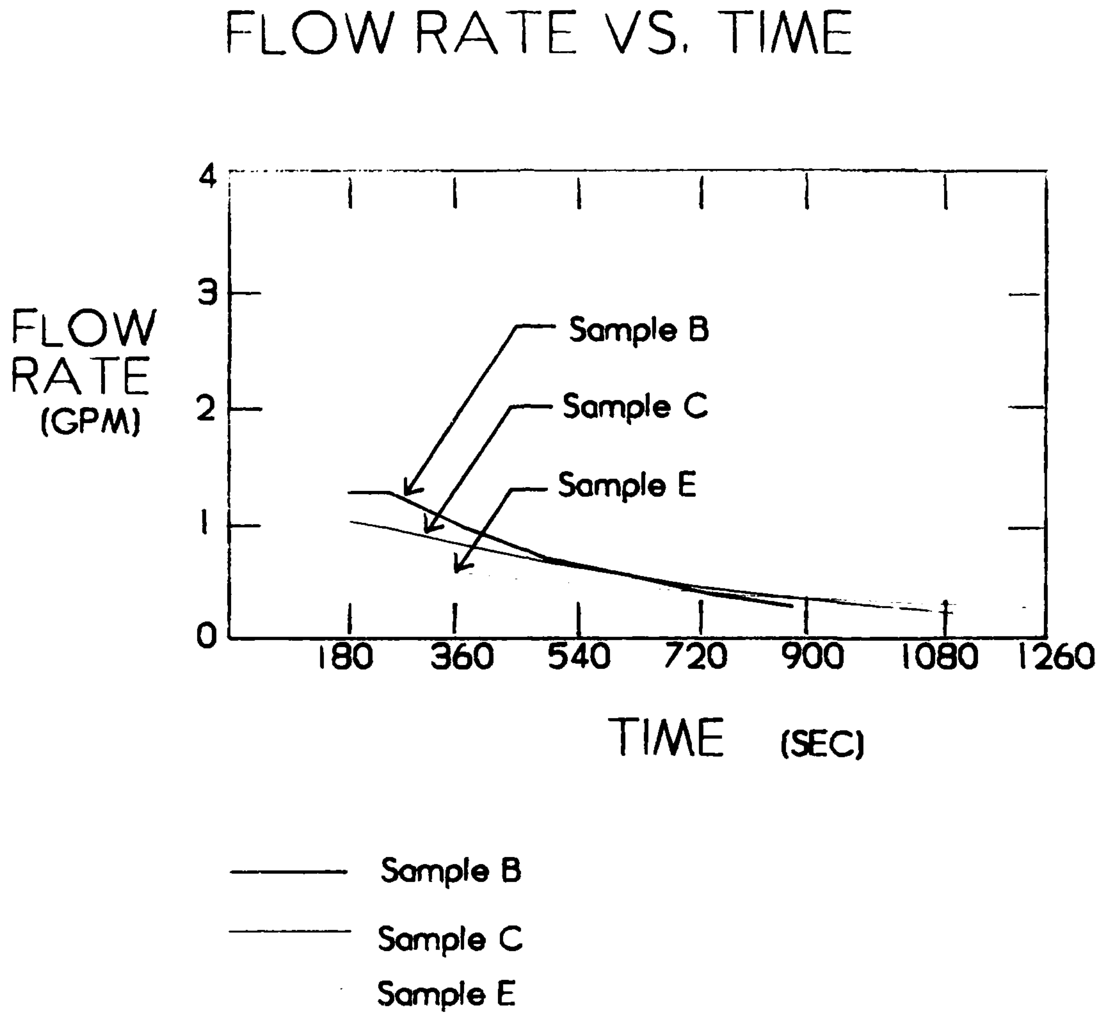


Figure 5F Flow Rate of Second Run with Sediment for Three Samples of Mirafi 100X reported when tested using the Brown Glacial Till. These results indicate that the VTM-51 procedure results provided by the manufacturers were conservative for this soil.

The two fabrics which were previously tested using VTM-51 were both declared to have filter efficiencies of 75 percent. These two fabrics had very different filter efficiencies when tested using the Brown Glacial Till, differing by over 10 percent. Although the VTM-51 is conservative, the filter efficiency value provided is not necessarily reliable without information about the soil used in the procedure.

The flow rate data indicates that between the first and second runs of the experiment for each sample the peak flow rate decreases significantly and the flow rate changes very little in subsequent runs. This initial decrease is primarily a result of fabric wetting and storage in the flume after the initial run. It is recommended that subsequent investigations construct the flume such that the exposed edge of the fabric is flush with the inner surfaces of the flume and that an initial run be performed without sediment to prewet the fabric.

Performing a trial with clean influent prior to and after the normal testing sequence demonstrated that the flow through the fabric was impeded by blinding, but with the volume of influent and concentration of sediment used in this testing procedure the progressive affects of blinding were not appreciable.

The fabric Apparent Opening Size did not accurately predict the filter efficiency of the geotextiles examined in this investigation. Of the two fabrics with the smallest pores, one had the highest filter efficiency of all the fabrics tested and the other had the lowest. It is not sufficient to specify the AOS of a fabric in order to achieve desired silt fence performance.

The flow rate for each run containing the normal sample of sediment was correlated with the filter efficiencies of each of the runs in order to determine if the flow rate through a fabric might help to predict the filter efficiency. The Pearson product-moment correlation between the flow rate and the filter efficiency was computed to be -0.429. This result indicates that a lower flow rate tends to produce a higher filter efficiency, but the correlation is not strong. A scatterplot of the flow rate versus the filter efficiency is provided in Figure 5.G.

Areas for Further Research

Due to time and material constraints, this investigation only scratched the surface of the research needed to accurately predict the filter performance of geotextiles used in silt fence applications. The apparatus proposed by the Virginia Highway and Transportation Research Council proved itself to be viable apparatus for conducting this type of investigation.

Many additional samples and soils must be tested in order to establish which of the parameters governing the passage of sediment and water through geotextiles will reliably predict the filter efficiency of the sample. This work would be aided by the cooperation of manufacturers in reporting geotextile properties in a clear and consistent form.

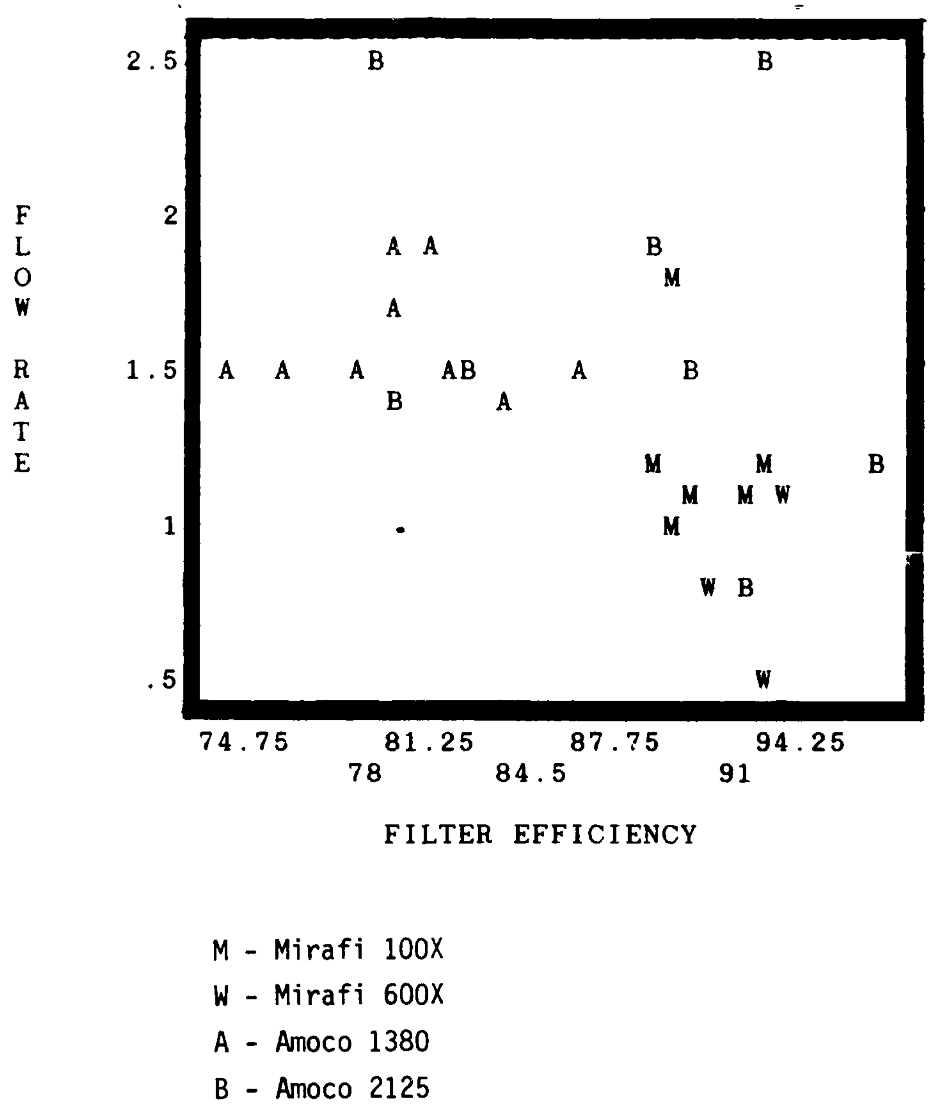


Figure 5.G. Flow Rate versus Filter Efficiency Scatterplot

It was observed during the course of this investigation that few contractors presently install silt fences using the recommended procedure. In fact, no properly installed silt fences were noted among the two dozen observed in the field. Improperly installed silt fences cannot function properly, and this may contribute to resistance to approve their use. An investigation into contractor installation procedures for silt fences in the Puget Sound area would be of interest.

BIBLIOGRAPHY

AND

APPENDICES

BIBLIOGRAPHY

1. American Public Health Association - American Water Works Association - Water Pollution Control Federation, 1985. Standard Methods for the Examination of Water and Wastewater, 16th Ed. American Public Health Association.

2. American Society of Civil Engineers, 1975. Sedimentation Engineering. American Society of Civil Engineers.

3. Amimoto, P. Y., 1978. Erosion and Sediment Control Handbook. Division of Mines and Geology, Department of Conservation, State of California.

4. AMOCO Fabrics and Fibers Company, 1988. *AMOCO Construction Fabrics*, (Product Literature). AMOCO Fabrics and Fibers Company.

5. American Society for Testing and Materials, 1988a. *"D4751-87 Standard Test Method for Determining Apparent Opening Size of a Geotextile"*, Annual Book of ASTM Standards Vol. 4.08. American Society for Testing and Materials.

6. American Society for Testing and Materials, 1988b. *"D4491-85 Standard Test Methods for Water Permeability of Geotextiles by Permittivity"*, Annual Book of ASTM Standards Vol. 4.08. American Society for Testing and Materials.

7. American Society for Testing and Materials, 1988c. *"D4354-84 Standard Practice for Sampling of Geotextiles for Testing"*, Annual Book of ASTM Standards Vol 4.08. American Society for Testing and Materials.

8. Atmatzidis, D.K., J.A. Fitzpatrick, J.T. Fornek, 1982. *"Evaluation of Geotextiles as Liquid Filter"*, Second International Conference on Geotextiles, Proceedings. Industrial Fabrics Association International.

9. Bedner, R.E., D.J. Fluke, 1980. Demonstration of Debris Basin Effectiveness in Sediment Control. Kentuckey Department of Natural Resources and Environmental Protection.

10. Bell, J.R., R.G. Hicks, 1984. Evaluation of Test Methods and Use Criteria for Geotechnical Fabrics in Highway Applications -- Final Report. Federal Highway Administration.

11. Bell, J.R., R.G. Hicks, et. al., 1980. Evaluation of Test Methods and Use Criteria for Geotechnical Fabrics in Highway Applications -- Interim Report. Federal Highway Administration.

12. Boysen, S.M., 1977. Erosion and Sediment Control in Urbanizing Areas. National Symposium on Soil Erosion and Sedimentation by Water, Proceedings. American Society of Agricultural Engineers.

13. Class Report -- CETS 564, University of Washington, 1986. *"Soil Stabilization: Research and Testing Project"*. Unpublished manuscript.

14. Fair, G.M., J.C. Geyer, D.A. Okun, 1971. Water and Wastewater Engineering. Wiley.

15. Foster, G.R., L.D. Meyer, 1977. *"Soil Erosion and Sedimentation by Water - An Overview"*. National Symposium on Soil Erosion and Sedimentation by Water, Proceedings. American Society of Agricultural Engineers.

16. Gilbreath, J.L., 1979. *"The State of the Art of Erosion and Sediment Control for Surface Mined Areas"*. Army Military Personnel Center.

17. Hainly, R.A., 1978. *"The Effects of Highway Construction on Sediment Discharge into Blockhouse Creek and Steam Valley Run, Pennsylvania"*. United States Geological Survey, Water Resources Division.

18. Hoover, 1982. "Evaluation of the Performance of Fabric Filters". Second International Conference on Geotextiles, Proceedings. Industrial Fabrics Association International.

19. Horz, R.C., 1986. *"Geotextiles for Drainage, Gas Venting, and Erosion Control at Hazardous Waste Sites"*. Army Engineer Waterways Experiment Station.

20. Israelson, C.E., et. al., 1980. *"Erosion Control During Highway Construction: Research Report"* (NCHRP Report 220). Transportation Research Board, National Cooperative Highway Research Program.

21. King County, Washington, Department of Public Works, 1987. Surface Water Design Manual (Draft). King County, WA.

22. Minnitti, A., L.D. Suits, T.H. Dickson, 1983. *"New York State Department of Transportation's Experience and Guidelines for use of Geotextiles"*, Transportation Research Record 916. Transportation Research Board, National Research Council, National Academy of Sciences.

23. Mirafi, Inc., 1987. *Products for Construction Applications* (Product Literature). Mirafi, Inc.

24. Reed, J.R. Jr., 1977. *"Stream Community Response to Road Construction Sediments"*. Virginia Polytechnic Institute and State University.

25. Sherwood, W.C., et. al., 1978. Erosion and Sedimentation Control Manual. Virginia Department of Highways and Transportation.

26. Soil Conservation Service, 1983. National Engineering Handbook, Section 3, Sedimentation. United States Department of Agriculture.

27. Transportation Research board, 1980. *Design of Sedimentation Basins*. Transportation Research Board, National Research Council, National Academy of Sciences.

28. Webtec, Inc., 1987. *Terratex Construction Fabrics* (Product Literature). Webtec, Inc.

29. Wilson, R.L., 1963. *"Sources of Erosion on Newly Constructed Logging Roads on the H.J. Andrews Experimental Forest"*. Unpublished manuscript.

30. Wischmeier, W.H., 1976. *"Use and Misuse of the Universal Soil Loss Equation"*. Journal of Soil and Water Conservation, Vol. 31, No. 1, pp 5-9.

31. Wyant, D.C., 1982. *"Efficiency of Erosion Control Practices of the Virginia Department of Highways and Transportation"*. Virginia Highway and Transportation Research Council.

32. Wyant, D.C., 1980. *"Evaluation of Filter Fabrics for use as Silt Fences"*. Virginia Highway and Transportation Research Council.

33. Wyant, D.C., 1976. *"Evaluation of Erosion and Siltation Control Fabrics"*. Virginia Highway and Transportation Research Council.

Appendix A

Residue Measurements and Filter Efficiency

The results are listed by manufacturer and manufacturer's designation for the fabric used. Each sample is a separate piece of geotextile affixed to the fabric frame. The test was performed three times for each sample. Each test is designated by a number in the "Run" column. For example, the Mirafi 100X fabric was tested using 5 samples, A through E, and each of the five samples was tested three times, the tests designated 1 through 3.

The residue measurements for each test are listed. The first row listed for each run is the residue measured from the influent. The second row provides the residue measured from the effluent after filtering through the fabric. The amount of residue was determined by subtracted the weight in the Filter and Support column from the weight shown in the Filter, Support, and Residue column. The last entry in the second row is the filter efficiency of the geotextile for that particular run expressed as a percent.

Averages of the filter efficiency are summarized for each fabric sample. Averages for the first, second, and third runs for each geotextile are also summarized. For example, the Run 1 average provided after the data for the Mirafi 100X is the average Filter Efficiency for samples A, B, and C from the first run for each.

The "In-test" and "Out-test" average values for the Amoco 2125 are the average values of the residue found in three samples from the influent of Sample A, Run 1, and three samples from the effluent of Sample B, Run 3, respectively. The additional samples were analyzed and recorded in order to check the reliability of the tube sampler used to draw samples.

Table A.1.

Mirafi 100X

Sample	Run	Filter & Support (g)	F&S + Residue (g)	Residue (g)	Filter Efficiency (%)
A	1	1.627	2.391	0.764	
		1.642	1.68	0.038	95.03
	2	1.63	2.338	0.708	
		1.649	1.698	0.049	93.08
	3	1.621	2.438	0.817	
		1.663	1.748	0.085	89.60
B	1	1.645	2.249	0.604	
		1.629	1.683	0.054	91.06
	2	1.665	2.262	0.597	
		1.606	1.679	0.073	87.77
	3	1.635	2.43	0.795	
		1.624	1.718	0.094	88.18
C	1	1.638	2.217	0.579	
		1.632	1.679	0.047	91.88
	2	1.617	2.216	0.599	
		1.604	1.672	0.068	88.65
	3	1.639	2.429	0.79	
		1.636	1.723	0.087	88.99
A avg.					92.57
B avg.					89.00
C avg.					89.84
Run 1 avg.					92.66
Run 2 avg.					89.68
Run 3 avg.					88.92
Overall avg.					90.47

Table A.2.

Mirafi 100X (minus #30 material only)

Sample	Run	Filter & Support (g)	F&S + Residue (g)	Residue (g)	Filter Efficiency (%)
D	1	1.611	2.216	0.605	
		1.606	1.657	0.051	91.57
	2	1.648	2.228	0.58	
		1.628	1.692	0.064	88.97
	3	1.619	2.266	0.647	
		1.619	1.711	0.092	85.78
E	1	1.625	2.325	0.7	
		1.648	1.692	0.044	93.71
	2	1.648	2.262	0.614	
		1.626	1.678	0.052	91.53
	3	1.647	2.231	0.584	
		1.656	1.722	0.066	88.70
D avg.					88.77
E avg.					91.31
Run 1 avg.					92.64
Run 2 avg.					90.25
Run 3 avg.					87.24
Overall avg.					90.04

Table A.3.

Mirafi 600X

Sample	Run	Filter & Support (g)	F&S + Residue (g)	Residue (g)	Filter Efficiency (%)
A	1	1.624	2.171	0.547	
		1.631	1.677	0.046	91.59
	2	1.611	2.128	0.517	
		1.618	1.672	0.054	89.56
	3	1.66	2.257	0.597	
		1.652	1.699	0.047	92.13
Overall avg.					91.09

Table A.4.

Amoco 1380

Sample	Run	Filter & Support (g)	F&S + Residue (g)	Residue (g)	Filter Efficiency (%)
A	1	1.651	2.137	0.486	
		1.644	1.748	0.104	78.60
	2	1.648	2.131	0.483	
		1.664	1.767	0.103	78.67
	3	1.624	2.152	0.528	
		1.641	1.748	0.107	79.73
B	1	1.638	2.176	0.538	
		1.611	1.734	0.123	77.14
	2	1.635	2.259	0.624	
		1.647	1.804	0.157	74.84
	3	1.607	2.192	0.585	
		1.636	1.796	0.16	72.65
C	1	1.655	2.247	0.592	
		1.629	1.716	0.087	85.30
	2	1.632	2.153	0.521	
		1.636	1.738	0.102	80.42
	3	1.64	2.298	0.658	
		1.647	1.76	0.113	82.83
A avg.					79.00
B avg.					74.88
C avg.					82.85
Run 1 avg.					80.35
Run 2 avg.					75.39
Run 3 avg.					78.40
Overall avg.					78.91

Table A.5.

Amoco 2125

Sample	Run	Filter & Support (g)	F&S + Residue (g)	Residue (g)	Filter Efficiency (%)
A	1.1	1.635	2.179	0.544	
		1.627	1.677	0.05	90.81
	2	1.649	2.105	0.456	
		1.596	1.646	0.05	89.04
	3	1.631	2.923	1.292	
		1.631	1.685	0.054	95.82
B	1	1.639	2.311	0.672	
		1.638	1.721	0.083	87.65
	2	1.634	2.931	1.297	
		1.637	1.749	0.112	91.36
	3	1.644	2.209	0.565	
	3.1	1.641	1.767	0.126	77.70
C	1	1.628	2.117	0.489	
		1.648	1.703	0.055	88.75
	2	1.618	2.104	0.486	
		1.634	1.724	0.09	81.48
	3	1.647	2.123	0.476	
		1.602	1.703	0.101	78.78
A (in)	1.2	1.636	2.065	0.429	
	1.3	1.663	2.277	0.614	
B (out)	3.2	1.638	1.76	0.122	
	3.3	1.637	1.772	0.135	
A avg.					91.89
B avg.					85.57
C avg.					83.01
Run 1 avg.					89.07
Run 2 avg.					86.03
Run 3 avg.					84.10

Overall avg.	86.82
In-test avg.	0.529
Out-test avg.	0.128

Appendix B

Flow Rate Measurements

The time required to fill the 1-quart container is shown in the first column for each run through the flume. Flow rate measurements were not recorded for Sample A of the Mirafi 100X fabric. The second column is the "instantaneous" time. It was determined by dividing the time required to capture 1 quart of flow by 2, then adding the result to time at which the flow measurement started. The instantaneous time is used because the flow rate often varied substantially during the time required for 1 quart to be measured. The resulting flow rate is actually the average of the rate occurring during the measurement period, therefore it is applied at the median time during the period in the Flow Rate graphs shown in section 4.

The Mirafi samples designated D and E were tested in the flume apparatus using water which contained no sediment. Each sample was tested three consecutive times using clear water. The sample of the Mirafi 600X fabric was also tested in this manner prior to introducing sediment into the testing procedure. The results for the three clear water tests are shown in Tables B.4., B.5., and B.8.

Three samples of the Amoco fabrics were tested once with clear water prior to the usual three runs with sediment-laden water. Each of these fabric samples was again tested once using clear water after the three runs using sediment-laden water were completed. The samples tested were the A and C for the Amoco 1380 geotextile and the sample designated C for the Amoco 2125. Results for these clear water tests are shown in Tables B.9., B.12., and B.16. The columns designated Start are the results of the first test prior to introducing influent containing sediment. The Finish columns contain the results of the test performed with clear water after the three tests with sediment-laden influent were completed.

Table B.1.

Mirafi 100X

Start time	B1 Time 1 Qt	B1 Inst Time	B1 Flow Rate	B2 Time 1 Qt	B2 Inst Time	B2 Flow Rate	B3 Time 1 Qt	B3 Inst Time	B3 Flow Rate
60									
120									
180	14	187	1.071	12	186	1.250	8	184	1.875
240	15	247	1.000	12	246	1.250	10	245	1.500
300									
360	20	370	0.750	16	368	0.938	15	367	1.000
420									
480	24	492	0.625	22	491	0.682	20	490	0.750
540									
600	29	614	0.517	28	614	0.536	29	614	0.517
660									
720	38	739	0.395	39	739	0.385	41	740	0.366
840	51	865	0.294	56	868	0.268	60	870	0.250
960	69	994	0.217						

Table B.2.

Mirafi 100X

Start time	C1 Time 1 Qt	C1 Inst Time	C1 Flow Rate	C2 Time 1 Qt	C2 Inst Time	C2 Flow Rate	C3 Time 1 Qt	C3 Inst Time	C3 Flow Rate
60									
120									
180	13	186	1.154	15	187	1.000	14	187	1.071
240	14	247	1.071	16	248	0.938	16	248	0.938
300									
360	18	369	0.833	19	369	0.789	19	369	0.789
420									
480	21	490	0.714	23	491	0.652	24	492	0.625
540									
600	26	613	0.577	28	614	0.536	29	614	0.517
660									
720	32	736	0.469	35	737	0.429	38	739	0.395
840	41	860	0.366	43	861	0.349	45	862	0.333
960	52	986	0.288	54	987	0.278	55	987	0.273
1080	67	1113	0.224	68	1114	0.221	45	1102	0.333
1200							55	1227	0.273
1320							77	1358	0.195

Table B.3.

Mirafi 100X

Start time	D1 Time 1 Qt	D1 Inst Time	D1 Flow Rate	D2 Time 1 Qt	D2 Inst Time	D2 Flow Rate	D3 Time 1 Qt	D3 Inst Time	D3 Flow Rate
60									
120									
180	10	185	1.500	9	184	1.667	9	184	1.667
240	11	245	1.364	10	245	1.500	10	245	1.500
300	12	306	1.250	12	306	1.250	12	306	1.250
360	14	367	1.071	14	367	1.071	14	367	1.071
420	17	428	0.882	17	428	0.882	17	428	0.882
480	20	490	0.750	19	489	0.789	21	490	0.714
540	22	551	0.682	23	551	0.652	26	553	0.577
600	27	613	0.556	29	614	0.517	33	616	0.455
660	35	677	0.429	39	679	0.385	46	683	0.326
720	42	741	0.357	57	748	0.263			
780	59	809	0.254						

Table B.4.

Mirafi 100X (NO SEDIMENT--FIRST RUN)

Start time	D1 Time 1 Qt	D1 Inst Time	D1 Flow Rate	D2 Time 1 Qt	D2 Inst Time	D2 Flow Rate	D3 Time 1 Qt	D3 Inst Time	D3 Flow Rate
60	8	64	1.875	7	63	2.143	7	63	2.143
120	7	123	2.143	6	123	2.500	6	123	2.500
180	8	184	1.875	7	183	2.143	7	183	2.143
240	9	244	1.667	9	244	1.667	9	244	1.667
300	11	305	1.364	11	305	1.364	12	306	1.250
360	14	367	1.071	14	367	1.071	15	367	1.000
420	17	428	0.882	18	429	0.833	19	429	0.789
480	21	490	0.714	24	492	0.625	27	493	0.556
540	30	555	0.500	35	557	0.429	40	560	0.375
600	43	621	0.349	55	627	0.273	72	636	0.208
660	67	693	0.224	177	748	0.085			

Table B.5.

Mirafi 100X (NO SEDIMENT--FIRST RUN)

Start time	E1 Time 1 Qt	E1 Inst Time	E1 Flow Rate	E2 Time 1 Qt	E2 Inst Time	E2 Flow Rate	E3 Time 1 Qt	E3 Inst Time	E3 Flow Rate
60	17	68	0.882	13	66	1.154	13	66	1.154
120	11	125	1.364	10	125	1.500	10	125	1.500
180	13	186	1.154	11	185	1.364	11	185	1.364
240	14	247	1.071	13	246	1.154	13	246	1.154
300	15	307	1.000	14	307	1.071	14	307	1.071
360	17	368	0.882	16	368	0.938	16	368	0.938
420	18	429	0.833	18	429	0.833	18	429	0.833
480	21	490	0.714	21	490	0.714	21	490	0.714
540	23	551	0.652	23	551	0.652	24	552	0.625
600	26	613	0.577	27	613	0.556	27	613	0.556
660	29	674	0.517	30	675	0.500	30	675	0.500
720	33	736	0.455	35	737	0.429	35	737	0.429
780	39	799	0.385	42	801	0.357	43	801	0.349
840	47	863	0.319	51	865	0.294	53	866	0.283
900	54	927	0.278	61	930	0.246	63	931	0.238
960	62	991	0.242						

Table B.6.

Mirafi 100X

Start time	E1 Time 1 Qt	E1 Inst Time	E1 Flow Rate	E2 Time 1 Qt	E2 Inst Time	E2 Flow Rate	E3 Time 1 Qt	E3 Inst Time	E3 Flow Rate
60									
120									
180	19	189	0.789	24	192	0.625	23	191	0.652
240	20	250	0.750	25	252	0.600	25	252	0.600
300	21	310	0.714	27	313	0.556	26	313	0.577
360	22	371	0.682	28	374	0.536	28	374	0.536
420	24	432	0.625	30	435	0.500	30	435	0.500
480	26	493	0.577	32	496	0.469	31	495	0.484
540	27	553	0.556	33	556	0.455	33	556	0.455
600	29	614	0.517	35	617	0.429	35	617	0.429
660	31	675	0.484	37	678	0.405	37	678	0.405
720	34	737	0.441	40	740	0.375	39	739	0.385
780	36	798	0.417	43	801	0.349	43	801	0.349
840	38	859	0.395	45	862	0.333	45	862	0.333
900	41	920	0.366	47	923	0.319	48	924	0.313
960	44	982	0.341	49	984	0.306	51	985	0.294
1020	47	1043	0.319	51	1045	0.294	55	1047	0.273
1080	52	1106	0.288	54	1107	0.278	57	1108	0.263
1140	57	1168	0.263	57	1168	0.263	59	1169	0.254
1200	64	1232	0.234	60	1230	0.250	62	1231	0.242

Table B.7.

Mirafi 600X

Start time	A1 Time 1 Qt	A1 Inst Time	A1 Flow Rate	A2 Time 1 Qt	A2 Inst Time	A2 Flow Rate	A3 Time 1 Qt	A3 Inst Time	A3 Flow Rate
60									
120									
180	32	196	0.469	19	189	0.789	14	187	1.071
240	37	258	0.405	25	252	0.600	21	250	0.714
300	42	321	0.357	31	315	0.484	26	313	0.577
360	46	383	0.326	39	379	0.385	30	375	0.500
420	50	445	0.300	42	441	0.357	34	437	0.441
480	53	506	0.283	48	504	0.313	38	499	0.395
540	57	568	0.263	55	567	0.273	43	561	0.349
600	61	630	0.246	61	630	0.246	48	624	0.313
660							52	686	0.288
720							57	748	0.263
780							62	811	0.242

Table B.8.

Mirafi 600X (NO SEDIMENT--FIRST RUN)

Start time	A1 Time 1 Qt	A1 Inst Time	A1 Flow Rate	A2 Time 1 Qt	A2 Inst Time	A2 Flow Rate	A3 Time 1 Qt	A3 Inst Time	A3 Flow Rate
60	8	64	1.875	10	65	1.500	11	65	1.364
120	9	124	1.667	8	124	1.875	9	124	1.667
180	13	186	1.154	12	186	1.250	12	186	1.250
240	18	249	0.833	15	247	1.000	14	247	1.071
300	23	311	0.652	18	309	0.833	17	308	0.882
360	27	373	0.556	21	370	0.714	20	370	0.750
420	32	436	0.469	26	433	0.577	24	432	0.625
480	38	499	0.395	30	495	0.500	28	494	0.536
540	44	562	0.341	34	557	0.441	33	556	0.455
600	49	624	0.306	39	619	0.385	39	619	0.385
660	56	688	0.268	45	682	0.333	45	682	0.333
720	61	750	0.246	51	745	0.294	51	745	0.294
780				57	808	0.263	59	809	0.254
840				67	873	0.224	67	873	0.224

Table B.9.

Amoco 1380 NO SEDIMENT

Start time	A START Time 1 Qt	Inst Time	Flow Rate	A FINISH Time 1 Qt	Inst Time	Flow Rate
60						
120	4	122	3.750	5	122	3.000
180	25	192	0.600	7	183	2.143
240	163	321	0.092	10	245	1.500
300				14	307	1.071
360				19	369	0.789
420				29	434	0.517
480				46	503	0.326
540				75	577	0.200

Table B.10.

Amoco 1380

Start time	A1 Time 1 Qt	Inst Time	Flow Rate	A2 Time 1 Qt	Inst Time	Flow Rate	A3 Time 1 Qt	Inst Time	Flow Rate
60									
120									
180	9	184	1.667	8	184	1.875	8	184	1.875
240	16	248	0.938	13	246	1.154	14	247	1.071
300									
360	43	381	0.349	33	376	0.455	33	376	0.455
420									
480	100	530	0.150	77	518	0.195	67	513	0.224

Table B.11.

Amoco 1380

Start time	B1 Time 1 Qt	B1 Inst Time	B1 Flow Rate	B2 Time 1 Qt	B2 Inst Time	B2 Flow Rate	B3 Time 1 Qt	B3 Inst Time	B3 Flow Rate
60									
120									
180	10	185	1.500	10	185	1.500	10	185	1.500
240	23	251	0.652	19	249	0.789	16	248	0.938
300				32	316	0.469	25	312	0.600
360	inf			47	383	0.319	25	372	0.600
420				inf			35	437	0.429
480							inf		

Table B.12.

Amoco 1380 NO SEDIMENT

Start time	C START Time 1 Qt	C START Inst Time	C START Flow Rate	C FINISH Time 1 Qt	C FINISH Inst Time	C FINISH Flow Rate
60	2	61	7.500	6	73	2.500
120	4	122	3.750	6	123	2.500
180	20	190	0.750	8	184	1.875
240	55	267	0.273	11	245	1.364
300	79	339	0.190	15	307	1.000
360				19	369	0.789
420				24	432	0.625
480				30	495	0.500
540				38	559	0.395
600				50	625	0.300
660				62	691	0.242

Table B.13.

Amoco 1380

Start time	C1 Time 1 Qt	C1 Inst Time	C1 Flow Rate	C2 Time 1 Qt	C2 Inst Time	C2 Flow Rate	C3 Time 1 Qt	C3 Inst Time	C3 Flow Rate
60									
120									
180	10	185	1.500	10	185	1.500	11	185	1.364
240	18	249	0.833	16	248	0.938	17	248	0.882
300				22	311	0.682	22	311	0.682
360	47	383	0.319	29	374	0.517	23	371	0.652
420	70	455	0.214	35	437	0.429	28	434	0.536
480				30	495	0.500	35	497	0.429
540				41	560	0.366	42	561	0.357
600				55	627	0.273	50	625	0.300
660				73	696	0.205	60	690	0.250

Table B.14.

Amoco 2125

Start time	A1 Time 1 Qt	A1 Inst Time	A1 Flow Rate	A2 Time 1 Qt	A2 Inst Time	A2 Flow Rate	A3 Time 1 Qt	A3 Inst Time	A3 Flow Rate
60									
120									
180	20	190	0.750	10	185	1.500	13	186	1.154
240	22	251	0.682	12	246	1.250	12	246	1.250
300									
360	27	373	0.556	19	369	0.789	16	368	0.938
420									
480	33	496	0.455	24	492	0.625	20	490	0.750
540									
600	40	620	0.375	35	617	0.429	24	612	0.625
660									
720	43	741	0.349	47	743	0.319	29	734	0.517
840	53	866	0.283	56	868	0.268	29	854	0.517
960	67	993	0.224	61	990	0.246	35	977	0.429
1080							42	1101	0.357
1200							49	1224	0.306
1320							54	1347	0.278
1440							61	1470	0.246

Table B.15.

Amoco 2125

Start time	B1 Time 1 Qt	B1 Inst Time	B1 Flow Rate	B2 Time 1 Qt	B2 Inst Time	B2 Flow Rate	B3 Time 1 Qt	B3 Inst Time	B3 Flow Rate
60									
120									
180	8	184	1.875	6	183	2.500	6	183	2.500
240	12	246	1.250	10	245	1.500	9	244	1.667
300									
360	20	370	0.750	18	369	0.833	17	368	0.882
420									
480	25	492	0.600	24	492	0.625	25	492	0.600
540									
600	45	622	0.333	43	621	0.349	43	621	0.349
660									
720	78	759	0.192	90	765	0.167	124	782	0.121

Table B.16.

Amoco 2125 NO SEDIMENT

Start time	C START Time 1 Qt	C START Inst Time	C START Flow Rate	C FINISH Time 1 Qt	C FINISH Inst Time	C FINISH Flow Rate
60						
120	5	122	3.000	8	124	1.875
180	6	183	2.500	8	184	1.875
240	10	245	1.500	10	245	1.500
300						
360	27	373	0.556	18	369	0.833
420						
480	143	551	0.105	30	495	0.500
540						
600				49	624	0.306
660						
720				78	759	0.192

Table B.17.

Amoco 2125

Start time	C1 Time 1 Qt	C1 Inst Time	C1 Flow Rate	C2 Time 1 Qt	C2 Inst Time	C2 Flow Rate	C3 Time 1 Qt	C3 Inst Time	C3 Flow Rate
60									
120									
180	10	185	1.500	10	185	1.500	11	185	1.364
240	18	249	0.833	16	248	0.938	17	248	0.882
300				22	311	0.682	22	311	0.682
360	47	383	0.319	29	374	0.517	23	371	0.652
420				35	437	0.429	28	434	0.536
480	70	515	0.214	30	495	0.500	35	497	0.429
540				41	560	0.366	42	561	0.357
600				55	627	0.273	50	625	0.300
660				73	696	0.205	60	690	0.250

Appendix C

The amount of residue from each 500-ml sample of the influent was measured and the average for all of the runs for each type of fabric determined. The average for all runs which contained sediment was also determined.

Table C.1.

Average Sediment Concentration in Influent

Mirafi 100X	0.695
Mirafi 600X	0.554
Amoco 1380	0.707
Amoco 2125	0.557

The temperature of the water used for these experiments was measured on several different days. Note that one fabric sample was tested each day, so that on some days more than one temperature reading was recorded. For example, three iterations of the test were performed using sample B of the Amoco 2125 fabric on a single day. The temperature of the water used for each of the three runs was recorded. The temperature listed for run 1 of sample B for the Amoco 2125 corresponds to the first batch of 13.2 gallons withdrawn from the water supply on the day sample B was tested; the temperature for run 2 was recorded for the next batch of water which was withdrawn approximately 1 hour later, etc. Note that the maximum temperature recorded is 21.8 °C and the minimum is 19.0 °C.

Table C.2.

Influent Water Temperatures

Fabric	Sample	Run	Temperature (°C)
Amoco 1380	C	1	21.1
2125	A	2	19.0
		3	19.1
	B	1	21.8
		2	19.5
		3	19.8
	C	1	20.2
		2	19.4
		3	19.7

END