EVALUATION OF EXFILTRATION SYSTEMS

BY

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THESIS

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ABSTRACT

Exfiltration systems release water from underground storage to the surrounding soil. Because of increasing growth in urban areas less surface storage areas are available, thus underground storage with exfiltration of the stored water becomes a viable option.

Actual construction practices for exfiltration systems were examined. During construction fine material and construction debris has to be eliminated from the rock and pipe. The removal of fine material from the aggregate by washing also will improve life expectancy.

Four design parameters were postulated to be the most important for exfiltration system performance over time, namely, initial stormwater solids loading, type of existing parent soil material (sandy or silty), woven or non-woven fabric, and water table location (wet or dry system). Sixteen experimental exfiltration tanks were built and stormwater added until the equivalent of 2 years of runoff from an impervious surface was added. Each system was designed to store the runoff from one inch of rainfall. About two years of rainfall-runoff processes were simulated.

The experimental data indicate that a reduction in stormwater solids results in higher exfiltration rates. The

type of parent existing soil material must be defined before a permeable fabric is chosen. The woven (Mirafi 700XG) fabric performed with a higher exfiltration rate when silty soil was present and a lower rate when sandy soil present. On the other hand, the non-woven (Mirafi 140N) fabric performed best when sandy soil was present. A comparison of systems built in the water table with those not in the water table indicated that significant storage is lost in the high water table situation but exfiltration rates are not significantly different between the low and high water table situations.

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CHAPTER I

INTRODUCTION

Exfiltration vs. Infiltration

In the practice of stormwater management, exfiltration and infiltration terminology is interchanged continuously. Therefore, it is necessary to define each term as it will be used for this work. Infiltration is most commonly used when a structure collects water. Exfiltration is when a structure releases water. Infiltration systems include: underdrains, trench or french drains, swales, porous pavement, and infiltration basins. These systems collect water and either route it to a connected stormwater retention pond or allow for penetration into the surrounding soil. Exfiltration systems are completely underground and receive stormwater from common drainage structures such as street gutters and pipes. The water is allowed to exfiltrate or leave the system through natural drainage into the surrounding soil. Exfiltration systems are the only type system which utilizes this method of drainage. It can be seen however that the exfiltration system is actually a combination of both exfiltration as defined above and infiltration. Water is exfiltrated from the system but infiltrated into the surrounding soil. The system releases the water while the soil collects the water. Infiltration systems perform the same operation as their corresponding soil through absorbance. In conclusion the infiltration system accepts water through or into it while exfiltration systems allows for the reverse action or water to leave it.

Need for Exfiltration Systems

The increased growth of urban areas has reduced available surface storage areas and has necessitated stormwater system innovations. Because of this growth several problems have risen regarding the natural surface and groundwater systems. These issues include: high peak flows in storm sewers and streams, lowering of water table, reduction of base flows in receiving streams, increased pollution of receiving streams and lakes, and damage from flooding due to increased rates and volumes of runoff. These factors as well as others contribute to the redirection of stormwater from its original site before development. In the natural environment much of the rainfall soaks into the earth where it falls. Current paving and building practices however, prevent this from happening. High peak flows in rivers and streams are a direct result of the increased runoff from developed areas. These increased flows necessitate larger transport systems being implemented resulting in higher costs and increased erosion of streams and sedimentation in lakes due to higher discharge velocities. Water which is not allowed to soak into the earth does not contribute to the groundwater supply. If the stormwater is prevented from soaking into the native soil, replenishment of the groundwater supply is greatly reduced and the water table can be lowered. This lowering of the water table can cause detrimental effects to existing vegetation and salt water intrusion in coastal areas. Another effect of a lower water table is the reduction of base flows in rivers and streams which can greatly change the aquatic life.

To enhance the natural drainage of stormwater into native soils, exfiltration (underground drainage) has been developed. With this stormwater disposal alternative many of the previous problems encountered with conventional systems can be reduced or eliminated. Advantages of using exfiltration systems for disposal of stormwater runoff may include: (1) decrease of stormwater volume to conventional systems therefore reducing cost of storage; (2) replenishment of the groundwater supply system by introducing stormwater to its natural drainage site; (3) removal of pollutants by passing stormwater though soil; (4) attenuation of peak discharges in areas where an existing outfall is not able to regulate these flows; and (5) reduction of land area required for conventional stormwater management surface ponds.

Current Exfiltration Design

An exfiltration system can be constructed in various ways to adapt easily to the existing collection and transport process. The usual configuration consists of a underground trench containing a perforated pipe surrounded by coarse aggregate enclosed within a filter fabric (see figure 1.1).

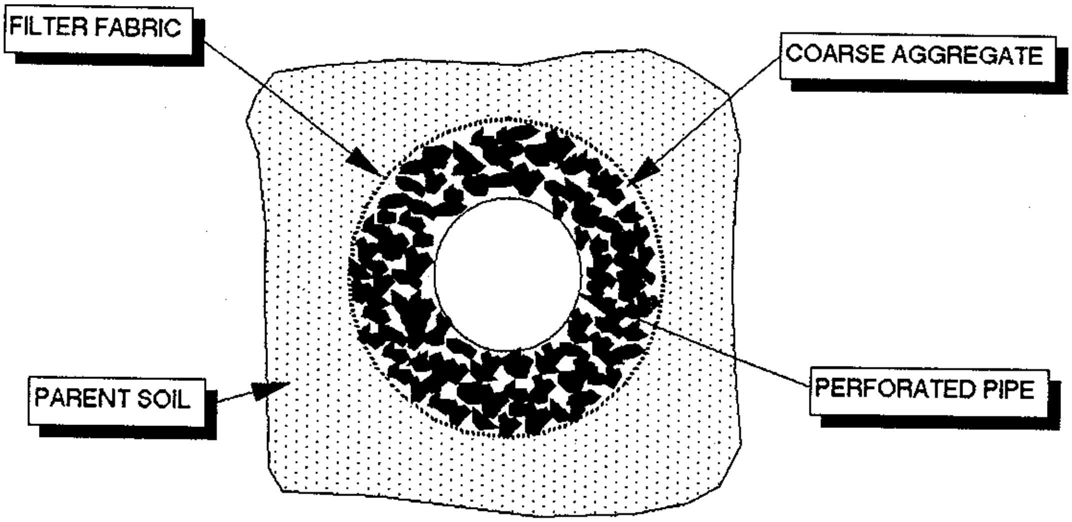


Figure 1.1. Exfiltration System Cross-Section.

The exfiltration system operates by gravity flow from the perforated pipe through the course aggregate, the filter fabric and into the parent soil. As the flow into the system occurs, the pipe and aggregate store stormwater and allow for natural infiltration into the parent soil. An increased depth of water in the aggregate and pipe develops due to the inability of the parent soil or filter fabric to infiltrate as fast as the input rate into the system. The increased depth contributes to a faster infiltration rate into the parent soil which partly compensates for the higher input flow rate. Stormwater which is usually collected from roadways, residential sites, and commercial areas contains suspended solids, greases, oils and other potential contaminants. To reduce this foreign material in the stormwater before input to the exfiltration trench, a sump or clean-out device is normally used. This clean-out structure is maintained on a regular basis to ensure that the system is not receiving an appreciable amount of foreign material.

Exfiltration systems can be installed in many different locations and do not require as much area as conventional systems. Typical locations include: under roadways, parking lots and buildings; within parks and recreational areas; along highway systems; and just about anywhere that facilitates groundwater infiltration. Caution must be taken to ensure proper design criteria and installation for efficient usage of an exfiltration system.

Types of Exfiltration and Infiltration Systems

There are many parameters involved when considering infiltration practices. With every infiltration structure it is necessary to have an established set of guidelines for proper installation and maintenance management. There are four common types of infiltration structures, namely infiltration basin, infiltration trench, porous asphalt pavement, and vegetated swale.

An infiltration basin uses the bed and sides of the system to temporarily store and infiltrate surface runoff.

During excavation, the need to preserve the natural infiltration rate of the parent soil is important. Because of this, lightweight construction equipment should be used around the site. After final excavation, the infiltration basin can be lined with a layer of filter material such as coarse sand to reduce the buildup of impervious deposition on the soil surface. After construction, follow up inspections should be made after at least one major storm per year. If stormwater from the design storm remains ponded in the basin three days after the storm event, the basin should be dewatered then tilled (MDNRWRA, 1985).

The infiltration trench is a long, narrow excavation, backfilled with stone aggregate that provides for temporary stormwater storage in the voids between the aggregate and allows for infiltration into the parent or surrounding soil. After excavation of the trench, a filter fabric is placed along the bottom and sides of the basin. An aggregate is then placed in the trench to the desired height. It is important that the aggregate be clean and free of debris. Within the infiltration trench, an observation well can allow observation of the time required for the trench to dewater following the storm. The inspection of infiltration trenches on a regular basis is particularly important because these devices are highly susceptible to clogging by the fine sediment carried by stormwater runoff. Severity of clogging conditions should be evaluated once a year. If inspection of the trench a few days after a rainfall shows water remaining, it is possible that the filter cloth and/or upper layers of aggregate are clogged. The fabric cover and top layer of aggregate should be replaced every two to five years, which will reduce clogging. Total rehabilitation of an unmanaged trench should be performed every ten to fifteen years (MDNRWRA 1985).

Another method of containing runoff for storage and treatment is by using porous pavement. The primary benefit is the significant reduction in runoff rate and volume from an otherwise impervious area. The construction of this type of pavement includes an asphalt without fine filling particles to leave voids between the larger aggregates. The asphalt is installed on a gravel base or in areas of inadequate stormwater drainage and can be installed on an impervious base. This system can prove very efficient if it is operating at one hundred percent efficiency but infiltration can be drastically reduced with the clogging of its pores.

Porous asphalt pavement is constructed with a material and aggregate base that allows for rapid infiltration and temporary storage of runoff. As with the infiltration basin and infiltration trench, it is important that during excavation care be taken to insure that the parent soil remains non-compacted to preserve the voids. After installation of subgrade, a filter fabric is installed. This fabric contains the aggregate placed next. The aggregate will be graded placing the large aggregate next to the filter fabric and the finer aggregate on top. Failure of porous pavement usually occurs in its early life due to earth-moving equipment on sites surrounding the pavement. This equipment will compact soil particles into the pavement thereby filling the voids resulting in impervious pavement. Maintenance for porous asphalt pavement includes vacuum sweeping followed by high pressure jet washing. If done properly, this maintenance procedure will generally restore higher infiltration rates to the pavement (MDNRWRA 1985).

A vegetated swale is a grassed channel with small earth dams, usually six to twenty four inches high, at specific intervals to create a series of pools for infiltration purposes. These check dams are typically utilized for swale slope gradients less than 5%. Earth dams are used to minimize erosion and provide limited volume within the swale to permit greater infiltration. Generally no maintenance except for mowing is necessary for the swale. However, inspections should be made to insure that the small earth dams remain (Wanielista et al. 1985).

In conclusion, with routine construction practices and defined maintenance schedules, these infiltration structures can perform well for a predictable lifetime.

CHAPTER II

LITERATURE REVIEW

Underground Disposal of Stormwater Runoff

With increased development in many urban areas, alternatives to conventional stormwater disposal systems are needed. The exfiltration system is one possible method for introducing stormwater into the ground. With this system water collects in underground trenches and then drains into the parent soil.

Disposal of stormwater by infiltration provides attractive alternatives to the more conventional stormwater conveyance systems. The imposition of no additional discharge (zero increase of runoff) within urban areas coupled with regulations on land developments provides an increased emphasis on exfiltration as an alternative for disposal of stormwater (Hannon 1980).

Exfiltration trenches provide flexibility for development in that they reduce flow into existing systems, streams, or rivers. Exfiltration trenches can serve to replenish groundwater supplies and increase groundwater levels, thus decreasing salt water intrusion into aquifers.

Trenches are a viable solution for long term disposal of stormwater underground where the parent material is suited for absorbance of large quantities of water. These systems can provide an economical alternative to surface disposal in urban development areas. Many parts of Florida are well suited for this type of system due to the high soil permeabilities. In South Florida the rock strata can support the slab-covered open type trench design.

The exfiltration trench, or in some areas it is called a french drain, may consist of unsupported open cuts with side slopes, or vertical sided trenches with concrete cover void of backfill and drainage conduits. Possibly the most common configuration is a trench backfilled with coarse aggregate surrounding a perforated aluminum pipe or slotted concrete pipe.

The addition of the perforated pipe, in the exfiltration system, as opposed to coarse aggregate backfill alone, increases the storage volume in the system as compared to conventional "French Drains" or dry wells by increasing the cross sectional water storage area (Hannon 1980).

Synthetic filter fabrics, used in most exfiltration systems, act both as separators, to keep fine erodible soils out of porous drains, and filters, to allow free flow of water while preventing movement of erodible soils. Materials used for these fabrics include polyvinylidene chloride, polypropylene, and other synthetic resins (Hannon 1980). Hannon (1980) states that these materials are not subject to rot, mildew, or insect and rodent attack but are sensitive to long term exposure to ultraviolet components of sunlight. To insure the performance in the exfiltration system synthetic fabrics either woven or non-woven should be selected based on physical properties required. Two very important functions must be considered in the selection of the fabric: (1) they must reduce clogging of the system by erodible soil or other material that could lead to erosion or piping, and (2) the fabric must not inhibit free flow of water.

The purpose of the perforated pipe is to distribute the inflow of stormwater among the aggregate backfill. To reduce aggregate backfill cost and increase available storage in the trench, the largest possible pipe should be used. The perforations in the pipe should be placed so that there is no restrictions to out flow from the pipe. The material used for most exfiltration systems is aluminum, which provides lightweight installation and minimum corrosion (Russell, 1989).

Determination of Infiltration Rate

The capability for the trench site to accept surface water and infiltrate it depends on many factors. These include: natural ground slope, type and properties of surface and subsurface soils, geologic conditions, and subsurface hydrologic conditions (Hannon 1980). In addition quantity and quality of runoff water greatly influence the capability of the systems to accept and exfiltrate water over a long-period of time. Contaminates can affect the infiltration capabilities of the system, these include: dissolved salts and other chemical substances, oil, grease, silt, clay and other suspended matter. These materials greatly reduce infiltration rates and are not frequently intercepted by catchment basins or removed by normal maintenance methods (Hannon 1980). Also included in the aspects that influences the infiltration rate is the depth of the water table, its natural slope, and the unsaturated and saturated horizontal and vertical permeabilities of soil formations.

Four aspects of infiltration and dissipation of water should be viewed for the design of exfiltration systems. (1) capability of water to enter the soil surface, (2) conduction of subsoils to allow water penetration into the underlying water table, (3) ground water flow capability to transport water away from site, and (4) flow from the system under mounding conditions at maximum infiltration rates (Hannon 1980). Also compaction, water turbidity, and limiting porosity of a soil layer can affect infiltration rates. In an area of varying soils, the layer with the least permeability will govern the infiltration rate of the system. Compaction can greatly vary the infiltration rate of the system, the greater the compaction the less the infiltration rate. Musgrave and Free (1937) found that even a slight turbidity in the water caused a considerable decrease in the infiltration rate. A recommendation for experimental models for testing infiltration is that they should have the same input water quality as that to be expected in the natural system (Hannon 1980).

Because of the many factors affecting infiltration rates, considerable judgement and experience are needed for selection of the proper test procedure to obtain results for design of an exfiltration system.

Mobility of Pollutants in Stormwater

Pollutants can be in the form of particulate or in a soluble form. The transport of pollutants from pervious lands can take place in many pathways and can involve many transport mechanisms. The main transport mechanism is water. Pollutants that exist in particulate form can be transported only by surface waters while the dissolved pollutants can be transported by surface and/or groundwater routes. To equate sediment loading between pollutants, many studies use a "potency factor". This factor can be expressed by the equation:

$$Y_i = P_i \times Y_s \qquad (1)$$

Y_i = Loading or concentration of pollutant i

Y_s = Loading or concentration of sediment

P_i = Potency factor for pollutant, related by concentration of pollutant in parent soil.

$$P_i = S_{is} \times ER_i \qquad (2)$$

S_{is} = Concentration of pollutant in soil g/g of soil

ER_i = Enrichment ratio for pollutant between source and point of interest or watershed outlet.

Enrichment ratio factor, defined by Massey and Jackson, is the concentration of constituent in the eroded material or stream sediment divided by its concentration in the parent soil expressed on an oven-dried basis (Novotny 1981). At most times, the enrichment ratio is at best a rough estimate. The potency factor is highly variable due to its dependency on soil characteristics, storm and overland flow characteristics, channel flow hydraulics, presence of sediment and pollutant sinks such as grassed areas or forest litter and mulch, and the nature of pollutants (Novotny 1981).

There are five processes that explain why concentrations of pollutants are higher in eroded material and stream sediment than in parent soil.

1. Selective removal of fine particles that have a higher pollutant concentration than the remainder of soil material.
2. Diffusion action from topsoil of pollutants and salts into surface runoff.
3. Desorption of pollutants from soil particles due to low dissolved concentrations in runoff water.
4. Flotation of low-density materials such as organic components from soil into surface runoff.
5. Deposition of coarse fractions containing little sorbed pollutant during overland and channel flow.

To better understand the concept of mobility of pollutants, pesticides will be used as an example.

Pesticides can be transported from the treated area through (1) atmosphere, (2) groundwater, and (3) surface water. Atmospheric losses of pesticides occur by drift during application, volatilization, and by wind erosion, measured by the amount of pesticides that do not reach the target area. This parameter depends on many geologic and weather conditions and accounts for 25%-75% of aerially applied pesticides (Novotny 1981).

Groundwater contamination by pesticides occurs through leaching determined by soil type, pesticide composition, and climatic factors. Leachability of a compound from soils depends primarily on the degree to which it is adsorbed. Pesticide adsorption relates closer to organic matter content than clay content for nearly all pesticides, and pesticides leach more readily from coarse-textured than from fine-textured soils. The solubility of the pesticides also contributes to their ability to move through the soil since solubility limits the concentration of the mobile portion of the compound in the soil solution. Because solubility relates inversely with adsorptivity, pesticides of high solubility are subject to vertical movement more than those of low solubility. The transport of pesticides through the soil also is dependent on amount, intensity, and frequency of water infiltration. The movement of pollutants through soils is then dependent on soil type, depth to water table, rainfall infiltration, and persistence of the compounding soil.

Sediment in Stormwater

The theory of sediment transport in streams explains the suspended fraction or washload in relation to the sediment size in stormwater. The channel transport of sediment can be divided into the suspended fraction of the sediment carried by the stream, and the fraction of sediment contained in moving stream beds. The primary variables known to influence sediment transport are flow velocity, flow depth, slope of the energy gradient, density, viscosity of the water-sediment mixture, mean full diameter of the particles, gradation of the bed sediments, cohesiveness of the sediments, and seepage force on the stream bed (Novotny 1981). The combination of the hydraulic factors can either cause sediment to be deposited or resuspended from the stream bed.

In channels, cohesive sediment flow differs from traditional models developed for noncohesive sediment. The main difference between the two classes of transport is that the coarse sediment travels as a direct relationship to stream discharge but a relationship does not exist for the finer particles. Suspended sediments, which include clays and silts, will settle only in zones of low velocity while the larger sediments can settle in more turbulent zones. This parameter indicates that in most cases finer sediment can be transported in just about all flow conditions.

A model was developed applicable to the transport of cohesive sediments such as clays and other fine soil fractions (Novotny 1981). This model was developed only after extensive laboratory research on the action of suspended solids in channel flow. Partheniades introduced fine sediment mixtures into a channel flow and observed when deposition occurred.

It was observed that deposition was also directly related to bed shear stress by the equation

$$\tau_b = \gamma \times H \times S \quad (3)$$

τ_b = bed shear stress (lb./ft^2)

γ = specific weight of water (lb./ft.^{3})

H = depth of water in channel (ft.)

S = energy slope (ft./ft.)

Findings concluded that erosion, or pickup of particles in the channel due to water movement, was uniform for uniform bed conditions. Also suspended sediment concentrations in the channel increased linearly with the flow velocity. The shear parameter (τ_b) used by Partheniades to evaluate concentrations of sediment in the streams can be directly related to the velocity in the stream. If the velocity is slow deposition occurs as long as there is enough time for the sediment to reach the bottom surface. As velocities increase deposition decreases and erosion begins. A value for the velocity in which erosion begins is variable due to the conditions of the sediment. These variable sediment parameters include: the physical, chemical characteristics of the sediment, their compactness, and their age (Ariathurai 1977). It is noted that the cohesiveness of the settled clays and fine soil particles make them more resistant to erosion.

To apply the theory of Partheniades an example to determine deposition or erosion in a gutter can be used.

A gutter with an average depth of .08m and a slope of .3m/km is carrying suspended cohesive settlement or washload. Determine deposition of sediments. Assume steady state flow conditions prevail.

Bed shear stress

$\tau_b = \gamma \times H \times S = (\gamma \times g) \times H \times S$ (3)

$\tau_b = (1\ g/cm^3) \times (981\ cm/s^2) \times (8\ cm) \times (.0003)$

$\tau_b = 2.35$ Dynes / cm^2

The critical bottom shear stress for deposition

τ_b min = 1.6 Dynes/cm^2.

$\tau_b - \tau_b$ min = 2.35 - 1.6 = .75 Dynes/cm^2

Using figure 5-23 from Novotny, V. p. 206 the corresponding value for C_{eq} / C_o = 40%. This translates to 100 - 40 = 60% deposition in the gutter with these flow parameters.

Efficiency of Street Sweeping to Remove Sediment

The process of street sweeping is a discriminating one that chooses larger particles while street flushing or surface runoff is selective for finer particles. To analyze accumulation of pollutants on impervious areas a simple mass balance equation can be used.

dP/dt = sum of I - sum of L (4)

where:

dP = amount of street refuse, dust or dirt present on surface.

dt = time period.

sum of I = sum of inputs / time period

sum of L = sum of losses / time period

<u>INPUTS:</u> Atmospheric fallout, litter deposits, vegetation residues, and traffic impact.

<u>LOSSES:</u> Translocation of the accumulated dust from the surface towards the curb and adjacent pervious areas. Natural and traffic induced wind, curb height, adjacent pervious areas that act as traps, and airflow patterns or canyon affects.

To reduce pollutants and improve appearance of the streets, two methods are used to remove sediment, street sweeping and street flushing. In the United States, street sweeping is primarily used to remove sediment and trash from roadways. In Europe however, street flushing is widely used for cleaning the roadways. Street sweeping is primarily used for aesthetic purposes because of the inability to remove finer particles from the roadways. Two types of street sweepers are used for removal of particles: the mechanical broom and the vacuum type. The mechanical broom type is rated at fifty percent efficiency and usually cannot remove particles from roadways less than 3.22 millimeters in diameter. The vacuum assisted type of street sweeper is an improvement of the mechanical broom type sweeper with the addition of the vacuum. This sweeper is more efficient but is still ineffective for silt and clay size particles. Street flushing as a substitute for sweeping is ineffective unless a complex combined sewer system is used which can handle the large volumes of sediment and water since the wash velocity must remain high to remove the finer particles. The water in the combined sewer system would have to be treated before discharge.

To estimate the actual wash of pollutants by surface runoff many models have been developed. The most common of the models used is the Yalin equation which takes into account gutter dimensions, volume of runoff, types of particles within sediment, tractive forces of debris and dust and the particle transport for debris and dust. This equation is accurate within the given parameters and can estimate the time in which the storage of the sediment in the gutter is depleted.

Soil Microorganisms

Soils contain five basic microorganisms which decompose organic material and/or are an integral part of the soil organic composition. These microorganisms are: bacteria, actinomycetous, fungi, algae, and protozoa.

Bacteria is the largest group of microorganisms in the soils and performs most of the decomposing processes. Bacteria is classified into two groups: autochthonous species, which are the true residents of the native soil, and allochthonous species, which are invaders that enter soil through precipitation, manure application, septic tank effluent, and others. Bacteria can also be classified as aerobic, anaerobic, or facultative groups. Aerobic organisms receive energy from an organic carbon source where strict anaerobes grow only in the absence of oxygen. Most soil bacteria however are facultative which defines that they can grow in both aerobic and anaerobic conditions. A product of bacterial decomposition is carbon dioxide which depletes the oxygen content in the soil.

Pathogenic microorganisms can also be found in the form of bacteria and viruses in soils. These microorganisms exist according to the availability of a host organism. Because of the frequent contamination of soils with animal droppings, manure, sewage containing disease agents, wastewater effluent applied on land, and tissues of diseased plants, these microorganisms can exist. Therefore, a constant surveillance for disposal of these contaminates needs to be made to control these microorganisms. Bacteria can survive in soil ranging from a few hours to several months. This variance depends on: the type of organism, the type of soil, moisture field capacity of soil, moisture in organic content of soil, pH, temperature, sunlight, precipitation, and predation of the resident microflora of the soil. There are a few factors which encourage the growth of bacteria. The survival of bacteria is enhanced by moist soil over dry soil. Survival time of bacteria is less in sandy permeable soil as opposed to a soil with a greater water holding capacity such a clayey soils or peat (Novotny 1981).

Actinomycetes, single-celled plants are classified by some as bacteria, others as fungi, and still others as an intermediate between the two. Actinomycetes are aerobic heterotroph, and their chief function in the ground is in the decomposition of dead organic matter (Hunt 1972).

Fungi, which include the molds, are as abundant in the ground as bacteria. Some fungi are parasites, however they are not necessarily pathogenic while other fungi are saprophytes. Like animals, fungi are incapable of photosynthesis. Fungi are generally microscopic is size, but a few are large (i.e. mushrooms). Fungi are less tolerant of salinity than bacteria but are more tolerant of acid conditions.

Algae which live in the soils are mostly simple types. Although they contain chlorophyll and are capable of photosynthesis, some can live deep in the soils where sunlight is not available. Algae requires moisture for growth and can obtain this from even the arid desert conditions. It is then obvious that algae can grow in almost any condition.

Viruses in soil are considered invaders and their survival depends on the nature of the soil, temperature, pH, moisture, and possibly antagonism from soil microflora. Viruses readily adsorb to soil particles and can survive as short as seven days and as long as six months. The survival of the viruses is greatly dependent on temperature. Viruses survival on crops is shorter than in soil because the viruses are exposed to deleterious environmental affects. Sunlight and the fact that viruses cannot reproduce in soil will eventually eliminate them. There are only a few ways to rid the soils of viruses. One method is to flush the soils with water and collect the water in drainage facilities for treatment. Another method and perhaps the most widely accepted is to use the soils natural adsorption abilities. This adsorption can be accelerated through controlling the pH of the soil. This pH level varies for different viruses, but generally stays at 7.0. With the control of bacteria and viruses, groundwater contamination can be also controlled.

Hardpan Formation

Hardpan is a term for a relatively impermeable layer which can form within a soil profile. Its formation has been related to denitrification, permeability changes, compaction, and cementation (Pitty 1979). The hardpan layer can form in either humid or dry regions, but by different means. In a humid region, the pan layer can result from excessive moisture increasing the amount of groundwater. In a dry region, the pan layer can form due to the absence of water by the precipitation of carbonates in the soil layers.

Hardpan is a type of soil layer which involves cementation. The cementing agents can be derived from different mineral compounds and from organic matter. The most strongly expressed hardpans occur in the transition stages between moderately well and poorly drained soils (Pitty 1979). An example of this transition can be viewed as the exfiltration system. Within this system the gravel which surrounds the pipe is very well drained. However, the parent soil, which is separated from the rock only by the fabric, is poorly drained. Iron oxide is a very common mineral compound found in hardpan formation in soils of humid climates. The contribution of iron is usually leached from the upper soils through drainage and where a condition of acidic soil exists. Two other minerals involved in the formation of hardpan are calcium carbonate and silica compounds (Gibson-Batten 1970). Organic hardpans are perhaps more widely distributed than mineral hardpans in humid regions. They occur over much of the Atlantic and Gulf coastal plains of the southeastern United States.

The cementation process that forms the hardpan in most cases combines iron, manganese, and thick organic surface layers. Within these layers, periodic water logging occurs which deposits all the constituents released during soil weathering. Common features of the concretion process are the inclusion of skeletal silt particles, chiefly quartz, and their cementation with an ochreous-brown substance (Pitty 1979). It is also important that frequent wetting and drying occur to harden the cementious material.

Concretion material in its initial form is a water stable aggregate near an accumulation of organic matter. To form the essential manganese, several narrow intervals of redox conditions are necessary. Manganese appears to function as condensation nucleus for catalytic acceleration of the precipitation of coagulations of MnO_2 and $Fe(OH)_3$. If these are in suspension from this process, nodules are formed and enlarge due to several chemical reactions, including reversible oxidation-reduction solubility (Pitty 1979). Some of these concretions have a distinct concentric structure, while other types may be formed by progressive weathering of small soil peds rather than by accretion.

Once this hardpan is formed, many problems can occur both agriculturally and physically. Usually a saturated condition will remain above a hardpan which will harm root systems of perennials, such as trees and vines. Flows in the subsurface of these soils are usually slow and can complicate the engineering uses of such soils.

CHAPTER III

RESEARCH OBJECTIVE

The objective of this research is to analyze exfiltration systems over time to determine the appropriate design criteria given specific tank size and field conditions. Preliminary investigations will be conducted on the fabric and aggregate types. The solids loading within the aggregate plus solids introduced during construction will be used. The other design and field conditions will be examined using model exfiltration tanks in which the construction and operation variables can be examined for thei effect on exfiltration rates. Four separate parameters will be varied in sixteen models to account for variations in design and field conditions. The four parameters that will be varied include: (1) sediment removal or non removal, (2) sandy or silty parent soil material, (3) Marafi 140N non-woven fabric or Marafi 700XG woven fabric and, (4) wet condition system or dry condition system. As seen in Figure 3.1 stormwater obtained from a detention pond will be introduced and branched into sediment removal or non-removal. From this point the two branches will be directed to a silty parent soil condition or a sandy parent soil condition. Within these two soil types the stormwater will be routed to a system which contains either the 140N fabric or the 700XG fabric. Finally, the soil column entered will either be dry or partly wet (saturated).

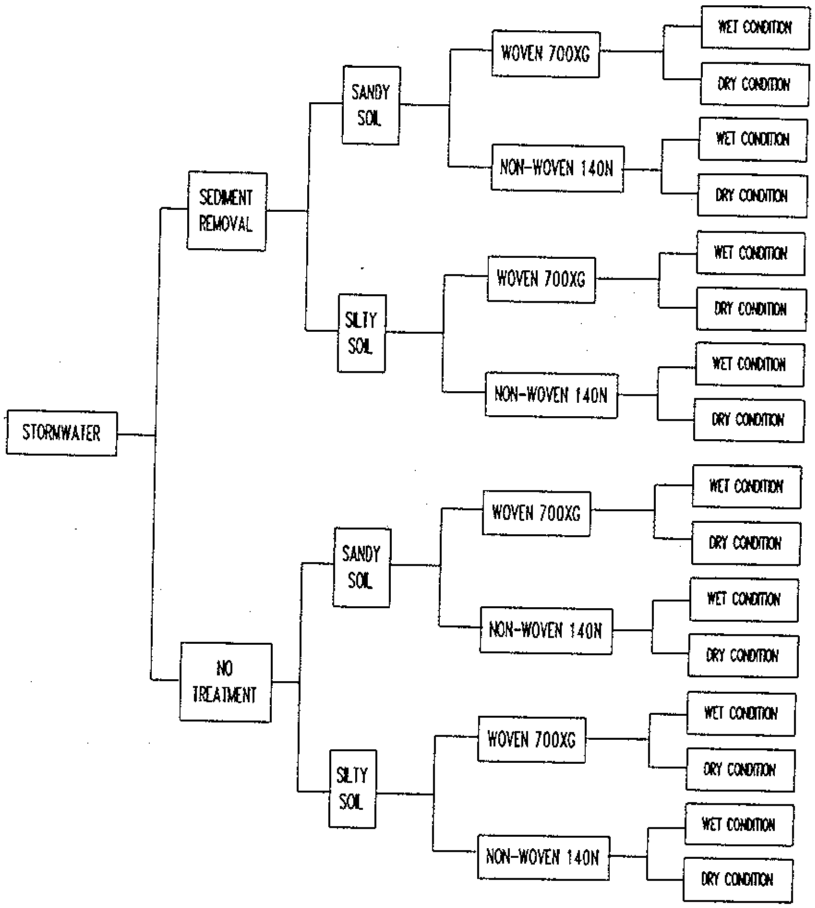


Figure 3.1. Experimental Setup.

Exfiltration rates will be measured for each system using rainfall and runoff conditions simulated for a period of two years. These rates will be compared to each other. To determine if a reduction in solids affects the exfiltration rate, loading data are obtained by measuring the suspended solids concentration in the stormwater and after solids removal. From the sixteen models using exfiltration rate comparisons the following questions will be challenged:

1. Does the reduction of sediment from the stormwater immediately affect the exfiltration rates in the systems?
2. After reducing the solids loading in the stormwater for a specific time period is the exfiltration rate significantly greater than the non-filtered system?
3. Does the type of parent material affect the exfiltration rate?
4. After a period of time does the parent soil affect the collection of solids on the fabric media?
5. Given the same system parameters does either the Marafi 140N fabric or the 700XG fabric allow a higher exfiltration rate?
6. Is there a relationship between the soil and fabric type?
7. Does the wet condition system decrease the exfiltration rate over time?

Conclusions will be made to establish guidelines for the design, construction, and operation of exfiltration systems. From these guidelines, attempts will be made to enlighten the current design practice and determine the causes leading to failure. Suggestions will also be made for further study in the area of exfiltration research.

CHAPTER IV

HYDROLOGIC AND HYDRAULIC DESIGN

To simulate an actual exfiltration system, historical hydrologic and hydraulic conditions need to be duplicated. The hydrologic comparison includes: rainfall volume, rainfall excess, rainfall intensity, inter-event dry period, and potential soil infiltration rates, which are needed for a system mass balance. The hydraulic comparison considers: design of a system for a volume of rainfall excess and an exfiltration flow rate. A third parameter not often used for design of exfiltration systems is the solids loading in the stormwater as a function of the exfiltration fabric area.

Hydrologic Factors

To model runoff conditions, estimates of rainfall volume and runoff duration are necessary. Actual rainfall statistics for the Orlando, Florida area are used in this work. A cumulative distribution for volume and duration are used to extract independent rainfall volumes. A storm event is defined as one producing a measurable quantity of rainfall and separated by at least 4 hours of no rainfall conditions. Runoff from rainfall on impervious surfaces usually occurs when the volume of rainfall exceeds .04 inches (Wenzeland and Voorhees 1981, Arnell 1982, and Schilling 1983). Based on Florida rainfall and runoff conditions, a volume and duration of rainfall exceeding .04 inches will be used to determine runoff volume into the experimental exfiltration tanks. Based on these statistics, 95 storm events per year will be used. To obtain the volumes for the events the cumulative frequency vs. rainfall curve was used (Figure 4.1). Frequencies were obtained using a random number generator and the

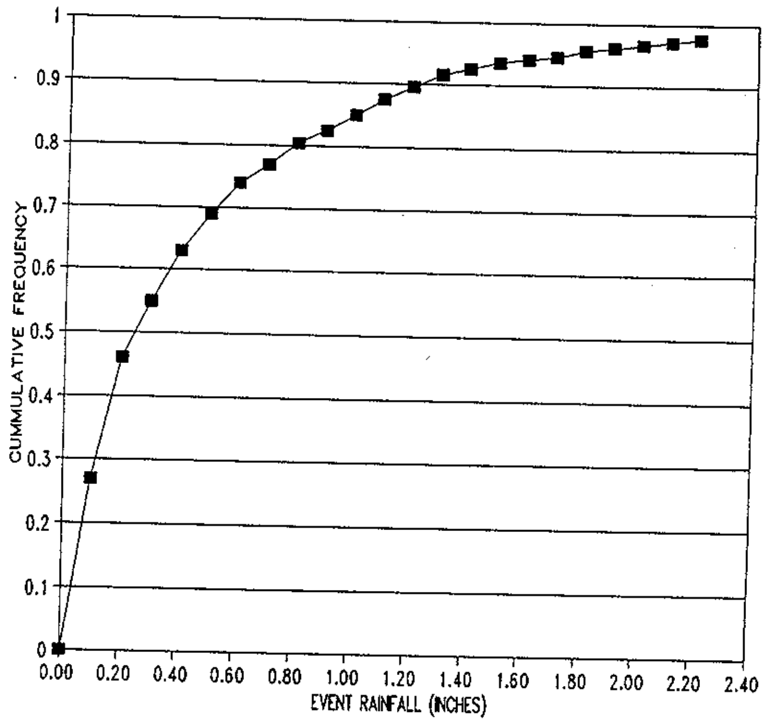


Figure 4.1. Cumulative Rainfall Distribution.

corresponding rainfall volume was established. In the same manner the duration for each storm was determined using the cumulative frequency vs. duration curve (Figure 4.2). Once the rainfall volume in inches and the duration in hours were established, the runoff volume was calculated.

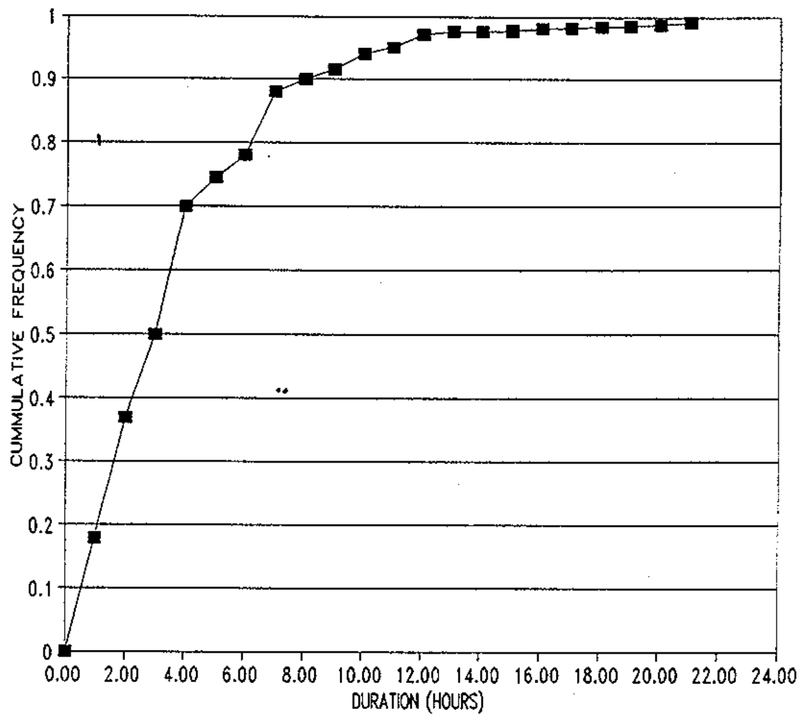


Figure 4.2. Cumulative Duration Distribution.

For the model experiments, a contributing area method for determining runoff volume was used. The size of the exfiltration systems was a six inch diameter pipe and a six inch uniformly distributed rock thickness around the pipe (excluding the top of the pipe). Further explanation of the trench volume design will be discussed in the hydraulic section of this chapter. The volume in the trench available for storage assuming a water level at the top of the perforated pipe was 1.51 ft^3. To calculate the contributing area, one inch of runoff was used over the impervious area. Therefore, the watershed area equals:

Volume of storage in trench / one inch

Area = 1.51 ft^3 / 1 in. / 12 in. / ft. = 18.1 ft^2.

The rainfall events would now be simulated from the impervious area of 18.1 ft^2 and the associated runoff volume calculated for the exfiltration systems.

To simulate actual rainfall runoff events, flow rates to the systems were varied similar to that of the falling limb of the runoff hydrograph. A computer program was written to tabulate the variability of the runoff over the predetermined duration of the event. A listing of the program and an example output form can be seen in Appendix A.

The quantity of runoff water removed by the exfiltration system was measured by its ability to drain the pipe and rock area into the parent soil material surrounding the permeable fabric. The infiltration rate of the soil in a properly designed system should be the limiting parameter for the outflow of the stormwater. Tests for determining the infiltration potential of the soil in an exfiltration trench were used to design the remaining parameters of the system. Variables that affect the passing of water through soil included: 1) grain size, 2) distribution of soil grains, 3) variability of soil types, 4) compaction of soil, 5) organic content, 6). water table elevation, and other factors. The moisture content in the soil media can greatly influence the ability for water to pass through. Within the soil lattice, moisture decreases the available storage capacity and inhibits passage of water. Due to this phenomena the flow of water must find a alternate passage from the exfiltration system into the surrounding groundwater. This is an important design parameter for determining the storage volume of the system. If the water table is located near the ground surface, the system must be considered to have a usable volume above the water surface. Careful attention must be made to determine the elevation of the highest ground water level to insure the storage volume in the exfiltration system is large enough.

In dry soil many factors affect the infiltration rates including: cohesion, electrostatics, and temperature. Water passing into the exfiltration system can be drawn out of the pipe and rock by the suction properties in the soil media. This suction is due to the capillary action with respect to electrostatic forces which attract water molecules through ionic charges. It is very difficult to measure the suction potential in the soil media and in certain areas this influence can greatly increase the exfiltration rate in the system.

Hydraulic Factors

Hydraulic design of the exfiltration system include sizing the trench capacity based on known criteria and an efficient method of passing stormwater through the complete system. To obtain hydraulic design parameters for the model exfiltration system two parameters must be considered.

1. The volume of water to be entered into the system.
2. The rate at which this stormwater will enter the system.

The volume of the system will be determined by the amount of runoff calculated for a design condition. For the models, a one inch depth was used over a impervious area of 18.1 ft^2 to obtain 1.51 ft^3 of storage required. The flow rate of this runoff is governed by the hydrograph from the rainfall event with a short time of concentration. This produces a maximum flow rate calculated from the maximum intensity of the storm event. To size the actual system, a perforated aluminum pipe six inches in diameter was chosen. The pipe is a common type used in most exfiltration systems and is commercially available. The shape of the pipe is spiral so that water which enters is channeled along the edges and can easily exit through the holes in the sides. The length of the system was fixed at twenty two inches so that two systems could be built out of one four foot by four foot bottom sheet of plexiglass. This pipe volume is calculated as:

$$\text{Volume} = \text{Length} * (\pi * \text{diameter}^2)/4$$

$$V(ft^3) = (22\text{ in.} * (\pi * 6^2)/4) * (ft^3 / 1728\text{ in}^3)$$

$$V(ft^3) = .37\ ft^3$$

The remaining volume of the system is determined by the pore space in the rock area surrounding the pipe. Many rock types were considered and all varied in available storage capacity. It was noted that the least resistance was required for the maximum flow rate of the water through the system and into the fabric. Therefore, a smooth river washed rock was selected for its capability to dissipate water easier. This was tested using the procedure outlined in chapter IV which compared different suitable rocks for their dispersion capabilities. To determine the available storage in this rock, a volume was placed in a container and weighed dry. Water was then added to the top surface of the rock and the sample was again weighed. The difference in weight was the water content in the container. The void volume in the rock was determined to be 50% or the available volume in the rock volume was 50%. The total volume of rock could be determined by knowing the needed volume and multiplying it by two. The needed volume was 1.51 ft^3 - .37 ft^3 (from the pipe) = 1.14 ft^3 * 2 or 2.28 ft^3 of rock in the model systems. The next factor to be considered is the thickness of the rock surrounding the pipe. By trial and error the cross sectional area associated with the known volume and length can be determined around the six inch perforated pipe. For the model systems, the rock thickness was found to be six inches. This rock density would provide sufficient flow length for the stormwater to deposit some suspended solids and at the same time ensure a maximum velocity into the filter fabric to promote rapid infiltration into the parent soil material.

Water Quality

The final parameter to consider for the design of the systems is the quality of the stormwater. Stormwater runoff can vary greatly in the amount of sediment and other pollutants which it picks up and carries within it. These materials can affect the operation of the exfiltration system immediately and over time. It is believed that this is the largest contributing factor in the blockage of the systems. Field systems are sometimes built with a cleanout sump in the entrance of the exfiltration system which collects sediment as it settles from the stormwater. However, since the stormwater can enter the exfiltration systems at rapid rates there is reduced settling of solids within the sump.

For the model systems two separate solid loadings were considered. First, the partial removal of sediment was accomplished by a filter fabric and half of the systems were fed by this water. The remaining eight exfiltration tanks had raw stormwater in the inlet similar to field systems. These systems were compared and analyzed for improvements in exfiltration rate, velocities through the system and the overall quality before and after the exfiltration system.

Another factor considered with the solids loading is the total fabric area available for the stormwater or the wetted fabric area during an exfiltration process. Since it was recognized that a possible cause for exfiltration failure could be within the surrounding fabric, a comparison of the solid load per wetted surface area was made. It is proposed that a greater life expectancy is possible for larger fabric area per load or lower loading rate (mass/area). Also lower loading rates will result in higher velocity of water as it passes through the fabric.

CHAPTER V

CONSTRUCTION OF EXPERIMENTAL SYSTEMS

Design of the Model Systems

Before the actual testing of the exfiltration systems a carefully planned construction procedure was prepared. The first stage of the planning operation included the determination of the general layout of the model tanks. It was important that all tanks remain similar in their construction, access to all portions of the system be maintained, and the entire system fit in the designated lab area. The area to be used for the construction of the models was the Civil and Environmental Field Lab (CEEFL) on the campus of the University of Central Florida. Since the size of each trench was determined to be twenty two inches long and four feet in width it was decided to build two tanks end to end in one four by four foot box (see Figure 5.1). The remaining parameter for the dimension of the exfiltration box is the height.

To determine the height of the exfiltration box two factors were evident. First, since the size of the exfiltration pipe was designed to be six inches in diameter and a rock thickness of six inches was to be used, the top and bottom cover would determine the required height of the box. The bottom thickness was designed so that minimal

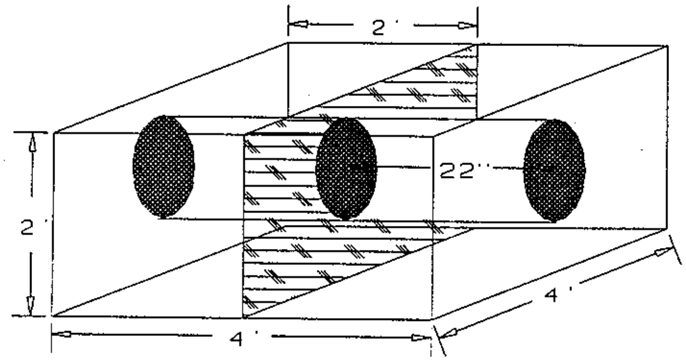


Figure 5.1. Exfiltration Box Dimensions.

influence from the bottom of the tank would be evident. The top thickness was only necessary if the system was installed in the field and influence from traffic loads was present. Therefore, the bottom thickness was set to five inches and the top thickness to one inch. This overall height was set to two feet in the model systems. The second parameter for determining the height of the systems included the inflow tank which would transport the stormwater from the retention pond to the exfiltration site. The truck was obtained from the City of Orlando and a 1000 gallon tank was welded on the back to hold the collected stormwater. The actual construction of the collection truck will be mentioned later. The height of the bottom of the truck tank as it sat level on the ground was forty inches. This height would be sufficient to gravity feed the exfiltration systems and include a distribution box for the desired arrangement. The purpose of the distribution box would be to input the stormwater from the stormwater truck into the required number of exfiltration tanks. Another purpose for the distribution box would be to filter the stormwater to one half of the systems to reduce the solids loading for one of the previously discussed comparisons. The final parameter controlled by the distribution box is the flow rate into the exfiltration tanks. This rate would be controlled by the adjustment of the height in the distribution box to vary the head and proportionately the flow rate of the stormwater. After the design of the systems was established the construction stage followed.

Construction of the Model Systems

For the construction of the model exfiltration systems, materials were chosen that could serve multiple purposes. The material for the tanks would have to be durable and transparent so that the exfiltration process could be easily viewed. Plexiglass seemed to serve this purpose and could easily be constructed and glued. The thickness was chosen to be three eights inch since this could be easily obtained and had the strength properties which were required. The joints of the boxes would be reinforced so that the combined weight of the soil and water would not cause a failure in the side wall of the tanks. Since the boxes would be free standing with a partition splitting the four by four box into two halves the walls on two sides would be two by two and the other two sides four by two dimensions. This four foot width was determined to be relatively unstable for the soil water forces so a reinforcing bar was inserted across the middle partition supporting the two four foot sides at their tops. The base of the tanks would support the entire load of the system and in the wet condition systems would include water and soil over long periods of time. It was then considered to use quarter inch plexiglass to support the required load. This base would need to have four drains in it which would serve both halves of the four by four box. Therefore, the box would be suspended on concrete blocks positioned under the bottom to distribute the load of the tanks and not interfere with the drain.

To simulate the under ground condition of the field exfiltration system it was important to keep the system out of the influence of sunlight and as anaerobic as possible. Sunlight could permit the growth of algae inside the systems if allowed to penetrate the plexiglass walls. This would not represent a field condition so a cover had to be designed to completely block the sunlight yet also permit removal when viewing of the system was necessary. This cover was constructed out of quarter inch plywood and consisted of a top and four sides which hung on hooks and eyes from the top panel. Each of the eight covers were constructed then sealed with a water sealer before painting to prevent rotting due to moisture. The insides of the covers were painted black so that light would not be reflected. The outsides were painted a light color so that light would be reflected away from the boxes, keeping the boxes at a uniform cooler temperature. Since the top cover was directly exposed to the inside of the exfiltration system it was decided to place a plastic liner on the underside of the top to further prevent rotting of the wood due to moisture. With the boxes constructed the next step was the placement and testing of the hydraulic features.

The Hydraulic Considerations

Perhaps the most challenging phase of the model construction was establishment of the hydraulic characteristics. These features included: 1) the design of the stormwater transport truck system, 2) the distribution boxes, 3) sizing of the lines to each box and valve arrangement and 4) the testing and calibration procedure.

The issue of stormwater transport stemmed from the need for stormwater with sediment for a true modeled field system. Previous models from various agencies used potable water from fire hydrants, or other nearby sources. The original method for transport was to obtain an evactor which is used to clean storm sewer systems. This unit would have to be towed behind a truck which would be able to carry the load of the evactor and the seven hundred and fifty gallons of water it carried at capacity. Since this plan seemed cumbersome a second plan was established that used a flat bed truck with the addition of a water tank which would serve as a complete unit. The truck was obtained from the City of Orlando which no longer used it as a spot repair vehicle for concrete applications. When the truck was obtained the condition was less than desirable so a decision was made to recondition so that it could be used for the extended life of the project. First, the existing cement mixer was removed from the truck and a one thousand gallon steel tank was welded on the bed of the truck. Special support was used to insure that the skid on the tank would support the water in the tank as the truck was moving and turning. Next the entire truck and tank were sandblasted to remove rust and concrete which had built up over the life of the truck. A rust prevention solution was then sprayed on the surface of the truck and tank to discourage any further rusting. Body work was then accomplished which repaired major damage to the body of the truck and filled in rusted areas. The entire truck was then stripped of all exterior and interior accessories, primed then painted with the original Ford white. The broken or missing accessories were replaced and all wiring for lights were repaired and checked. The next step on the truck was to clean the tank since it had previously been used for waste oil storage. This was accomplished by continuous rinsing with a acid mixture as well as a harsh detergent which removed enough of the oil from the tank so that it could not be detected in a sample of clean water from the tank. Any oil that could have been left however, would have simulated runoff from a road with the grease and oils from vehicles. The final step for the preparation of the tank was to connect the hydraulic system used for pumping water from the pond and a recirculation system for keeping the stormwater well mixed. The pump was selected to overcome approximately a twenty foot lift at 1500 GPM and to be of the diaphragm type which can pass solids. A CH&E model #5202 pump was selected since it matched the specifications and was lightweight enough for the existing support on the truck. A two inch PVC system was used for the truck since the discharge and suction of the pump were two inch. This system was design to operate with one pump which served two purposes. First, water could be drawn from a pond with a seventy-five foot flexible hose. Second, once the storm event was ready to be run through a valve arrangement the pump could be used to recirculate the water through the tank for optimum mixing and uniform distribution of solids. The pump would not, however, be used to force water into the exfiltration systems since the discharge of the truck was higher than the input to the distribution boxes which enabled the systems to be gravity fed.

The pipe system was selected based on two requirements. First, since the stormwater contained sediment it was necessary for the pipe to pass any solids which were present. At the end of the collection hose, which was used to extract stormwater from the detention pond, was a screen which would not allow any solid to pass larger than one half inch. Therefore, the pipe size selected for this requirement and including a safety factor was three fourths inch PVC. The second parameter in selection of the pipe was the velocity of the stormwater as it passed from the distribution box to the model tanks. It was important that the velocity be great enough so that settling of the solids did not occur. It was decided that three fourths inch PVC would also satisfy this condition.

The arrangement of the pipes, distribution boxes and model tanks is shown in the Figure 5.2. Each tank was

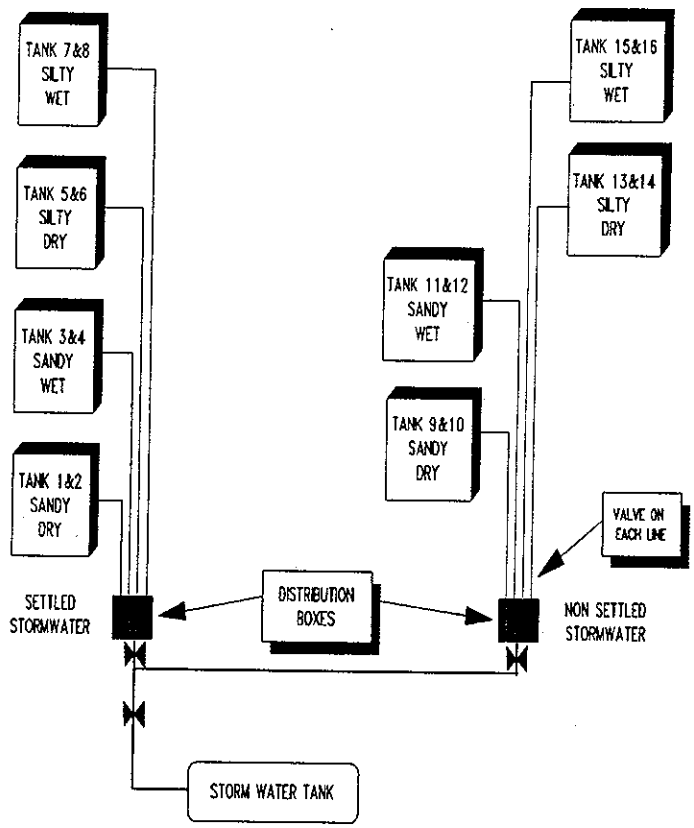


Figure 5.2. Exfiltration Model Arrangement.

separated into two halves which contained the same parent soil, water table elevation and sediment loading. The variable in each half was the fabric type either the 140N (odd numbered) or the 700XG (even numbered). The valve arrangement was determined to allow any one system to operate independently of the other. This included the drain valves on the bottom of the tanks and the input valves on the top of the tanks. Each tank which included two separate tanks was fed by one line then split into two separate lines within the tank. A valve was placed on the end of the settled half of the systems so that a sample of filtered stormwater could be withdrawn and tested for the reduction of solids. The distribution boxes were used to accurately control the rate of input into the model systems as well as to accommodate a filtering device for half of the tanks. To simulate the settling of the stormwater a filter was used which could effectively remove approximately twenty percent of the solids. Each box received input from the truck tank through a two inch PVC line. On this line was a flow meter which regulated input from the tank and a series of valves which enabled the operator to finely tune the input rate of the stormwater. Once in the distribution box the flow rate of the water could be monitored by the calibration marks on the sides. The maximum flow rate into the models was .85 GPM (4.5 in/hr over 18.1 square feet) and was designated as the highest possible level in the distribution box. Once the system was constructed a calibration procedure needed to be established before the actual exfiltration trenches were installed.

To insure the accuracy of the experiments a calibration of the hydraulic system was necessary. Since the exfiltration system was buried within the plexiglass tanks it would be difficult to correct a change in flow rate due to clogging of the PVC. Therefore, it was important that the flow rates be calibrated and tested with actual stormwater under all conditions before installation of the soil, pipe and rock. The first step was to run all sixteen tanks with a known input from a metered source until the valves on each line could be adjusted to achieve a constant height in the distribution box. Once this was achieved the source was shut down and the pipes allowed to drain. It was determined that if the pipes were allowed to dry, then restarted with a flush of water, that channelization to one side of the paired tanks would occur. This problem was caused by the trapping of air in the lines at the PVC tee which split the input into both tanks. After much analysis a solution was arrived upon by trial and error. To correct the channelizing in the tee a valve was placed on either side and partially shut to create a back pressure in the tee and force the air through one of the valves. To validate this occurrence, careful repetitious testing was performed to conclusively prove that the flow rate on both sides of the tank was constant and equal to the other tanks. When this process was complete actual stormwater was introduced into the systems numerous times to check if the sediment in the water had any effect on the flow rates. After many trials, including long pauses between, enabling the pipes to completely dry, it was decided that the hydraulic system was dependable and the exfiltration systems could be constructed.

Construction of the Exfiltration Systems

The last phase of construction before the storm events could be run was the building of the exfiltration trenches. The process included the installation of the bottom drain, soil, filter fabric, rock and perforated aluminum pipe. The bottom drain was installed to ensure that the two drains in the bottom of the tank would not limit the capability of the

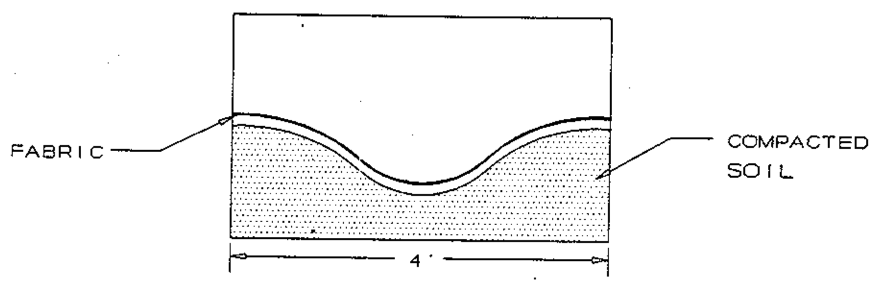


Figure 5.3. Fabric Installation.

soil to discharge water. The design developed included a two inch layer of river washed rock on the bottom of the tank with a layer of the Marafi 700XG fabric over the top of the rock. This fabric was taped to the sides of the tank so that water would not be allowed to channelize along the side and therefore carry soil into the drains. Next the soil was placed on the fabric and shaped in a concave fashion so that the fabric could be properly positioned in place (see Figure 5.3). The fabric was cut so that it would completely surround the rock and pipe and allow for overlap on the top of the system. The fabric was laid in the tank and it too was taped to the side so that water would be forced to exit through it and not along the sides of the tank. As the system was built upward a rotation from taping the fabric, placement of the rock aggregate, and parent soil addition was utilized to insure correct dimensions. As the soil was added attention was made to the degree of compaction so that it resembled as close as possible its native state. When the rock was installed to the height of six inches the aluminum pipe was inserted and glued to the sides of the tank with adhesive caulk so that the water would be forced to exit through the holes in the pipe. The input PVC pipe was inserted into the aluminum pipe through a pre made hole in the top. The glue was allowed to dry overnight and the final rock and soil was added. The fabric was wrapped over the top of the rock and taped in place so that no distortion in the shape of the system would occur as it was operated. It was believed that settling would occur in the soil and rock but that extra soil from the top of the system would replace any voids caused by this process. After all the systems were installed with the various soil types and fabric types the covers were put in place and the experimental procedure was ready to take place.

CHAPTER VI

METHODS AND MATERIALS

Preliminary Investigations

Selection of Rock Type

Before design and construction of the exfiltration models, initial experimentation was conducted to determine the optimum materials to best simulate the field condition. The first experiment was the selection of the rock type which involved three different samples. The samples included: 1) lime rock, 2) slag rock, and 3) river washed rock. Lime rock has been the most utilized type of aggregate for all exfiltration and infiltration practices. This is because of its availability in Florida and thus its low cost. South Florida has a abundant supply of lime rock which lies near the ground surface. This rock appears grey and white with a chalky texture. The shape is angular with many flat sides. Slag rock is formed by the rapid cooling of molten rock as it contacts water. This rock is porous and lightweight. It is not as popular as limestone and is used more often in the Northern part of Florida. The shape is also angular but its sides are rounded. The texture of the slag rock is very rough with many pores running throughout. The third rock tested was river washed rock which is becoming the popular choice for most exfiltration systems. This rock is the most costly of the three and is obtained North of Florida in areas of fast moving streams. It is characterized by being very rounded and smooth in texture.

An experiment was designed to test the three types of rocks for their ability to disperse water. The experimental apparatus consists of a two foot wide by two foot long by two foot high plexiglass box with wire mesh attached to the bottom. The rock was placed in the box to a height of twelve inches supported by the wire mesh (see Figure 6.1).

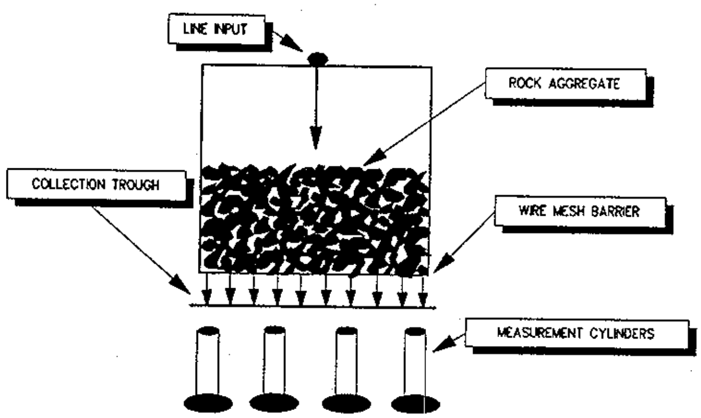


Figure 6.1. Rock Test Apparatus

The box was then set on two saw horses with a drain pan placed beneath. The collection pan under the rock consisted of a series of troughs two and one half inches apart. These troughs were used to determine the amount of water dispersed by the rock knowing the distance from the input. The water was fed into the rock by a PVC pipe which ran through the center of the box. This pipe was perforated in a single row which simulated a line source input. The collection troughs were arranged parallel to the line input. Each rock was placed in the tank and varying flow rates were used for observation. Data collected from this experiment is presented in Appendix B. The channel # in the tables relates to the position of the troughs. Channel #4 is the center trough and #3 and #5 are adjacent to #4 going away from the center. It is evident that the further the channel is away from the center the flow rate decreases. The results of the test showed the river rock to be the better overall for dispersing water. This is noted by the higher flow rates in the furthest channels from the center. Since the rock is used to direct the water to the filter fabric it was concluded that the larger the dispersion in a given distance the larger the exfiltrated area through the fabric. This is important when considering that the solids load in the stormwater would be distributed over a larger area with more dispersion present thus less load per area of fabric.

Fabric for Drain Experiment

The drain in the bottom of the exfiltration system incorporated a filter fabric to prohibit the passing of soil to the two drain holes. This fabric had to be selected to enable free passage of the water from the soil while prohibiting the soil to pass. An experiment was set up to test various fabrics for use in the drains of the exfiltration systems. By this time the exfiltration tanks had been constructed so they could be used as test tanks for the fabric experiment. Three different fabrics were tested for permeability of water and soil: 1) Marafi 700XG, 2) Marafi 140N and, 3) Drain field fabric. Two separate tests were performed on each fabric. The first test determined if sediment in stormwater would prohibit passage of water after continued application. Stormwater was applied to the fabric as it lay in the bottom of the tank over a one inch layer of rock. A flow rate of .75 GPM was maintained until clogging or a collection of sediment prevented passage into the rock. After four hundred gallons of stormwater with an average of two hundred mg/l of solids loading was passed through the 22 inch x 48 inch fabric areas, all were still operating efficiently. The drain field fabric had collected the most solids, then the Marafi 140N. The Marafi 700XG had very little collection of solids.

The second test consisted of adding both soil types to each fabric type and introducing clean water to see if the soil type affected the infiltration through the fabric. The pre-assembled tanks were used for the test. Two tanks were used for each fabric with the silty soil added to the fabric in one tank and sandy soil added to the fabric in another tank. Clean water was introduced to these tanks at a rate of .75 GPM similar to the first fabric experiment. The results of this test determined that the soil alone was not the cause of failure since all tanks were operating efficiently. Both soils contained a small amount of organics which collected in layers. This process continued but the water tended to find an alternate path and continue to drain.

After these tests, a final test was performed to view the effect of stormwater on the soil surface. The second fabric experiment was repeated but instead of clean water, stormwater was introduced. Again a flow rate of .75 GPM was maintained and allowed to run on top of the soil into each fabric tested and through the drains. Under these conditions all tanks failed and began to retain water with very little infiltration into the soil. The water source was closed and all tanks were allowed to drain down for inspection for the cause of failure. A thin glossy substance remained on the surface of the soil. Samples of this substance were analyzed and determined to be a very fine soil introduced from the stormwater. Apparently the fine particles being very cohesive attached to the larger soil grains on the surface. From this collection other fine particles could attach on the surface and eventually form a near impermeable layer on the top of each type of soil. It was noted that the silty soils seemed to collect the finer particles slightly faster than the sandy soils.

The fabric chosen for the drain was the Marafi 700XG due to its high porosity and flow rate. This choice was based on the first experiment which introduced stormwater only and by recognizing the ability for the fabric to retain the soil without allowing it to pass into the drainage holes in the bottom of the tank.

Suspended Solids Test

To obtain the amount of loading in the stormwater the suspended solids test was used. This test was performed on each stormwater load obtained from the retention pond. The procedure was performed according to A.S.T.M. standards in a laboratory at the University of Central Florida campus. Two samples were taken for each stormwater tank one at the entrance of the non-settled tanks and one at the entrance of the settled tanks. From each sample two trials were run and the average used for the test. The suspended solids test consists of running the stormwater through a filter and measuring the amount of solids collected on the filter. The procedure for the suspended solids test was as follows:

1. Set up experimental apparatus consisting of :
    a. 1000 ml glass flask with connection for vacuum hose
    b. filter holder which fits on top of glass flask
    c. vacuum pump
    d. aluminum pans for drying filters
    e. drying oven set at 103° C
2. Clean filter by running 200ml of distilled water through it with the experimental apparatus.

3. Place filter on aluminum pan and place in oven for one hour.
4. Cool filter in moisture free desiccator.
5. When cool weigh filter and pan to the nearest .0001 gram.
6. Remove filter from pan and place in filter holder.
7. Measure sample in volumetric flask.
8. Turn on pump and pour sample over filter.
9. Rinse flask and sides of filter holder with distilled water and pour through filter.
10. Remove filter and solid sample from holder and place on aluminum pan.
11. Place pan in over and dry one hour at 103° C.
12. Remove from oven and place sample and pan into desiccator for one hour.
13. Remove pan and sample from oven and weigh to the nearest .0001.
14. Record initial weight, volume of sample used and, final weight.

The amount of solids contained in the sample is determined by dividing the difference of the initial and final weights by the volume of sample used. This value will be the load in mg/l of the sample.

Selection of Two Soil Types

To effectively model the field exfiltration systems soil characteristics were documented. In the Florida region two main types of soils are encountered. These types include the silty non-granular and the sandy-granular soils. These soils were to be located, excavated, then classified with the use of a sieve analysis. The soils were located on the campus of the University of Central Florida since soils were constantly being disturbed or imported and could be easily transported to the test site. The sandy soil selected had a tan appearance and was considered to be granular. A sieve analysis was performed and the result is tabulated in Table 6-1.

TABLE 6.1.

SANDY SOIL TYPE

SIEVE NUMBER	SIEVE OPENING (MM)	PERCENT FINER THAN STATED SIEVE
10	2.00	99.95
20	.841	99.65
40	.420	96.10
60	.250	69.19
100	.150	7.71
200	.074	1.41

TABLE 6.2.

SILTY SOIL TYPE

SIEVE NUMBER	SIEVE OPENING (MM)	PERCENT FINER THAN STATED SIEVE
10	2.00	99.39
20	.841	98.84
40	.420	94.38
60	.250	76.34
100	.150	16.50
200	.074	6.00

The silty soil was also obtained from the campus and had a dark appearance. This soil was cohesive and contained organic material. The sieve analysis result is tabulated in Table 6.2. The two soils obtained for the exfiltration experimentation differed in the amount of fine material within the sample. Since one of the believed causes for failure of the exfiltration system was the collection of fine material in the fabric these two soils were classified as sandy (low degree of fine material) or silty (high degree of fine material).

Soil Permeability Test

To establish a possible cause for the decrease in exfiltration rates a soil permeability test was performed. The results from this test could be compared to the actual exfiltration rates. If the soil rate was lower or equal to the exfiltration rate then a conclusion could be drawn that the parent material might be causing a failure. However, if the soil permeability rate was higher than the actual exfiltration rate then a component of the system could be the cause of the reduced rate. An in-situ soil permeabilty test was performed within the constructed tanks. The apparatus used for the test is shown in Figure 6.2. A six inch alluminum pipe two feet in length was used to bore a hole in four of the exfiltration tanks. This pipe was then covered with one layer of 700XG fabric and a impermeable plate installed in the bottom. This plate would prevent direct vertical exfiltration from the test apparatus. The pipe was

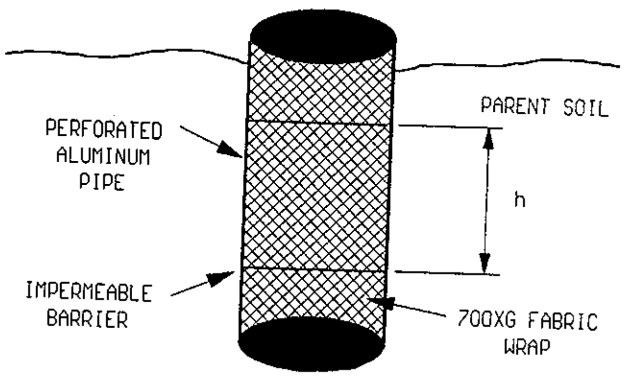


Figure 6.2. Permeability Test Apparatus.

then placed in the bore hole and clean water filled to a level "h". This level was maintained until a constant flow rate into the pipe was obtained. The volume, time of fill, and constant height were recorded for each system and presented in Table 6.3.

TABLE 6.3

PERMEABILITY TEST

Soil Type	TANK #	VOLUME (ml)	TIME (sec)	HEIGHT (in)	I (in/hr)
Sand/6%Silt	5	500	30	6.25	31.07
"	6	500	40	8.75	16.64 ?
Sand	10	500	19	6.50	47.16
Sand/6%Silt	14	500	40	7.12	20.44

The exfiltration rate from the pipe or the infiltration rate of the parent soil was obtained from the following equation:

$$I = V/T \times 1l/1000ml \times 61.02\ in^3/1l \times 1/(\pi \times D \times h) \times 3600s/hr$$

where:

I = Exfiltration rate (in/hr)

V = Volume of water into the pipe (ml)

T = Time to input water into pipe (sec)

D = Diameter of pipe (in)

h = Height of water in pipe from impervious surface (in)

The actual rate related to the amount of water which exfiltrated through the area of the pipe at a height h. The sandy soil in tank ten showed a higher rate than the silty type soils in the other three tanks.

Exfiltration Experimentation

Data Collection Method

To collect data for the exfiltration systems an organized method for controlling inputs and outputs was established. To understand the system configuration and the variables involved a path will be taken from the stormwater collection tank to the exit drains in the exfiltration systems. The input from the collection tank is varied with a gate valve to the pair of control boxes. Each control box is calibrated so that the input flow rate to each side can be carefully monitored. To flush the pvc lines to each system a valve was placed directly after the control boxes. This valve would serve to stage the level of water in the boxes to the maximum height. At this time the valves would be opened and the water would be released to the exfiltration tanks. This methodology was used to insure no air pockets remained in the lines which could cause a false flow rate. The stormwater enters the exfiltration pipe through a hole in the top. A cap with two calibrated holes in the end of the pvc input pipe serve to regulate the flow into the system and to direct the flow throughout the perforated aluminum pipe. A valve before the end of the pipe will serve to pre-regulate the back pressure to insure a full pipe condition at all flow rates. The water is dispersed in the aluminum pipe and allowed to exfiltrate into the rock, through the fabric and into the parent soil material. At this point the driving force of the water is gravity and a suction potential in the media. The water passes through the bottom fabric and out through the drains on the bottom of the exfiltration tanks. A portion of this water is collected and an analysis is performed to determine the degree of pollutants removed from the stormwater.

To measure the actual exfiltration rate a change in stormwater height versus time relationship is used in the

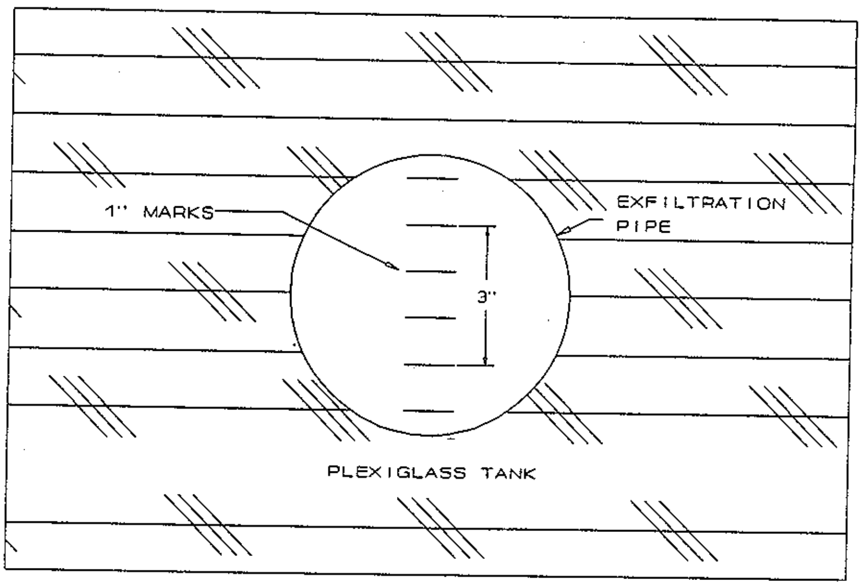


Figure 6.3. Measurement Marks.

perforated aluminum pipe. Calibrated marks were placed on the side of the plexiglass tank indicating one inch differences in the exfiltration pipe. From these marks a change in the level of stormwater in the pipe could be viewed and the time between elevations recorded. It was noted that the exfiltration rate obtained from these readings had to be related to the average drop in the pipe and translated to the actual exfiltration rate through the fabric area. To insure that the average value for the drop in the pipe was accurate several experiments were used for comparison. First, timed increments were taken for a change in height of the stormwater of one inch for the entire diameter of six inches of the pipe. Second, various height vs. time trials were performed. A three inch drop in the center of the pipe was chosen as a close average of all six measures. Both of the tests proved the three inch drop was a close average of the actual exfiltration rate. A relationship was established to relate the drop in the pipe to an actual exfiltration rate. An exfiltration rate was defined as the flow of the stormwater through the wetted fabric area. The drop in the pipe of three inches exfiltrated through half the fabric area. Therefore, the area of fabric relating to a three inch drop in the pipe is:

$$\text{Area} = (\pi \times 1.5 \text{ ft.} \times 22 \text{ in.} \times 1 \text{ ft.} / 12 \text{ in.}) / 2 = 4.3 \text{ ft.}^2$$

The volume of stormwater exfiltrated through a 3 in. drop in the pipe:

Volume = (.5 ft. x .25 ft. x 22/12) + ((1.5 ft x .25 ft. x 22/12) - (.5 ft x .25 ft x 22/12)) /2)

Volume = .46 $ft.^3$

Therefore, for a 3 in. drop in the pipe an equivalent drop through the fabric is:

Drop = .46 $ft.^3$ / 4.3 $ft.^2$ x 12 in. / ft. = 1.28 in.

The procedure for measuring the exfiltration rate considered input flow rates as well as the actual drop in the aluminum pipe. A valve at the stormwater tank was opened and the two inch input line allowed to fill. At this time a gate valve was opened and the two control boxes were allowed to fill before opening the individual valves to the exfiltration tanks. The initial reading of the flow meter was recorded to determine the total amount of stormwater input to the system. The valves were then opened and the systems began to accept stormwater. A stopwatch was then started to monitor the flow rate into the models which would simulate the falling limb of the runoff hydrograph. The initial rate was .85 GPM and fell to zero at the end of the event. After the event each tank was timed for the drop of three inches in the perforated pipe and recorded. This data was collected and organized on a spreadsheet format so that comparisons could be noted.

CHAPTER VII

RESULTS AND DISCUSSION

The results from the exfiltration events were collected and presented as raw data and as a moving average. Periodic data were collected throughout the length of the experimentation. Each event was operated to simulate the falling limb of the runoff hydrograph by controlling a series of valves and meters within the system. As data points were collected by two operators, recordings of exfiltration rates were calculated for each system. The raw data for the exfiltration rates was entered into a spread sheet format so it could be evaluated as average data. The raw data as presented in Tables 7.1 - 7.4 includes the event number, event volume, and the cumulative volume in inches. For each event, sixteen exfiltration rates were obtained and presented in the tables.

Average data was used to correlate the raw data into comparable format for each variable. This average was obtained from averaging the raw data points as the events progressed. This average was calculated by adding the current rate to the previous rates and dividing by the total number of events. This value then became the current value.

$$\text{Average} = (Q_i + Q_{i+1} + 000 + Q_n) / N_n$$

Q_i = exfiltration rate of event i

Q_{i+1} = exfiltration rate of event i+1

N = number of events

From the moving average an exfiltration rate could be analyzed and compared easily with other moving average data. The moving average data obtained from the raw data are presented in Tables 7.5 and 7.6. Only the events that were actually recorded are shown in these tables.

After calculating the moving averages, data comparisons were made for the various parameters selected. This included sediment removal vs. non removal, sandy vs. silty soils, woven 700XG vs. non-woven 140N fabric, and dry vs. wet condition water tables. For each comparison, three of the variables were held constant so that only one variable was compared. For each comparison eight different graphs were obtained comparing two tanks at a time. As seen in Figure 7.1 the settled condition out-performed the non-settled condition. The system which had sediment removed from the stormwater operated more efficiently than the system which contained raw stormwater. The sediment removal efficiency of the filter system which simulated the settling process was approximately twenty percent according to the actual load and the distribution of the fine sediment. In the second comparison the silty soil was compared to the sandy soil for effectiveness to improve exfiltration rates. Two examples of this comparison are shown in Figures 7.2 and 7.3. In each of these figures an important feature is noted. When the 140N

TABLE 7.1.
EXFILTRATION EVENTS - RAW DATA (in/hr)

EVENT #	1	2	3	4	5	6	7	8	9	10A
VOLUME (IN.)	3.85	0.86	1.03	6.42	9.84	1.54	3.00	0.68	1.97	9.93
CUMM. VOL. (IN.)	3.85	4.71	5.74	12.16	22.00	23.54	26.54	27.22	29.19	39.12
TANK #										
1	-	-	-	22.91	-	-	11.48	-	-	7.11
2	-	-	-	7.30	-	-	1.11	-	-	0.60
3	-	-	-	51.20	-	-	37.46	-	-	24.32
4	-	-	-	4.52	-	-	3.52	-	-	0.86
5	-	-	-	26.03	-	-	8.49	-	-	11.82
6	-	-	-	34.35	-	-	42.71	-	-	38.27
7	-	-	-	34.90	-	-	18.73	-	-	18.26
8	-	-	-	32.69	-	-	4.73	-	-	7.81
9	-	-	-	23.26	-	-	3.49	-	-	1.39
10	-	-	-	2.94	-	-	0.88	-	-	0.68
11	-	-	-	23.64	-	-	21.60	-	-	17.45
12	-	-	-	10.37	-	-	2.89	-	-	2.73
13	-	-	-	15.23	-	-	11.91	-	-	4.23
14	-	-	-	26.00	-	-	19.20	-	-	38.10
15	-	-	-	59.10	-	-	19.69	-	-	17.67
16	-	-	-	40.41	-	-	27.93	-	-	28.98

TABLE 7.2.
EXFILTRATION EVENTS - RAW DATA (in/hr)

EVENT #	10B	11	12	13A	13B	14	15	16	17	18
VOLUME (IN.)	4.19	1.54	5.31	5.82	4.02	1.03	0.86	0.43	1.71	1.63
CUMM. VOL. (IN.)	43.31	44.85	50.16	55.98	60.01	61.03	61.89	62.32	64.03	65.66
TANK #										
1	8.59	-	12.29	4.21	8.88	-	-	-	9.86	-
2	0.76	-	1.08	0.96	2.95	-	-	-	7.13	-
3	28.98	-	29.49	14.87	22.23	-	-	-	24.22	-
4	0.70	-	0.61	0.94	1.15	-	-	-	12.37	-
5	9.73	-	14.17	17.28	32.20	-	-	-	29.44	-
6	48.61	-	47.85	45.53	42.64	-	-	-	45.91	-
7	16.29	-	15.62	16.56	15.85	-	-	-	14.76	-
8	14.44	-	14.59	16.17	18.91	-	-	-	20.69	-
9	1.17	-	1.30	1.13	6.66	-	-	-	3.51	-
10	0.70	-	0.57	0.58	0.70	-	-	-	0.70	-
11	16.73	-	15.96	16.15	14.69	-	-	-	15.57	-
12	2.51	-	1.78	1.05	1.71	-	-	-	3.14	-
13	3.75	-	1.81	1.26	13.22	-	-	-	25.18	-
14	40.14	-	39.85	34.01	42.80	-	-	-	40.41	-
15	23.02	-	19.63	17.61	18.86	-	-	-	22.20	-
16	31.43	-	30.55	25.08	30.81	-	-	-	31.79	-

TABLE 7.3.
EXFILTRATION EVENTS - RAW DATA (in/hr)

EVENT #	19	20	21	22	23	24	25	26	27	28
VOLUME (IN.)	0.51	1.80	3.60	0.86	0.86	1.28	3.94	3.51	0.86	0.51
CUMM. VOL. (IN.)	66.17	67.97	71.56	72.42	73.27	74.56	78.50	82.00	82.86	83.37
TANK #										
1	-	2.48	5.80	-	-	-	0.84	-	-	-
2	-	10.90	20.75	-	-	-	3.64	-	-	-
3	-	24.15	24.96	-	-	-	15.04	-	-	-
4	-	5.55	11.18	-	-	-	1.75	-	-	-
5	-	28.08	25.90	-	-	-	20.07	-	-	-
6	-	45.02	48.20	-	-	-	43.68	-	-	-
7	-	18.91	17.35	-	-	-	10.32	-	-	-
8	-	18.70	18.75	-	-	-	14.77	-	-	-
9	-	2.68	2.67	-	-	-	1.90	-	-	-
10	-	0.58	0.61	-	-	-	0.39	-	-	-
11	-	9.10	7.89	-	-	-	1.67	-	-	-
12	-	1.52	3.19	-	-	-	1.05	-	-	-
13	-	15.92	22.60	-	-	-	14.09	-	-	-
14	-	38.74	34.82	-	-	-	25.73	-	-	-
15	-	19.99	17.98	-	-	-	12.45	-	-	-
16	-	32.18	31.37	-	-	-	24.24	-	-	-

TABLE 7.4.
EXFILTRATION EVENTS - RAW DATA (in/hr)

EVENT #	29	30	31	32A	32B	33	34	35	36A	36B
VOLUME (IN.)	0.26	0.60	0.60	4.28	4.28	1.63	0.51	0.17	5.02	4.72
CUMM. VOL. (IN.)	83.63	84.23	84.83	89.11	93.39	95.02	95.53	95.70	100.72	105.43
TANK #										
1	0.80	-	-	0.64	-	4.01	-	-	0.42	0.52
2	11.17	-	-	3.99	-	13.88	-	-	6.08	7.81
3	7.78	-	-	2.27	-	6.93	-	-	1.70	3.03
4	5.66	-	-	1.71	-	14.84	-	-	5.53	9.69
5	18.04	-	-	14.49	-	20.78	-	-	12.28	13.80
6	42.05	-	-	44.04	-	48.71	-	-	49.13	46.08
7	8.88	-	-	5.04	-	10.59	-	-	5.10	8.61
8	17.06	-	-	17.07	-	15.57	-	-	13.35	12.18
9	2.91	-	-	1.27	-	6.40	-	-	1.23	1.83
10	0.35	-	-	0.40	-	0.37	-	-	0.19	0.21
11	3.33	-	-	2.37	-	1.89	-	-	0.91	1.28
12	0.86	-	-	1.53	-	1.15	-	-	0.84	1.07
13	3.22	-	-	2.65	-	4.27	-	-	1.27	1.83
14	16.52	-	-	25.48	-	31.32	-	-	21.48	22.91
15	7.62	-	-	3.06	-	13.77	-	-	3.78	6.90
16	19.64	-	-	22.20	-	24.35	-	-	17.62	18.09

TABLE 7.5.
EXFILTRATION EVENTS - AVG. DATA (in/hr)

EVENT #	4	7	10a	10b	12	13a	13b	17
CUMM VOL. (IN.)	12.16	26.54	39.12	43.31	50.16	55.98	60.01	64.03
TANK#								
1	22.91	17.20	13.83	12.52	12.48	11.10	10.78	10.66
2	7.30	4.21	3.00	2.44	2.17	1.97	2.11	2.74
3	51.20	44.33	37.66	35.49	34.29	31.06	29.79	29.10
4	4.52	4.02	2.97	2.40	2.04	1.86	1.76	3.08
5	26.03	17.26	15.45	14.02	14.05	14.59	17.10	18.65
6	34.35	38.53	38.44	40.99	42.36	42.89	42.85	43.23
7	34.90	26.82	23.97	22.05	20.76	20.06	19.46	18.87
8	32.69	18.71	15.07	14.91	14.85	15.07	15.62	16.25
9	23.26	13.37	9.38	7.33	6.12	5.29	5.49	5.24
10	2.94	1.91	1.50	1.30	1.15	1.06	1.01	0.97
11	23.64	22.62	20.90	19.85	19.08	18.59	18.03	17.72
12	10.37	6.63	5.33	4.62	4.06	3.55	3.29	3.27
13	15.23	13.57	10.46	8.78	7.39	6.37	7.35	9.57
14	26.00	22.60	27.77	30.86	32.66	32.89	34.30	35.07
15	59.10	39.40	32.15	29.87	27.82	26.12	25.08	24.72
16	40.41	34.17	32.44	32.19	31.86	30.73	30.74	30.87

TABLE 7.6.
EXFILTRATION EVENTS - AVG. DATA (in/hr)

EVENT #	20	21	29	32A	33	36A	36B
CUMM VOL. (IN.)	67.97	71.56	83.63	89.11	95.02	100.72	105.43
TANK#							
1	9.75	9.36	7.94	7.38	7.13	6.69	6.30
2	3.64	5.35	5.70	5.56	6.16	6.15	6.26
3	28.55	28.19	25.39	23.61	22.42	21.04	19.92
4	3.36	4.14	4.07	3.89	4.67	4.72	5.03
5	19.69	20.31	20.10	19.67	19.75	19.25	18.91
6	43.43	43.91	43.73	43.76	44.11	44.45	44.55
7	18.88	18.72	17.20	16.27	15.86	15.14	14.74
8	16.53	16.75	16.61	16.64	16.57	16.35	16.09
9	4.95	4.72	4.34	4.10	4.27	4.06	3.92
10	0.93	0.89	0.81	0.78	0.75	0.71	0.68
11	16.77	15.88	13.65	12.78	12.00	11.26	10.64
12	3.08	3.09	2.73	2.64	2.53	2.42	2.34
13	10.28	11.51	11.04	10.39	9.95	9.37	8.90
14	35.47	35.41	33.03	32.45	32.37	31.64	31.10
15	24.19	23.57	21.32	19.91	19.47	18.43	17.71
16	31.02	31.05	29.53	28.97	28.64	27.91	27.29

fabric was utilized in the sandy soil the exfiltration rate was higher than the 700XG in the sandy soil. Also when the 700XG fabric was placed in the silty soil the exfiltration rate was higher than the 140N placed in the silty soil. This relationship was again verified when comparing the fabrics and keeping the remaining three variables constant. As seen in Figure 7.4 when the 140N was placed in the sandy soil the exfiltration rate was higher than the 700XG in the same soil. Also as shown in Figure 7.5 the 700XG placed in the silty soil enabled better exfiltration rates than the 140N in the same type soil.

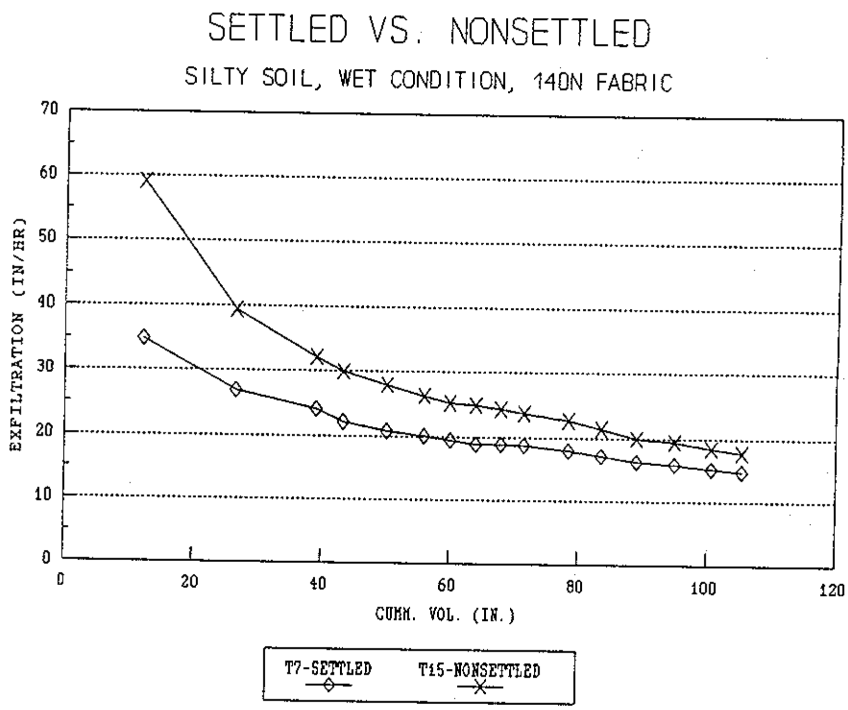


Figure 7.1. Settled vs. Nonsettled Comparison.

The final comparison considered the system built within the water table vs. the system built above the water table. Each

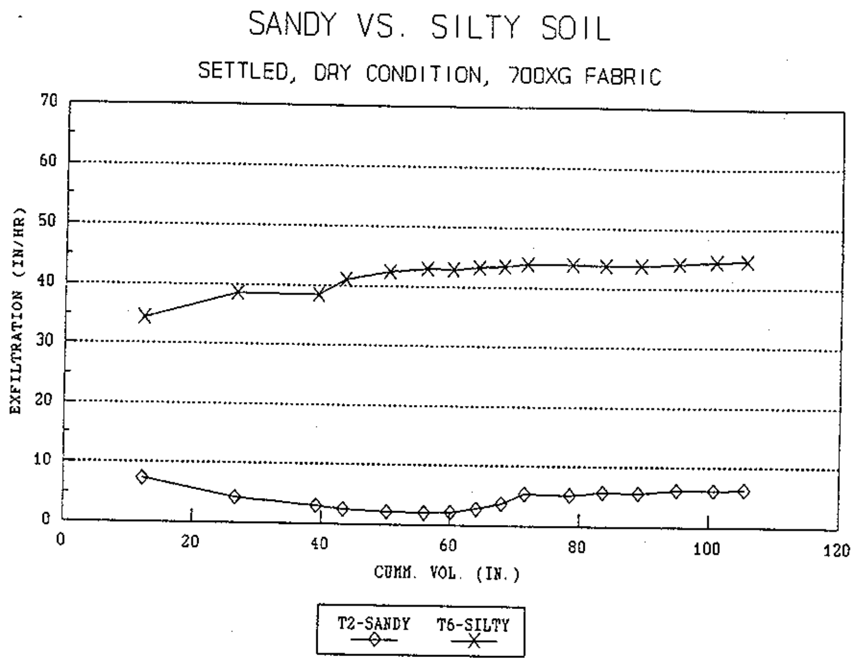


Figure 7.2. Sandy vs. Silty Soil Comparison.

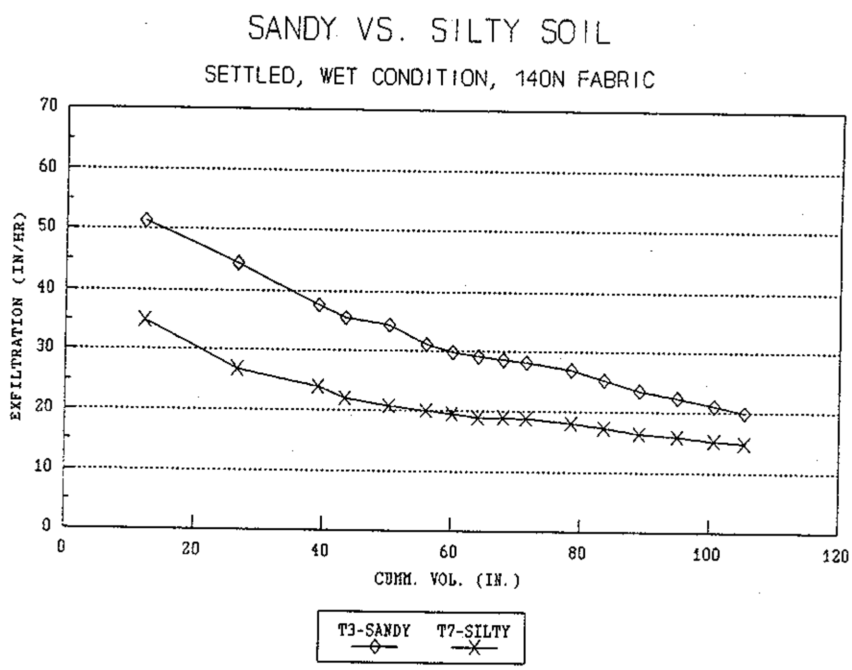


Figure 7.3. Sandy vs. Silty Soil Comparison.

system in the water table was kept wet to a level within the perforated pipe. Exfiltration rates were measured from the top of the pipe to the stable water table elevation and recorded. An example of the dry vs. the wet system is shown in Figure 7.6. The comparison of each variable in the average data and raw data is presented in graphic form in Appendix C.

To effectively analyze the total amount of solids introduced to the system, samples from each tank of stormwater obtained from the retention pond were collected and a

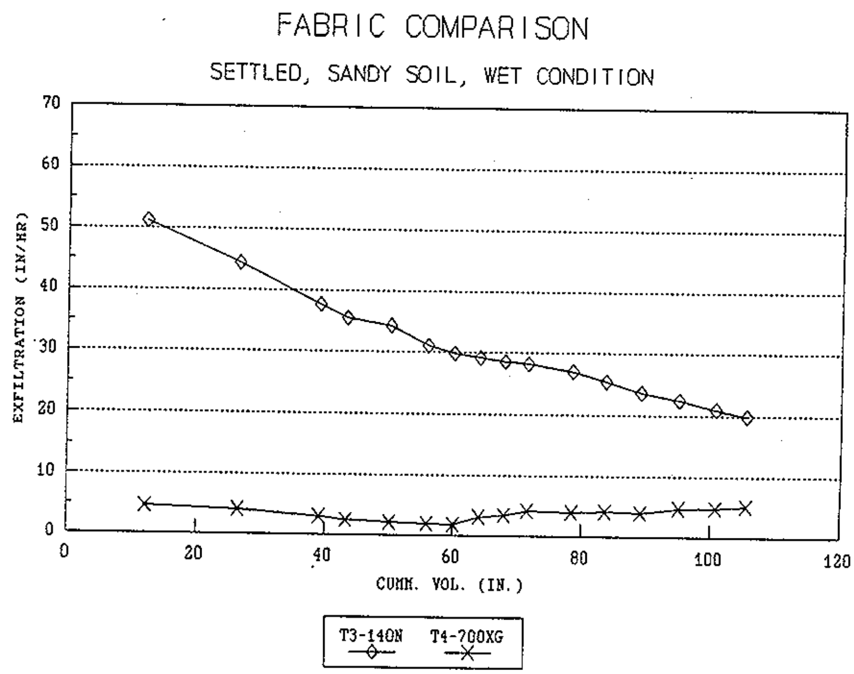


Figure 7.4. Fabric Comparison.

suspended solids test was performed. The results of the suspended solids tests measured as a concentration (mg/l) and a loading rate (grams) are presented in Table 7.7 and 7.8. Table 7.7 presents the loading the settled systems which have had a reduction in the amount of solids. Table 7.8 presents

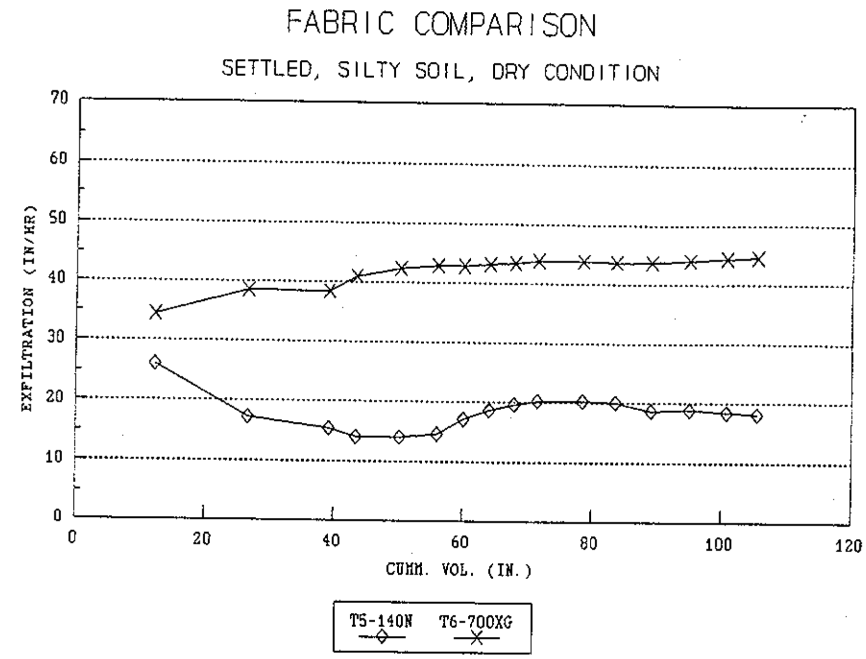


Figure 7.5. Fabric Comparison.

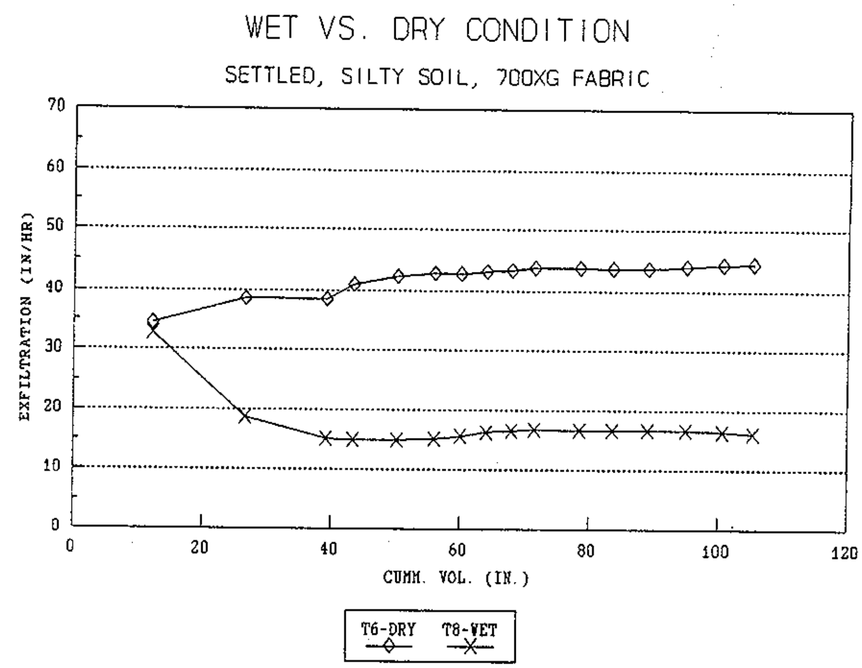


Figure 7.6. Wet vs. Dry Water Table Comparison.

data for the systems which were operated with raw stormwater. It is noted that the average concentration for the settled systems was 84.97 mg/l and the average value for the non-settled systems is 101.63 mg/l. This reduction in the solids of twenty percent showed an improvement in the operation of the exfiltration systems.

TABLE 7.7.
EXFILTRATION EVENTS - SETTLED SYSTEMS

EVENT #	VOLUME (IN)	CUMM. VOL. (IN.)	VOLUME (GAL)	VOLUME (LITERS)	CONC. (MG/L)	LOAD (GRAMS)	CUMM.LOAD (GRAMS)
1	3.85	3.85	43.48	164.59	132.00	21.73	21.73
2	0.86	4.71	9.66	36.57	970.00	35.47	57.20
3	1.03	5.74	11.59	43.87	313.00	13.73	70.93
4-A	2.57	8.30	28.96	109.63	319.00	34.97	105.90
4-B	3.86	12.16	43.50	164.67	25.00	4.12	110.02
5-A	3.18	15.34	35.87	135.78	289.00	39.24	149.26
5-B	2.24	17.58	25.28	95.68	25.00	2.39	151.65
5-C	4.43	22.01	49.98	189.20	20.00	3.78	155.43
6	1.54	23.55	17.39	65.83	63.00	4.15	159.58
7	3.00	26.55	33.82	128.02	85.00	10.88	170.46
8	0.69	27.23	7.73	29.26	61.00	1.78	172.25
9	1.97	29.20	22.22	84.11	61.00	5.13	177.38
10-A	3.09	32.29	34.85	131.92	17.50	2.31	179.69
10-B	3.93	36.22	44.34	167.85	2.50	0.42	180.11
10-C	4.23	40.45	47.68	180.49	23.00	4.15	184.26
10-D	2.88	43.33	32.52	123.10	60.50	7.45	191.71
11	1.54	44.87	17.39	65.83	17.50	1.15	192.86
12-A	0.75	45.62	8.50	32.18	60.50	1.95	194.80
12-B	2.50	48.12	28.17	106.64	12.00	1.28	196.08
12-C	2.05	50.17	23.13	87.56	23.00	2.01	198.10
13-A	1.04	51.21	11.69	44.25	23.00	1.02	199.12
13-B	5.33	56.54	60.12	227.58	10.80	2.46	201.57
13-C	2.18	58.72	24.59	93.08	0.50	0.05	201.62
13-D	1.30	60.02	14.66	55.49	16.80	0.93	202.55
14	1.03	61.04	11.59	43.87	16.80	0.74	203.29
15	0.86	61.90	9.66	36.57	5.75	0.21	203.50
16	0.43	62.33	4.83	18.28	5.75	0.11	203.60
17	1.71	64.04	19.32	73.13	5.75	0.42	204.03
18	1.63	65.67	18.36	69.50	5.75	0.40	204.43
19	0.51	66.18	5.80	21.96	5.75	0.13	204.55
20	1.80	67.98	20.29	76.81	14.50	1.11	205.66
21-A	0.96	68.94	10.84	41.03	14.50	0.59	206.26
21-B	2.64	71.58	29.74	112.58	22.00	2.48	208.74
22	0.86	72.43	9.66	36.57	22.00	0.80	209.54
23	0.86	73.29	9.66	36.57	22.00	0.80	210.35
24-A	0.25	73.54	2.81	10.64	22.00	0.23	210.58
24-B	1.04	74.57	11.68	44.21	0.50	0.02	210.60
25-A	3.30	77.87	37.21	140.86	0.50	0.07	210.67
25-B	0.64	78.51	7.22	27.33	657.00	17.96	228.63
26	3.51	82.02	39.61	149.94	19.00	2.85	231.48
27	0.86	82.88	9.66	36.57	19.00	0.69	232.17
28	0.51	83.39	5.80	21.96	173.00	3.80	235.97
29	0.26	83.65	2.90	10.98	173.00	1.90	237.87
30	0.60	84.25	6.76	25.59	173.00	4.43	242.30
31	0.60	84.85	6.76	25.59	173.00	4.43	246.72
32-A	1.87	86.72	21.08	79.80	173.00	13.80	260.53
32-B	5.41	92.13	61.09	231.25	9.50	2.20	262.73
32-C	1.29	93.42	14.50	54.89	34.75	1.91	264.63
33	1.63	95.04	18.36	69.50	34.75	2.42	267.05
34	0.51	95.56	5.80	21.96	34.75	0.76	267.81
35	0.17	95.73	1.93	7.31	34.75	0.25	268.06
36-A	0.84	96.57	9.52	36.04	34.75	1.25	269.32
36-B	4.17	100.75	47.09	178.26	25.25	4.50	273.82
36-C	4.72	105.47	53.25	201.57	25.75	5.19	279.01

TABLE 7.8.
EXFILTRATION EVENTS - NON-SETTLED SYSTEMS

EVENT #	VOLUME (IN)	CUMM. VOL (IN)	VOLUME (GAL)	VOLUME (LITERS)	CONC. (MG/L)	LOAD (GRAMS)	CUMM.LOAD (GRAMS)
1	3.85	3.85	43.48	164.59	325.00	53.49	53.49
2	0.86	4.71	9.66	36.57	1020.00	37.30	90.79
3	1.03	5.74	11.59	43.87	611.00	26.81	117.60
4-A	2.57	8.30	28.96	109.63	330.00	36.18	153.77
4-B	3.86	12.16	43.50	164.67	34.00	5.60	159.37
5-A	3.18	15.34	35.87	135.78	358.00	48.61	207.98
5-B	2.24	17.58	25.28	95.68	31.00	2.97	210.95
5-C	4.43	22.01	49.98	189.20	33.00	6.24	217.19
6	1.54	23.55	17.39	65.83	72.00	4.74	221.93
7	3.00	26.55	33.82	128.02	99.00	12.67	234.61
8	0.69	27.23	7.73	29.26	67.00	1.96	236.57
9	1.97	29.20	22.22	84.11	67.00	5.64	242.20
10-A	3.09	32.29	34.85	131.92	19.50	2.57	244.78
10-B	3.93	36.22	44.34	167.85	9.00	1.51	246.29
10-C	4.23	40.45	47.68	180.49	45.80	8.27	254.55
10-D	2.88	43.33	32.52	123.10	63.80	7.85	262.41
11	1.54	44.87	17.39	65.83	19.50	1.28	263.69
12-A	0.75	45.62	8.50	32.18	63.80	2.05	265.74
12-B	2.50	48.12	28.17	106.64	16.80	1.79	267.53
12-C	2.05	50.17	23.13	87.56	22.80	2.00	269.53
13-A	1.04	51.21	11.69	44.25	22.80	1.01	270.54
13-B	5.33	56.54	60.12	227.58	14.00	3.19	273.73
13-C	2.18	58.72	24.59	93.08	2.50	0.23	273.96
13-D	1.30	60.02	14.66	55.49	27.80	1.54	275.50
14	1.03	61.04	11.59	43.87	27.80	1.22	276.72
15	0.86	61.90	9.66	36.57	14.75	0.54	277.26
16	0.43	62.33	4.83	18.28	14.75	0.27	277.53
17	1.71	64.04	19.32	73.13	14.75	1.08	278.61
18	1.63	65.67	18.36	69.50	14.75	1.03	279.63
19	0.51	66.18	5.80	21.96	14.75	0.32	279.96
20	1.80	67.98	20.29	76.81	20.00	1.54	281.49
21-A	0.96	68.94	10.84	41.03	20.00	0.82	282.31
21-B	2.64	71.58	29.74	112.58	10.50	1.18	283.50
22	0.86	72.43	9.66	36.57	10.50	0.38	283.88
23	0.86	73.29	9.66	36.57	10.50	0.38	284.26
24-A	0.25	73.54	2.81	10.64	22.00	0.23	284.50
24-B	1.04	74.57	11.68	44.21	0.50	0.02	284.52
25-A	3.30	77.87	37.21	140.86	0.50	0.07	284.59
25-B	0.64	78.51	7.22	27.33	583.00	15.93	300.52
26	3.51	82.02	39.61	149.94	58.00	8.70	309.22
27	0.86	82.88	9.66	36.57	58.00	2.12	311.34
28	0.51	83.39	5.80	21.96	192.00	4.22	315.56
29	0.26	83.65	2.90	10.98	192.00	2.11	317.67
30	0.60	84.25	6.76	25.59	192.00	4.91	322.58
31	0.60	84.85	6.76	25.59	192.00	4.91	327.49
32-A	1.87	86.72	21.08	79.80	192.00	15.32	342.81
32-B	5.41	92.13	61.09	231.25	9.00	2.08	344.89
32-C	1.29	93.42	14.50	54.89	34.50	1.89	346.79
33	1.63	95.04	18.36	69.50	34.50	2.40	349.19
34	0.51	95.56	5.80	21.96	34.50	0.76	349.94
35	0.17	95.73	1.93	7.31	34.50	0.25	350.20
36-A	0.84	96.57	9.52	36.04	34.50	1.24	351.44
36-B	4.17	100.75	47.09	178.26	36.12	6.44	357.88
36-C	4.72	105.47	53.25	201.57	40.50	8.16	366.04

CHAPTER VIII

CONCLUSIONS AND RECOMMENDATIONS

From the experimental data and the arrangement of the results from the four variables conclusions pertaining to the operation of the exfiltration systems and recommendations for future construction can be made. The four different comparisons viewed included: 1) removal of solids from the stormwater vs. non-removal, 2) using sandy soil as the parent material vs. silty soil as the parent material, 3) non-woven 140N fabric in the system or woven 700XG fabric, or 4) construction of the exfiltration systems in a wet condition (within the water table) or construction above the water table. These four variables were compared for each system to a system with similar constants.

From the diagrams in Appendix C it can be seen that with a reduction in the solids of the stormwater an increase in exfiltration rates can be accomplished. In most systems the settled stormwater seemed to pass through the perforated pipe and fabric material without substantial build up of sediment and debris. This factor can be very important both during the operation of the system as well as during the construction phase.

During frequent visits to field installation sites it was noted that as the installation of the systems was taking place care was not taken to insure that sand and debris did not fall into the fabric, rock or pipe. It was also noticed that the aggregate selected for the installation contained considerable amounts of fine material. As this aggregate is installed in the system fines can be trapped in the fabric which only adds to the blockage of the stormwater prematurely. If the aggregate can be washed before delivery and care be taken not to introduce debris into the system during construction it is believed that the life of the system can be optimized.

An analysis of the sandy vs. silty soil was presented in the previous chapter. It is again noted that the soil and the fabric types need to be matched in order to insure optimum performance. As was recorded, the 140N non-woven fabric operated more effectively in the sandy parent material and the 700XG operated more effectively in the silty parent material. From the literary research the topic of hardpan formation could be closely related to the theory behind the soils and fabric matching. The hardpan is formed when a difference in the soil layers occur or perhaps within a region of organic material. From the fluctuation in the water table and the deposition of fine material the two dissimilar materials tend to form a impermeable layer or a hardpan between them. This difference in materials can be related to the porosities in the soils and the fabrics. The porosity of the 140N fabric was closer to the sandy soil than the silty soil. The 700XG and the silty parent material also presented similar porosities. However, these may not be the only similar characteristics.

The fabric comparison also exhibited the fabric soil interaction and can be seen in Appendix C. The fabrics chosen represented both woven and non-woven types with a wide range of permeability and porosity. These fabrics along with others with similar characteristics are widely used in the Central Florida area and can be obtained easily. For this reason it is concluded that either fabric is suitable depending on the condition and type of soil in which the exfiltration system is to be constructed. Care must be taken not to puncture or leave gaps in the fabric to insure that the parent material does not infiltrate into the system and cause a reduction in performance.

The final comparison is the wet condition installation vs. the dry system. The water table condition simulated in this experimentation kept eight of the sixteen tanks wet at all times. The initial thought was that the hardpan condition would be duplicated in the boundary between the fabric and rock aggregate, which would contribute to a reduction in exfiltration rate. In some of the systems the wet condition actually out performed the dry condition. This occurrence possibly contributed to the re-suspension of the solids in the stormwater which would not allow impingement into the fabric. The disadvantage of the wet system is the reduction of the available storage volume which requires a larger storage area and more cost. It is recommended that the systems be installed in areas where the rock area within the pipe can be above the water table.

From the results of the permeability tests three of the four systems tested showed that the soil was not the limiting parameter for the exfiltration rate. These three systems included both sandy and silty type soils. For this reason it was concluded that the limiting parameter lies within the exfiltration system which could be due to fabric interface, fabric material, rock debris, or silty materials introduced into the system from the stormwater.

From the analysis of the exfiltration system it is evident that this technique can be utilized to reduce the amount of surface ponds required within a development which can result in a more efficient utilization of the property.

Future Work

Future development of the exfiltration system can be designed to include many features. To reduce solids in stormwater an efficient method can be developed to remove fine material and prevent future clogging of the system. To effectively remove solids from the stormwater a process would have to be developed which could be installed before the exfiltration system. Since size for this system would be critical, a settling basin would not be reasonable due to the input rate of the stormwater. A settling basin would have to be very large to bring the velocity of the stormwater below the settling velocity of the solids. Other possible systems could consist of an elaborate sump which could be maintained on a regular basis so that solids would not build up and inhibit collection.

Future modeling of the exfiltration systems might include the rearrangement of the parameters used for this experiment. Since it was noted that settled stormwater allowed for higher exfiltration rates in the systems this parameter could be eliminated. Soil grades could be varied by backfilling around the fabric with well graded course builders sand to measure the effect of the immediate soil interface. Other fabric materials could also be selected for testing as well as the absence of the fabric liner. Another type of system which could be viewed might include multiple pipes with small diameters which could be utilized in areas of high water tables. This system would act much like a drain field for effluent from a septic tank.

The combinations of future experimentation with the involvement in the construction practice will prove the exfiltration system to be a valid substitute for surface stormwater ponds. Management of these stormwater systems could rely on a few simple measurements which could be automated to insure proper operation. Water quality from the exfiltration system would be maintained by the surrounding soil therefore allowing more efficient removal of pollutants. The exfiltration system can effectively be applied if proper design criteria, installation, and maintenance be provided.

APPENDICES

APPENDIX A

RAINFALL EVENT PROGRAM AND EXAMPLE OUTPUT

```
10 CLEAR:COLOR 2:CLS:KEY OFF
20 PRINT"                    *******************************************"
30 PRINT"                    *                                         *"
40 PRINT"                    *        EXFILTRATION PROJECT             *"
50 PRINT"                    *                                         *"
60 PRINT"                    *              F. D. O. T.                *"
70 PRINT"                    *                                         *"
80 PRINT"                    *              WRITTEN BY:                *"
90 PRINT"                    *                                         *"
100 PRINT"                   *              DAVID EVANS                *"
110 PRINT"                   *                                         *"
120 PRINT"                   *******************************************"
130 PRINT""
140 INPUT"     DO YOU WISH TO INPUT A YEAR OF RAINFALL EVENTS (Y/N) ";X$
150 PRINT""
160 IF X$="N" OR  X$="n" THEN GOTO 400
170 INPUT"     DRIVE NAME AND NAME OF FILE TO BE ENTERED (EX. A:YEAR1) ";A$
180 PRINT""
190 INPUT"     NUMBER OF EVENTS TO BE INPUT = ";A
200 B$=A$
210 CLS
220 LOCATE 3,23
230 PRINT"********** DATA INPUT **********"
240 PRINT""
250 PRINT""
260 OPEN "R",#1,A$,32
270 FIELD #1,10 AS A$
280 LSET A$=MKS$(A)
290 PUT #1,1
300 FOR I=2 TO A+1
310 CODE%=I
320 PRINT USING"EVENT #### (IN.) =";I-1,:INPUT B
330 LSET A$=MKS$(B)
340 PUT#1,CODE%
350 NEXT I
360 CLOSE #1
370 CLS
380 LOCATE 3
390 GOTO 430
400 CLS:LOCATE 3
410 COLOR 3
420 INPUT"     DRIVE NAME AND NAME OF FILE TO BE USED (EX. A:YEAR1) ";B$
430 OPEN "R",#1,B$,32
440 FIELD #1,10 AS A$
450 PRINT""
460 GET #1,1
470 IF X$="Y" OR X$="y" THEN GOTO 490
480 PRINT"     NUMBER OF EVENTS IN THIS YEAR = ";CVS(A$)
490 A=CVS(A$)
500 PRINT""
510 FOR I= 2 TO A+1
520 CODE%=I
530 GET #1,CODE%
540 PRINT USING"####=##.##";I-1,CVS(A$)
550 IF I-1>=18 AND I-1<=36 THEN LOCATE ,13
560 IF I-1>=36 AND I-1<=54 THEN LOCATE ,25
570 IF I-1>=54 AND I-1<=72 THEN LOCATE ,37
580 IF I-1>=72 AND I-1<=90 THEN LOCATE ,49
590 IF I-1>=90 THEN LOCATE ,61
600 IF I-1=18 THEN LOCATE I-13
610 IF I-1=36 THEN LOCATE I-31
620 IF I-1=54 THEN LOCATE I-49
630 IF I-1=72 THEN LOCATE I-67
640 IF I-1=90 THEN LOCATE I-85
650 IF I=1+A THEN LOCATE 23
660 NEXT I
670 INPUT"RETURN";S
680 CLOSE #1
690 GOTO 740
700 IF X$="Y" OR X$="y" THEN INPUT"     ARE ALL OF THE DATA ENTRIES CORRECT (Y/N
) ";Z$
710 IF Z$="Y" OR Z$="y" THEN GOTO 740
720 A$=B$
730 GOTO 210
740 CLS:COLOR 2
750 PRINT""
760 PRINT"     *************** PRINTOUT OF EACH EVENT ***************"
770 PRINT""
780 INPUT"     ENTER FIRST EVENT # TO BE PRINTED = ";C
```

```
790 PRINT""
800 INPUT"     ENTER LAST EVENT # TO BE PRINTED  = ";F
810 OPEN "R",#1,B$,32
820 FIELD #1,10 AS A$
830 PRINT""
840 FOR I=C+1 TO F+1
850 GET #1,I
852 LOCATE 10
854 PRINT USING"     DURATION OF EVENT #### = ####.## MIN.";I-1,(((CVS(A$)*18.1)
/12)*7.48)/.65
856 PRINT""
858 K=1
860 LPRINT""
870 LPRINT""
880 LPRINT"
890 LPRINT""                                  EXFILTRATION PROJECT"
900 LPRINT"
910 LPRINT""                              EVENT COORDINATOR: DAVID EVANS  "
920 LPRINT"
930 LPRINT""                                       EVENT # ";I-1
940 LPRINT"     DATE OF EVENT _________________"
950 LPRINT""
960 LPRINT"     TIME OF EVENT _________________"
970 LPRINT""
980 LPRINT USING"     VOLUME OF EVENT (IN) ===========================>  #####.#
#";CVS(A$)
990 LPRINT""
1000 LPRINT USING"     VOLUME OF EVENT (GAL) =========================>  #####.
##";((CVS(A$)*18.1)/12)*7.48
1010 LPRINT""
1020 LPRINT"     CONTRIBUTING AREA (FT^2) ======================>     18.10"
1030 LPRINT""
1040 V=((CVS(A$)*18.1)/12)*7.48
1050 D=V/.65
1080 LPRINT"     ------------------------------------------------------------
----"
1090 LPRINT""
1100 LPRINT"         DISTRIBUTION OF DURATION AND FLOWRATES THROUGHOUT EVENT"
1110 LPRINT""
1120 LPRINT"        FLOW RATE (GPM)          DURATION (MIN)          TOTAL (MIN)"
1130 LPRINT"        ---------------          --------------          -----------"
1140 LPRINT""
1150 LPRINT USING"             .85         FOR        ####.#                ####
.#";D/4,D/4
1160 LPRINT""
1170 LPRINT USING"             .70         FOR        ####.#                ####
.#";D/4,D/2
1180 LPRINT""
1190 LPRINT USING"             .60         FOR        ####.#                ####
.#";D/4,(D*3)/4
1200 LPRINT""
1210 T1=D/4:T2=D/4:T3=D/4
1220 V1=.85*T1
1230 V2=(.7*T2)
1240 V3=(.6*T3)
1250 V4=V-(V1+V2+V3)
1260 T4A=V4/.5
1270 LPRINT USING"             .50         FOR        ####.#                ####
.#";T4A,T4A+((D*3)/4)
1280 LPRINT""
1290 LPRINT"     ------------------------------------------------------------
----"
1300 LPRINT""
1310 LPRINT"     FINAL FLOWMETER READING            ________________
1320 LPRINT""
1330 LPRINT"     INITIAL FLOWMETER READING          ________________
1340 LPRINT""
1350 LPRINT"     TOTAL VOLUME=READING*1.69 (GAL) ____________  :  _________ G
AL / TANK"
1360 LPRINT""
1370 LPRINT"     SAMPLE # RAW STORM WATER       ____,____,____: ____,____,____
 mg / L"
1380 LPRINT""
1390 LPRINT"     SAMPLE # SETTLED STORMWATER____,____,____: ____,____,____
 mg / L"
1400 LPRINT""
1410 LPRINT""
1420 LPRINT""
1430 LPRINT"     EVENT PERFORMED BY                 ____________,____________"
```

```
1440 LPRINT""
1445 FOR X=1 TO K
1450 IF X=1 THEN LPRINT CHR$(12)
1460 LOCATE 3
1470 LPRINT"                              INFILTRATION RATES"
1475 LPRINT"    "
1477 LPRINT"                         TIME OF READING __________"
1480 LPRINT"      ____________________________________________________________
    "
1490 FOR J= 1 TO 16
1500 IF J=9 THEN LPRINT CHR$(12)
1510 LPRINT"                                   TANK #  ";J
1515 GOSUB 2000
1520 LPRINT"     CHANGE IN ELEVATION IN PIPE (IN)      ____________"
1530 LPRINT"     TIME FOR CHANGE IN ELEVATION (SEC)    ____________"
1540 LPRINT"     INFILTRATION RATE (IN/HR)             ____________"
1550 LPRINT"     ____________________________________________________________
    "
1560 NEXT J
1570 LPRINT CHR$(12)
1573 NEXT X
1575 GOSUB 3000
1578 LPRINT CHR$(12)
1580 NEXT I
1590 END
2000 IF J=1 THEN LPRINT"     * SETTLED, 140N, SANDY, LOW GWT *"
2010 IF J=2 THEN LPRINT"     * SETTLED, 700XG, SANDY, LOW GWT *"
2030 IF J=3 THEN LPRINT"     * SETTLED, 140N, SANDY, HIGH GWT *"
2040 IF J=4 THEN LPRINT"     * SETTLED, 700XG, SANDY, HIGH GWT *"
2050 IF J=5 THEN LPRINT"     * SETTLED, 140N, SILTY, LOW GWT *"
2060 IF J=6 THEN LPRINT"     * SETTLED, 700XG, SILTY, LOW GWT *"
2070 IF J=7 THEN LPRINT"     * SETTLED, 140N, SILTY, HIGH GWT *"
2080 IF J=8 THEN LPRINT"     * SETTLED, 700XG, SILTY, HIGH GWT *"
2090 IF J=9 THEN LPRINT"     * RAW, 140N, SANDY, LOW GWT *"
2100 IF J=10 THEN LPRINT"     * RAW, 700XG, SANDY, LOW GWT *"
2110 IF J=11 THEN LPRINT"     * RAW, 140N, SANDY, HIGH GWT *"
2120 IF J=12 THEN LPRINT"     * RAW, 700XG, SANDY, HIGH GWT *"
2130 IF J=13 THEN LPRINT"     * RAW, 140N, SILTY, LOW GWT *"
2140 IF J=14 THEN LPRINT"     * RAW, 700XG, SILTY, LOW GWT *"
2150 IF J=15 THEN LPRINT"     * RAW, 140N, SILTY, HIGH GWT *"
2160 IF J=16 THEN LPRINT"     * RAW, 700XG, SILTY, HIGH GWT *"
2170 RETURN
3000 LPRINT""
3010 LPRINT"                         HEIGHT IN PIPE AT TIME 't'"
3012 LPRINT""
3015 LPRINT"     TIME DURING EVENT WHICH LEVEL IS TAKEN (MIN) __________ "
3017 LPRINT""
3018 LPRINT"     ------------------------------------------------------------
-"
3020 FOR C=1 TO 16
3030 LPRINT""
3040 LPRINT""
3050 LPRINT USING"     ELEVATION IN TANK ### (IN)     ____________ ";C
3060 NEXT C
3070 RETURN
```

EXFILTRATION PROJECT

EVENT COORDINATOR: DAVID EVANS

EVENT # 1

DATE OF EVENT ____________________

TIME OF EVENT ____________________

VOLUME OF EVENT (IN) ============================> 0.45

VOLUME OF EVENT (GAL) ===========================> 5.08

CONTRIBUTING AREA (FT^2) ========================> 18.10

DISTRIBUTION OF DURATION AND FLOWRATES THROUGHOUT EVENT

FLOW RATE (GPM)		DURATION (MIN)	TOTAL (MIN)
.85	FOR	2.0	2.0
.70	FOR	2.0	3.9
.60	FOR	2.0	5.9
.50	FOR	1.8	7.6

FINAL FLOWMETER READING ____________________

INITIAL FLOWMETER READING ____________________

TOTAL VOL.=READING*1.69 (GAL) _____________ : _________ GAL/TANK

SAMPLE # RAW _____,_____,_____ : ______,_____,______ mg/L

SAMPLE # SETTLED _____,_____,_____ : _____,_____,______ mg/L

EVENT PERFORMED BY ________________,_______________

INFILTRATION RATES

TIME OF READING ____________

TANK # 1
* SETTLED, 140N, SANDY, LOW GWT *
CHANGE IN ELEVATION IN PIPE (IN) ____________
TIME FOR CHANGE IN ELEVATION (SEC) ____________
INFILTRATION RATE (IN/HR) ____________

TANK # 2
* SETTLED, 700XG, SANDY, LOW GWT *
CHANGE IN ELEVATION IN PIPE (IN) ____________
TIME FOR CHANGE IN ELEVATION (SEC) ____________
INFILTRATION RATE (IN/HR) ____________

TANK # 3
* SETTLED, 140N, SANDY, HIGH GWT *
CHANGE IN ELEVATION IN PIPE (IN) ____________
TIME FOR CHANGE IN ELEVATION (SEC) ____________
INFILTRATION RATE (IN/HR) ____________

TANK # 4
* SETTLED, 700XG, SANDY, HIGH GWT *
CHANGE IN ELEVATION IN PIPE (IN) ____________
TIME FOR CHANGE IN ELEVATION (SEC) ____________
INFILTRATION RATE (IN/HR) ____________

TANK # 5
* SETTLED, 140N, SILTY, LOW GWT *
CHANGE IN ELEVATION IN PIPE (IN) ____________
TIME FOR CHANGE IN ELEVATION (SEC) ____________
INFILTRATION RATE (IN/HR) ____________

TANK # 6
* SETTLED, 700XG, SILTY, LOW GWT *
CHANGE IN ELEVATION IN PIPE (IN) ____________
TIME FOR CHANGE IN ELEVATION (SEC) ____________
INFILTRATION RATE (IN/HR) ____________

TANK # 7
* SETTLED, 140N, SILTY, HIGH GWT *
CHANGE IN ELEVATION IN PIPE (IN) ____________
TIME FOR CHANGE IN ELEVATION (SEC) ____________
INFILTRATION RATE (IN/HR) ____________

TANK # 8
* SETTLED, 700XG, SILTY, HIGH GWT *
CHANGE IN ELEVATION IN PIPE (IN) ____________
TIME FOR CHANGE IN ELEVATION (SEC) ____________
INFILTRATION RATE (IN/HR) ____________

TANK # 9

* RAW, 140N, SANDY, LOW GWT *

CHANGE IN ELEVATION IN PIPE (IN) ____________

TIME FOR CHANGE IN ELEVATION (SEC) ____________

INFILTRATION RATE (IN/HR) ____________

TANK # 10

* RAW, 700XG, SANDY, LOW GWT *

CHANGE IN ELEVATION IN PIPE (IN) ____________

TIME FOR CHANGE IN ELEVATION (SEC) ____________

INFILTRATION RATE (IN/HR) ____________

TANK # 11

* RAW, 140N, SANDY, HIGH GWT *

CHANGE IN ELEVATION IN PIPE (IN) ____________

TIME FOR CHANGE IN ELEVATION (SEC) ____________

INFILTRATION RATE (IN/HR) ____________

TANK # 12

* RAW, 700XG, SANDY, HIGH GWT *

CHANGE IN ELEVATION IN PIPE (IN) ____________

TIME FOR CHANGE IN ELEVATION (SEC) ____________

INFILTRATION RATE (IN/HR) ____________

TANK # 13

* RAW, 140N, SILTY, LOW GWT *

CHANGE IN ELEVATION IN PIPE (IN) ____________

TIME FOR CHANGE IN ELEVATION (SEC) ____________

INFILTRATION RATE (IN/HR) ____________

TANK # 14

* RAW, 700XG, SILTY, LOW GWT *

CHANGE IN ELEVATION IN PIPE (IN) ____________

TIME FOR CHANGE IN ELEVATION (SEC) ____________

INFILTRATION RATE (IN/HR) ____________

TANK # 15

* RAW, 140N, SILTY, HIGH GWT *

CHANGE IN ELEVATION IN PIPE (IN) ____________

TIME FOR CHANGE IN ELEVATION (SEC) ____________

INFILTRATION RATE (IN/HR) ____________

TANK # 16

* RAW, 700XG, SILTY, HIGH GWT *

CHANGE IN ELEVATION IN PIPE (IN) ____________

TIME FOR CHANGE IN ELEVATION (SEC) ____________

INFILTRATION RATE (IN/HR) ____________

HEIGHT IN PIPE AT TIME 't'

TIME DURING EVENT WHICH LEVEL IS TAKEN (MIN) ____________

ELEVATION IN TANK 1 (IN) ________

ELEVATION IN TANK 2 (IN) ________

ELEVATION IN TANK 3 (IN) ________

ELEVATION IN TANK 4 (IN) ________

ELEVATION IN TANK 5 (IN) ________

ELEVATION IN TANK 6 (IN) ________

ELEVATION IN TANK 7 (IN) ________

ELEVATION IN TANK 8 (IN) ________

ELEVATION IN TANK 9 (IN) ________

ELEVATION IN TANK 10 (IN) ________

ELEVATION IN TANK 11 (IN) ________

ELEVATION IN TANK 12 (IN) ________

ELEVATION IN TANK 13 (IN) ________

ELEVATION IN TANK 14 (IN) ________

ELEVATION IN TANK 15 (IN) ________

ELEVATION IN TANK 16 (IN) ________

APPENDIX B

DISPERSION RESULTS

DISPERSION EXPERIMENT
LIME ROCK

INPUT RATE .45 GPM

CHANNEL #	1	2	3	4	5	6	7
VOL.(ML)	0.00	123.00	310.00	350.00	310.00	85.00	0.00
TIME(SEC)	0.00	170.00	50.11	27.00	44.25	175.20	0.00
RATE(ML/S)	0.00	0.72	6.19	12.96	7.01	0.49	0.00

INPUT RATE .85 GPM

CHANNEL #	1	2	3	4	5	6	7
VOL.(ML)	0.00	187.00	310.00	400.00	338.00	240.00	0.00
TIME(SEC)	0.00	125.60	27.80	16.22	36.58	110.22	0.00
RATE(ML/S)	0.00	1.49	11.15	24.66	9.24	2.18	0.00

INPUT RATE 1.7 GPM

CHANNEL #	1	2	3	4	5	6	7
VOL.(ML)	0.00	325.22	355.80	415.20	358.23	258.00	0.00
TIME(SEC)	0.00	65.28	15.69	10.22	13.66	85.25	0.00
RATE(ML/S)	0.00	4.98	22.68	40.63	26.22	3.03	0.00

INPUT RATE 2.5 GPM

CHANNEL #	1	2	3	4	5	6	7
VOL.(ML)	0.00	268.00	468.00	475.00	460.00	288.00	0.00
TIME(SEC)	0.00	49.23	16.55	10.22	12.55	49.25	0.00
RATE(ML/S)	0.00	5.44	28.28	46.48	36.65	5.85	0.00

INPUT RATE 3.0 GPM

CHANNEL #	1	2	3	4	5	6	7
VOL.(ML)	228.00	360.00	125.00	368.00	401.00	340.00	175.00
TIME(SEC)	437.00	38.50	9.02	5.26	6.90	39.11	215.00
RATE(ML/S)	0.52	9.35	13.86	69.96	58.12	8.69	0.81

INPUT RATE 4.2 GPM

CHANNEL #	1	2	3	4	5	6	7
VOL.(ML)	205.20	360.00	475.00	430.00	425.00	402.00	150.00
TIME(SEC)	162.12	15.22	6.58	4.65	6.55	35.88	241.25
RATE(ML/S)	1.27	23.65	72.19	92.47	64.89	11.20	0.62

DISPERSION EXPERIMENT
SLAG ROCK

INPUT RATE .45 GPM

CHANNEL #	1	2	3	4	5	6	7
VOL.(ML)	0.00	135.00	319.00	367.00	335.00	91.00	0.00
TIME(SEC)	0.00	167.94	49.22	29.04	43.12	172.50	0.00
RATE(ML/S)	0.00	0.80	6.48	12.64	7.77	0.53	0.00

INPUT RATE .90 GPM

CHANNEL #	1	2	3	4	5	6	7
VOL.(ML)	0.00	192.00	333.00	401.00	347.00	244.00	0.00
TIME(SEC)	0.00	121.10	26.43	15.09	29.78	114.60	0.00
RATE(ML/S)	0.00	1.59	12.60	26.57	11.65	2.13	0.00

INPUT RATE 1.9 GPM

CHANNEL #	1	2	3	4	5	6	7
VOL.(ML)	0.00	330.00	366.00	421.00	360.00	269.00	0.00
TIME(SEC)	0.00	63.84	13.32	8.09	12.63	86.09	0.00
RATE(ML/S)	0.00	5.17	27.48	52.04	28.50	3.12	0.00

INPUT RATE 2.4 GPM

CHANNEL #	1	2	3	4	5	6	7
VOL.(ML)	0.00	264.00	456.00	460.00	451.00	285.00	0.00
TIME(SEC)	0.00	48.25	14.50	6.57	11.66	47.94	0.00
RATE(ML/S)	0.00	5.47	31.45	70.02	38.68	5.94	0.00

INPUT RATE 3.4 GPM

CHANNEL #	1	2	3	4	5	6	7
VOL.(ML)	230.00	368.00	447.00	400.00	408.00	343.00	182.00
TIME(SEC)	433.00	35.97	8.28	4.56	6.84	38.25	205.56
RATE(ML/S)	0.53	10.23	53.99	87.72	59.65	8.97	0.89

INPUT RATE 4.0 GPM

CHANNEL #	1	2	3	4	5	6	7
VOL.(ML)	195.00	351.00	460.00	425.00	420.00	400.00	141.00
TIME(SEC)	164.18	21.88	6.82	4.97	6.97	39.47	249.32
RATE(ML/S)	1.19	16.04	67.45	85.51	60.26	10.13	0.57

INPUT RATE 4.8 GPM

CHANNEL #	1	2	3	4	5	6	7
VOL.(ML)	270.00	435.00	467.00	449.00	384.00	351.00	158.00
TIME(SEC)	179.22	16.75	4.69	4.22	5.56	26.69	274.47
RATE(ML/S)	1.51	25.97	99.57	106.40	69.06	13.15	0.58

DISPERSION EXPERIMENT
RIVER-WASHED ROCK

INPUT RATE .45 GPM

CHANNEL #	1	2	3	4	5	6	7
VOL.(ML)	0.00	145.00	312.00	345.00	355.00	125.00	0.00
TIME(SEC)	0.00	242.41	64.69	29.66	65.09	129.65	0.00
RATE(ML/S)	0.00	0.60	4.82	11.63	5.45	0.96	0.00

INPUT RATE 1.0 GPM

CHANNEL #	1	2	3	4	5	6	7
VOL.(ML)	0.00	203.00	336.00	362.00	355.00	226.00	0.00
TIME(SEC)	0.00	89.51	25.91	11.56	25.53	85.00	0.00
RATE(ML/S)	0.00	2.27	12.97	31.31	13.91	2.66	0.00

INPUT RATE 1.6 GPM

CHANNEL #	1	2	3	4	5	6	7
VOL.(ML)	0.00	335.00	346.00	405.00	325.00	221.00	0.00
TIME(SEC)	0.00	54.10	17.28	9.06	14.66	72.66	0.00
RATE(ML/S)	0.00	6.19	20.02	44.70	22.17	3.04	0.00

INPUT RATE 1.9 GPM

CHANNEL #	1	2	3	4	5	6	7
VOL.(ML)	0.00	249.00	347.00	321.00	336.00	122.00	0.00
TIME(SEC)	0.00	30.94	12.75	5.44	11.38	32.37	0.00
RATE(ML/S)	0.00	8.05	27.22	59.01	29.53	3.77	0.00

INPUT RATE 2.6 GPM

CHANNEL #	1	2	3	4	5	6	7
VOL.(ML)	0.00	247.00	404.00	410.00	370.00	261.00	0.00
TIME(SEC)	0.00	29.78	11.41	6.19	10.50	34.35	0.00
RATE(ML/S)	0.00	8.29	35.41	66.24	35.24	7.60	0.00

INPUT RATE 3.0 GPM

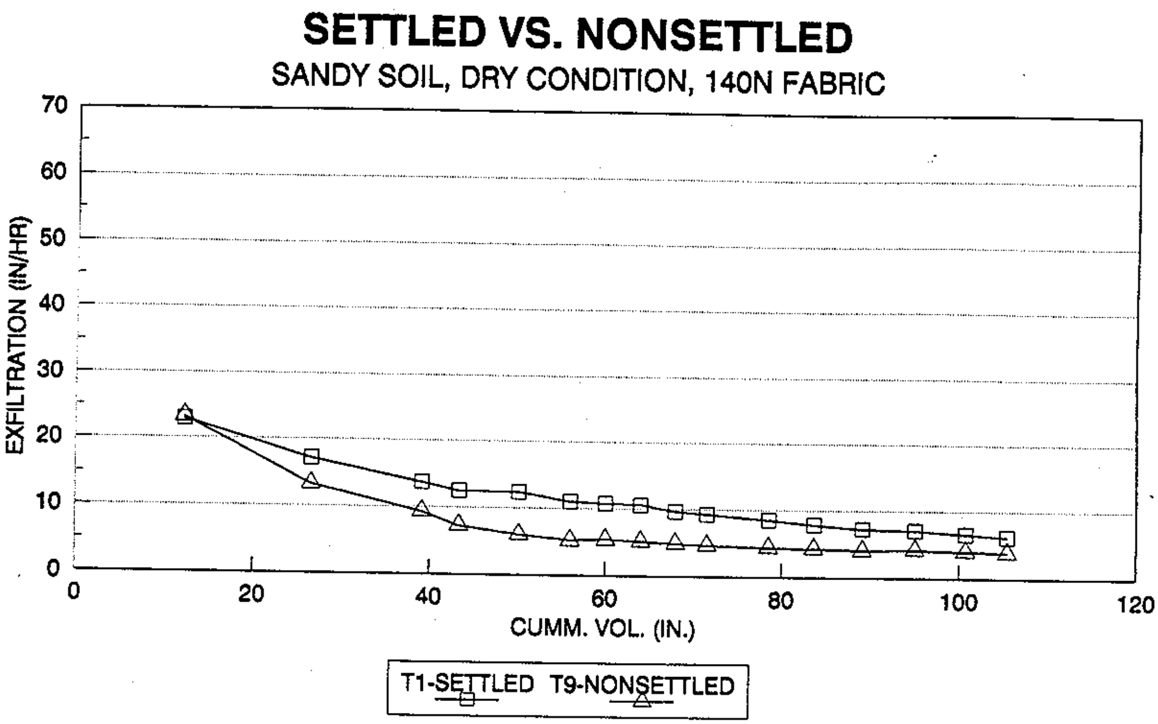
CHANNEL #	1	2	3	4	5	6	7
VOL.(ML)	0.00	497.00	340.00	302.00	320.00	250.00	0.00
TIME(SEC)	0.00	38.44	7.75	6.19	6.56	32.16	0.00
RATE(ML/S)	0.00	12.93	43.87	48.79	48.78	7.77	0.00

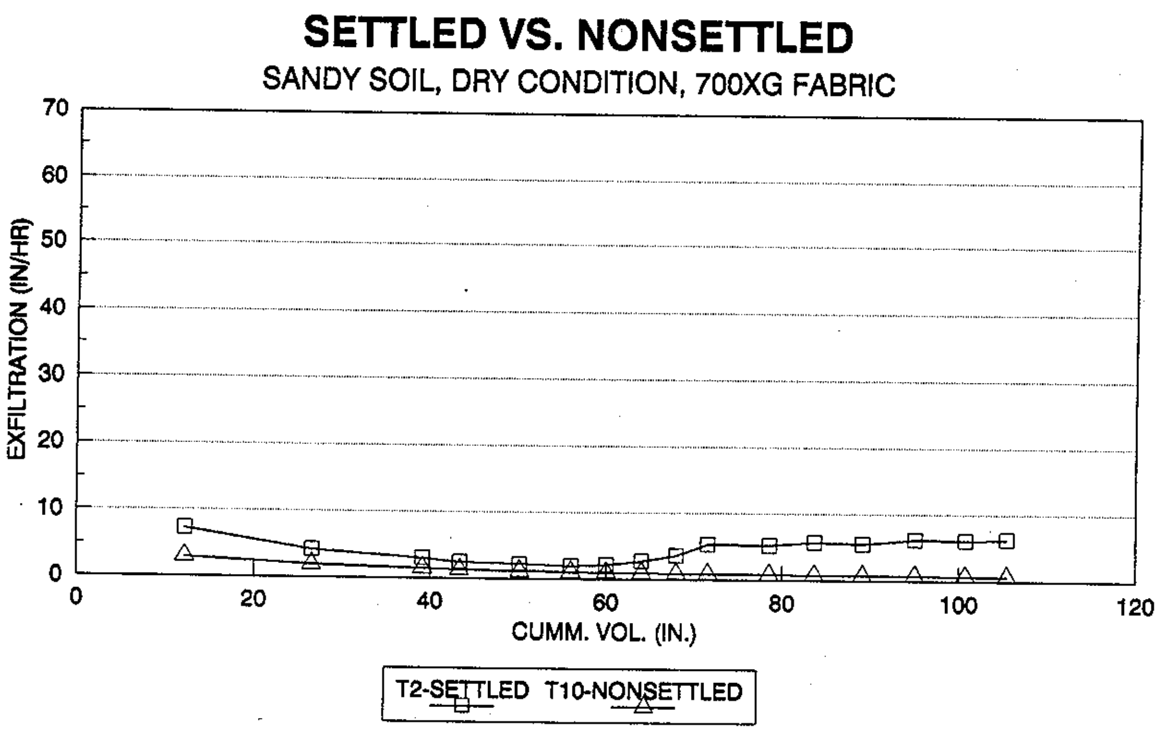
APPENDIX C

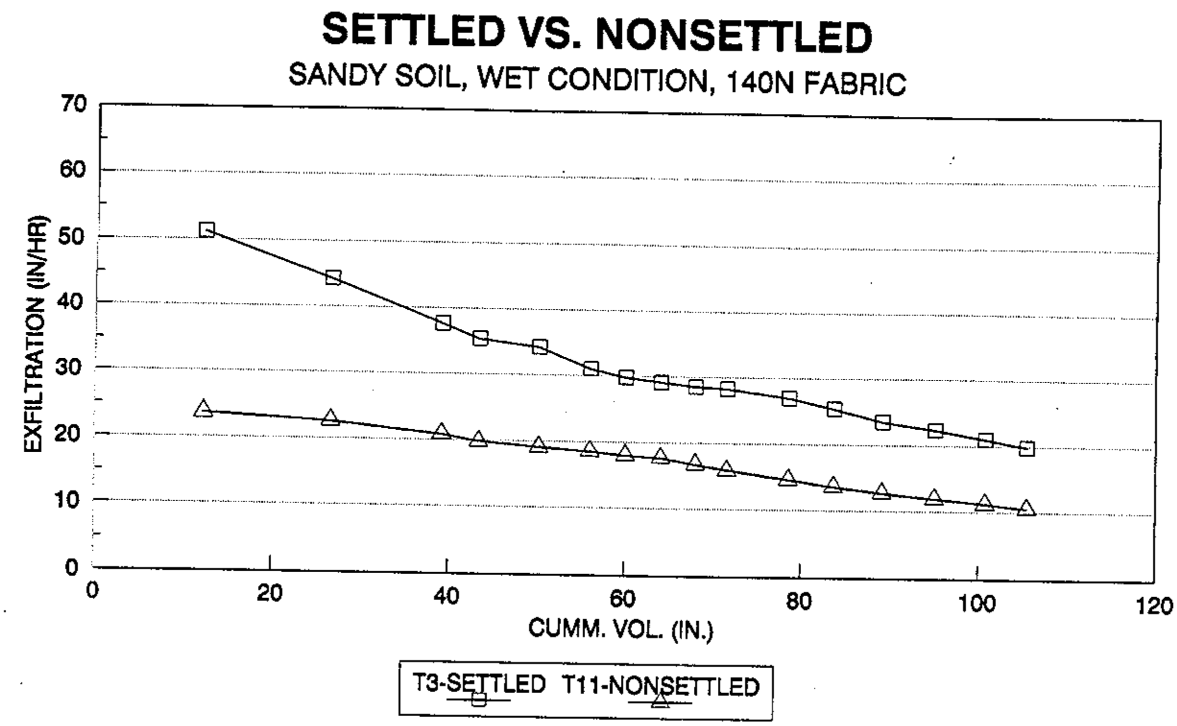
EXFILTRATION RESULTS

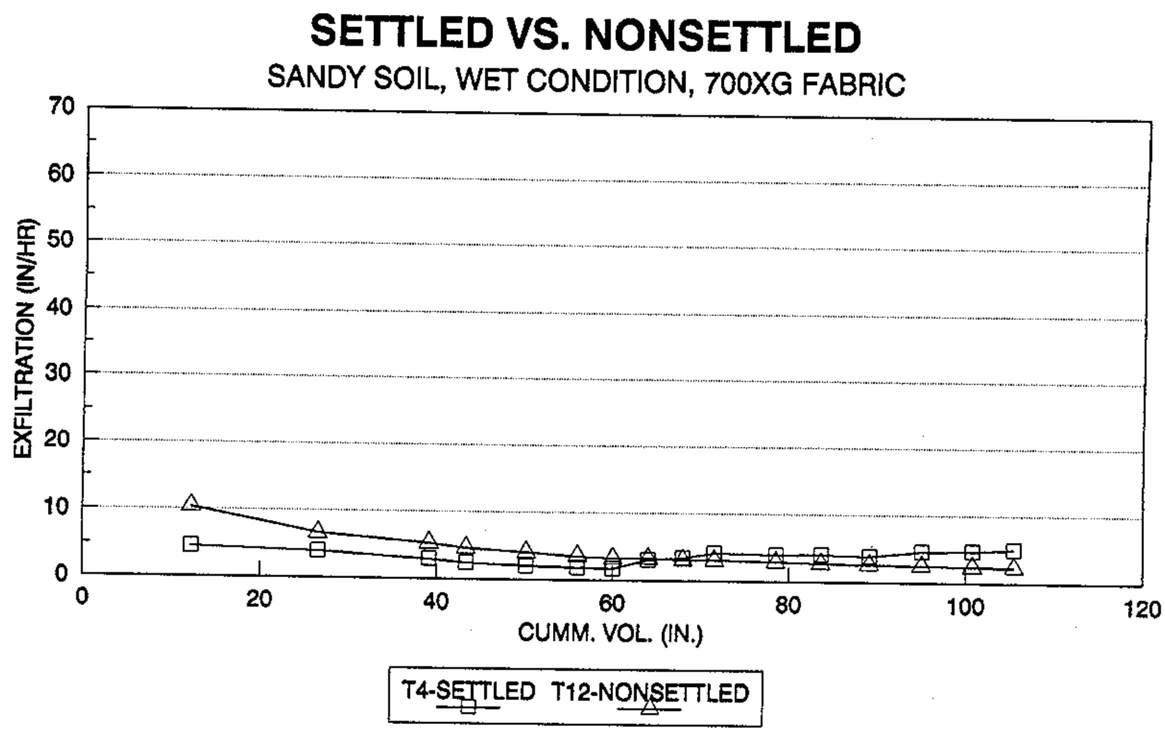
APPENDIX C-1

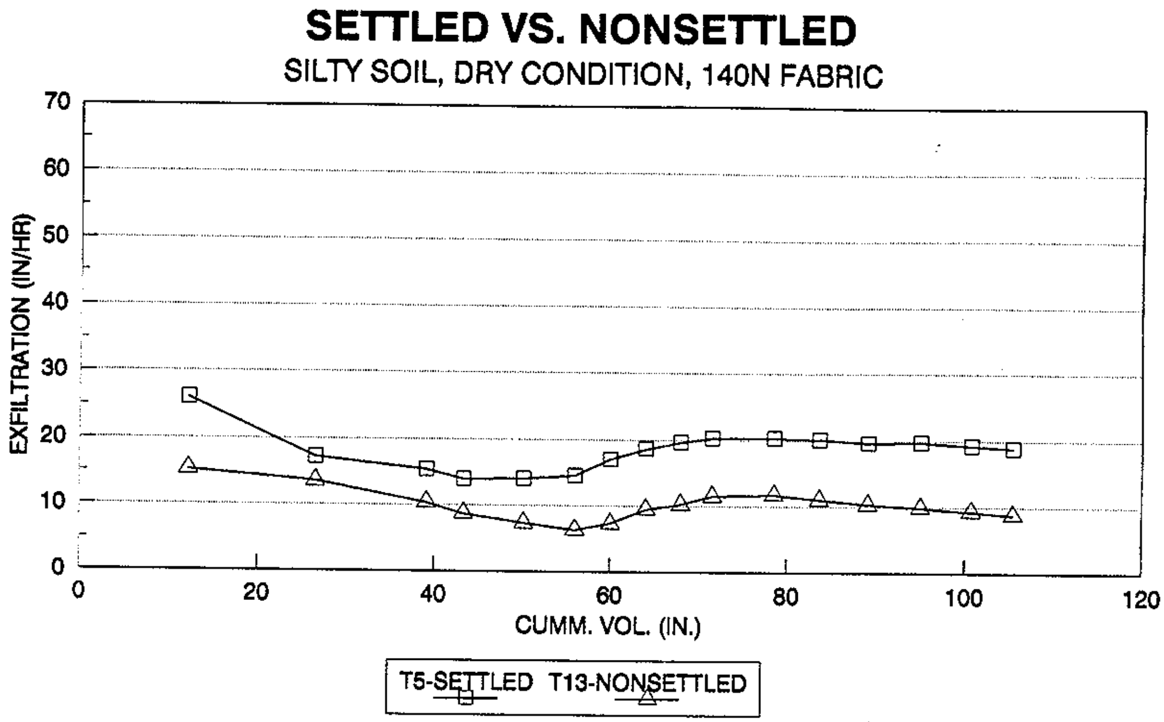
AVERAGE DATA

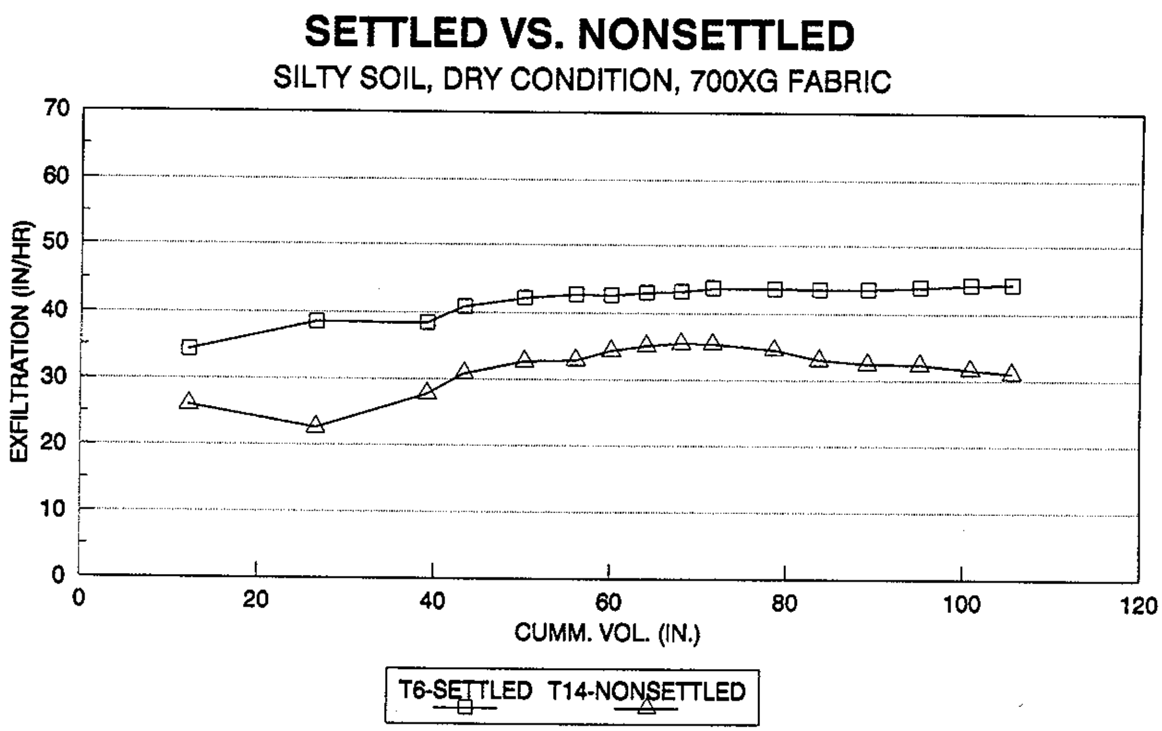

SETTLED VS. NONSETTLED
SANDY SOIL, DRY CONDITION, 140N FABRIC
EXFILTRATION (IN/HR)
70
60
50
40
30
20
10
0
0
20
40
60
80
100
120
CUMM. VOL. (IN.)
T1-SETTLED
T9-NONSETTLED

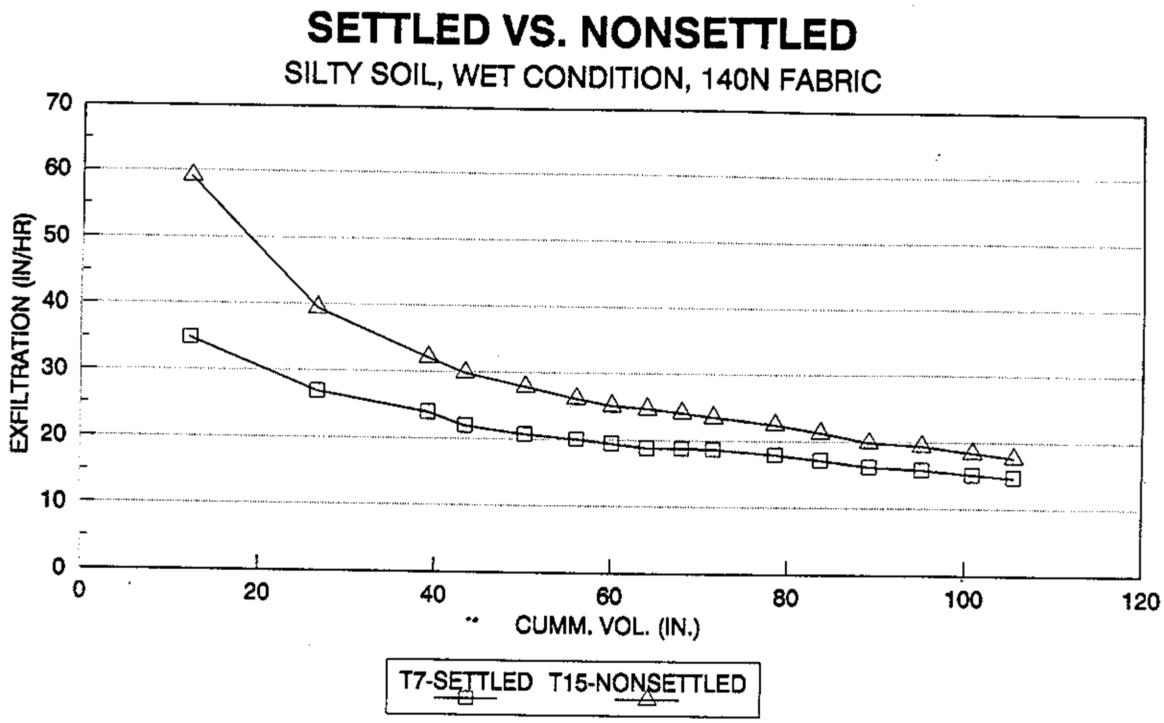

SETTLED VS. NONSETTLED
SANDY SOIL, DRY CONDITION, 700XG FABRIC
EXFILTRATION (IN/HR)
70
60
50
40
30
20
10
0
0
20
40
60
80
100
120
CUMM. VOL. (IN.)
T2-SETTLED
T10-NONSETTLED

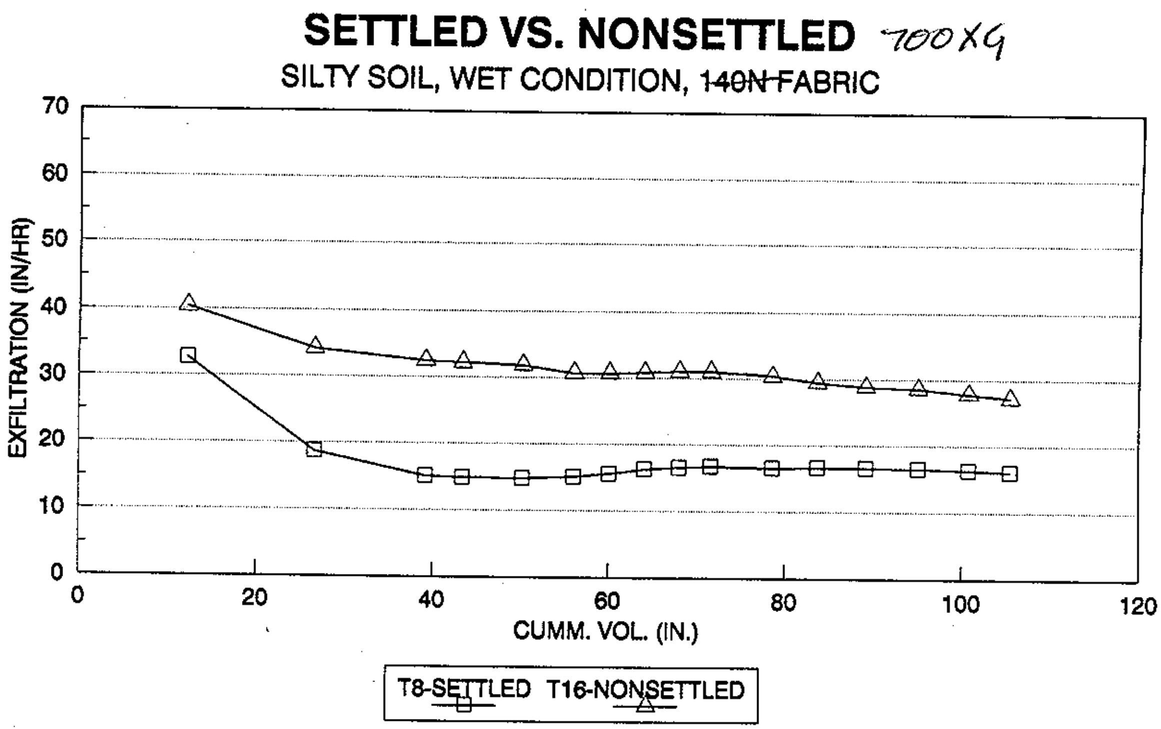

SETTLED VS. NONSETTLED
SANDY SOIL, WET CONDITION, 140N FABRIC
EXFILTRATION (IN/HR)
70
60
50
40
30
20
10
0
0
20
40
60
80
100
120
CUMM. VOL. (IN.)
T3-SETTLED
T11-NONSETTLED

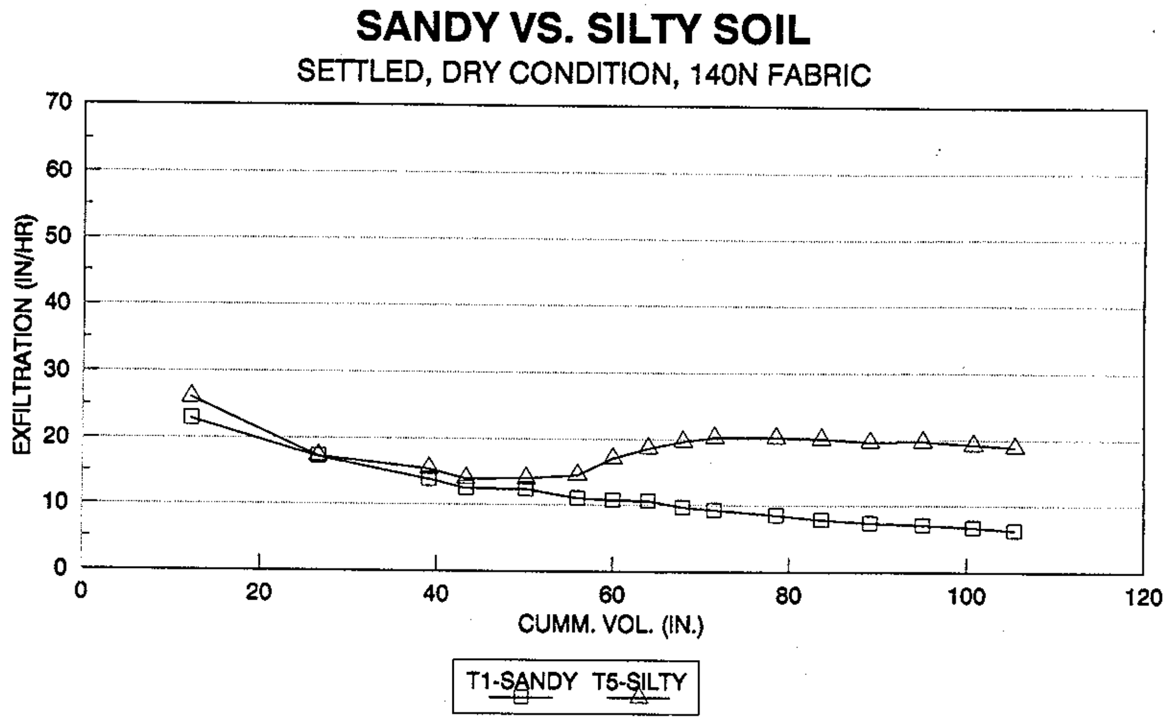

SETTLED VS. NONSETTLED
SANDY SOIL, WET CONDITION, 700XG FABRIC
EXFILTRATION (IN/HR)
70
60
50
40
30
20
10
0
0
20
40
60
80
100
120
CUMM. VOL. (IN.)
T4-SETTLED
T12-NONSETTLED

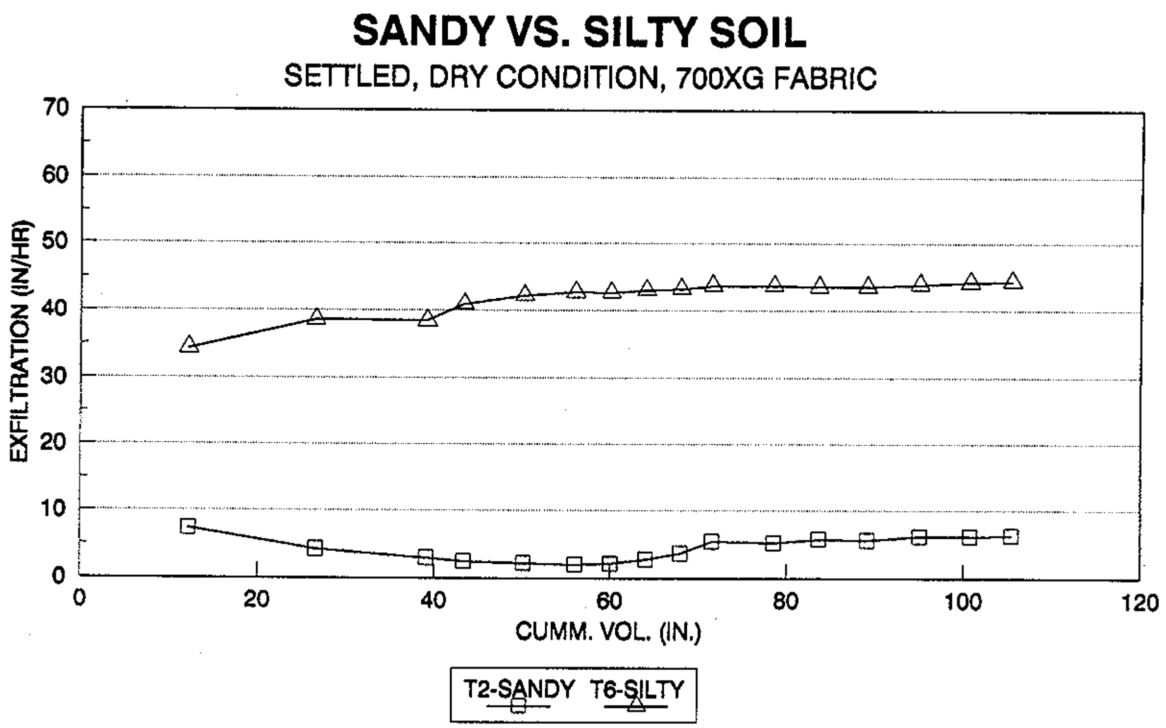

SETTLED VS. NONSETTLED
SILTY SOIL, DRY CONDITION, 140N FABRIC
EXFILTRATION (IN/HR)
0
10
20
30
40
50
60
70
0
20
40
60
80
100
120
CUMM. VOL. (IN.)
T5-SETTLED
T13-NONSETTLED


SETTLED VS. NONSETTLED
SILTY SOIL, DRY CONDITION, 700XG FABRIC
EXFILTRATION (IN/HR)
0
10
20
30
40
50
60
70
0
20
40
60
80
100
120
CUMM. VOL. (IN.)
T6-SETTLED
T14-NONSETTLED


SETTLED VS. NONSETTLED
SILTY SOIL, WET CONDITION, 140N FABRIC
EXFILTRATION (IN/HR)
CUMM. VOL. (IN.)
T7-SETTLED
T15-NONSETTLED

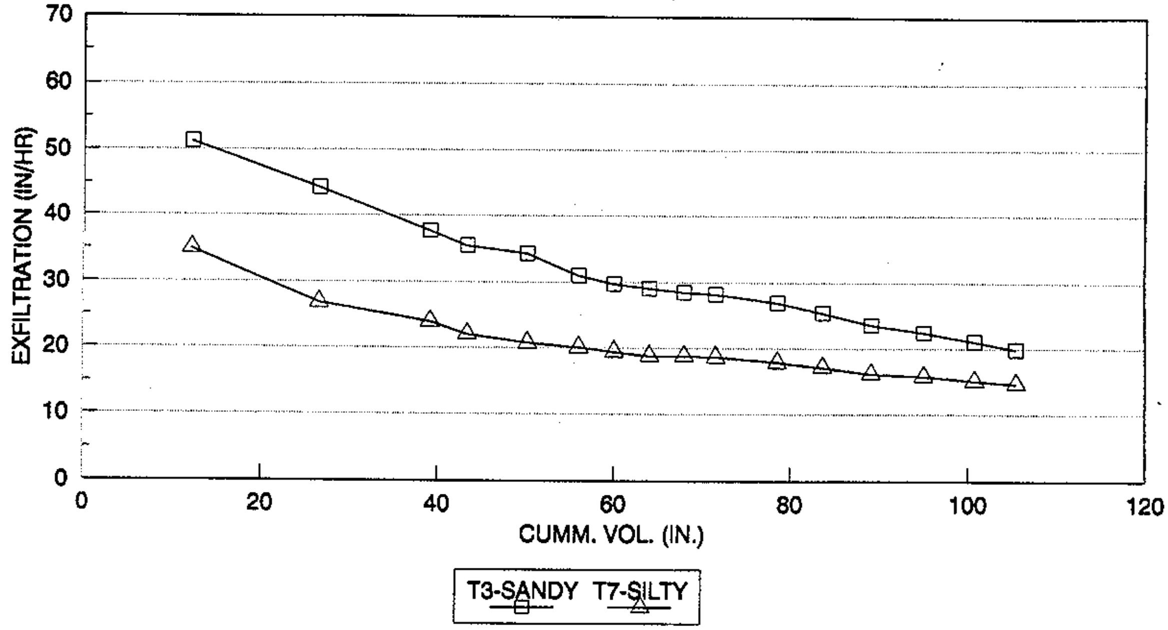

SETTLED VS. NONSETTLED
700XG
SILTY SOIL, WET CONDITION, 140N FABRIC
EXFILTRATION (IN/HR)
CUMM. VOL. (IN.)
T8-SETTLED
T16-NONSETTLED


SANDY VS. SILTY SOIL
SETTLED, DRY CONDITION, 140N FABRIC
EXFILTRATION (IN/HR)
70
60
50
40
30
20
10
0
0
20
40
60
80
100
120
CUMM. VOL. (IN.)
T1-SANDY
T5-SILTY


SANDY VS. SILTY SOIL
SETTLED, DRY CONDITION, 700XG FABRIC
EXFILTRATION (IN/HR)
70
60
50
40
30
20
10
0
0
20
40
60
80
100
120
CUMM. VOL. (IN.)
T2-SANDY
T6-SILTY

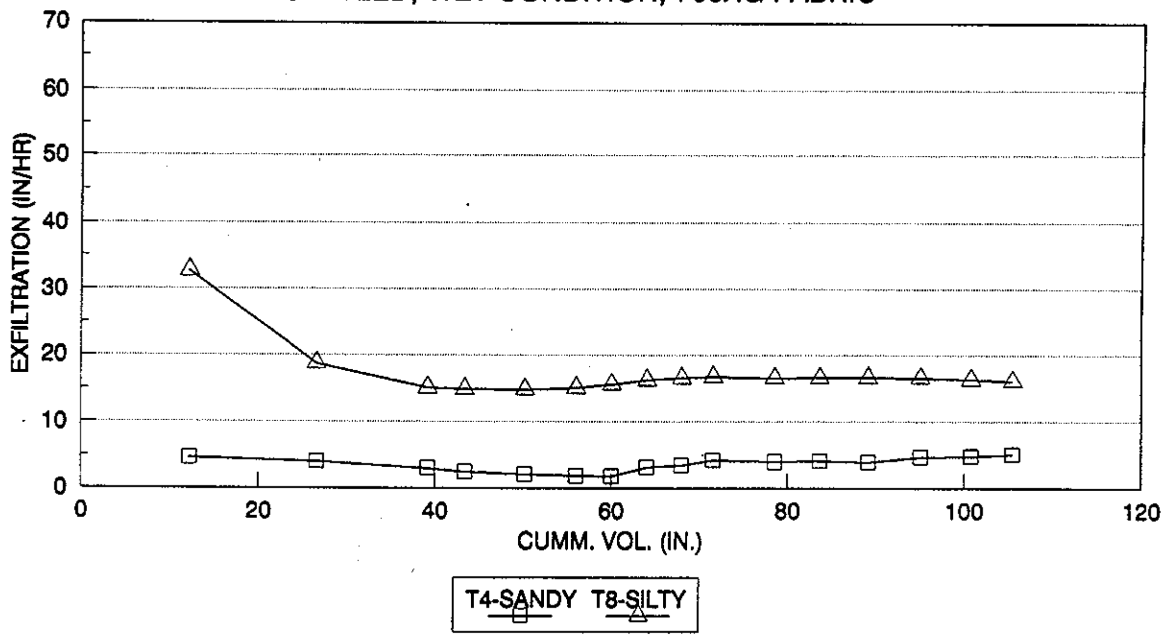
SANDY VS. SILTY SOIL

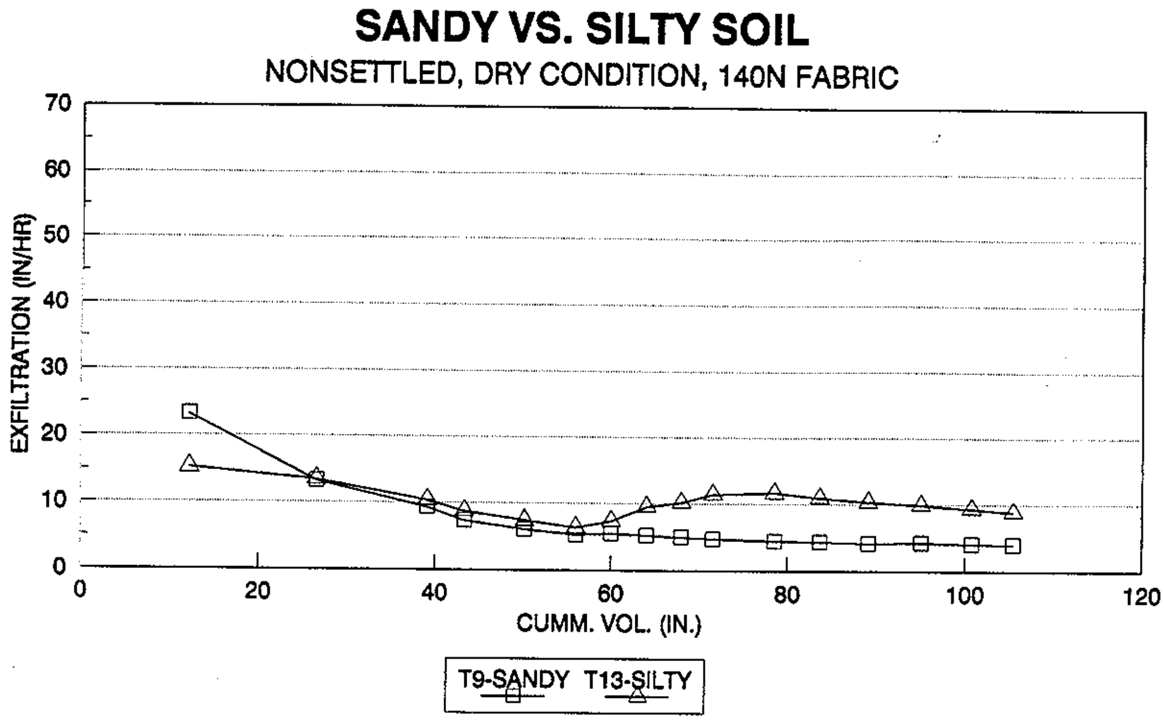
SETTLED, WET CONDITION, 140N FABRIC

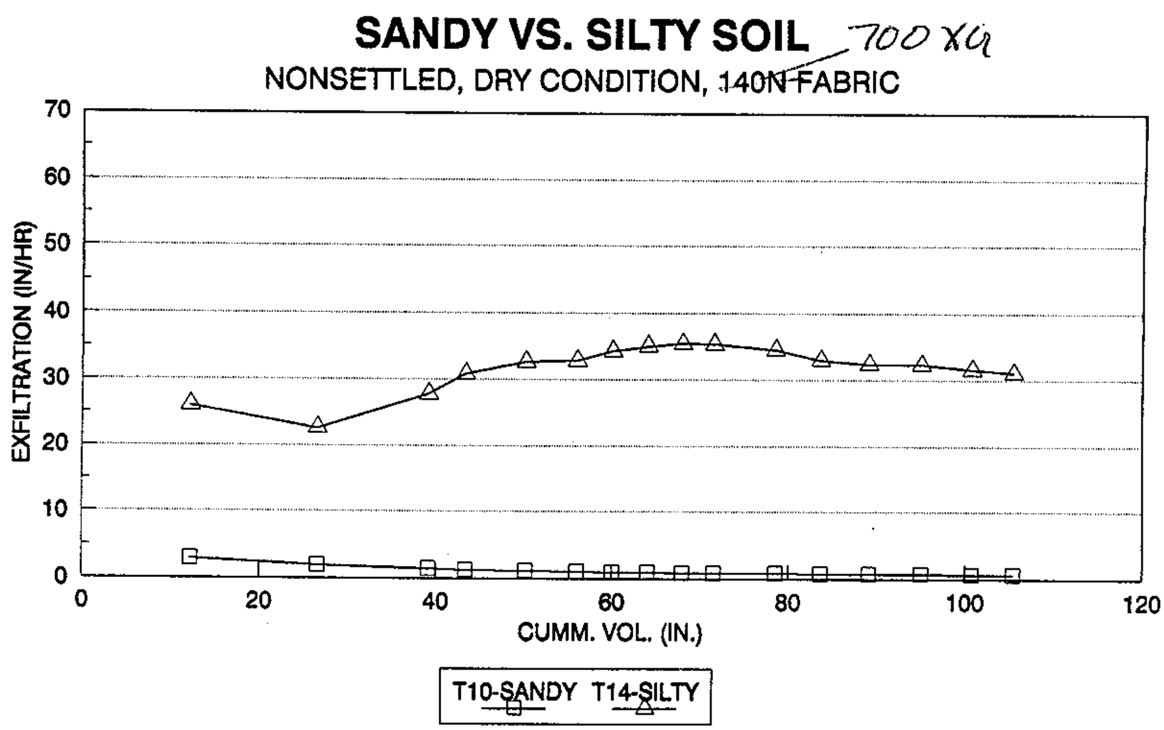


SANDY VS. SILTY SOIL

SETTLED, WET CONDITION, 700XG FABRIC

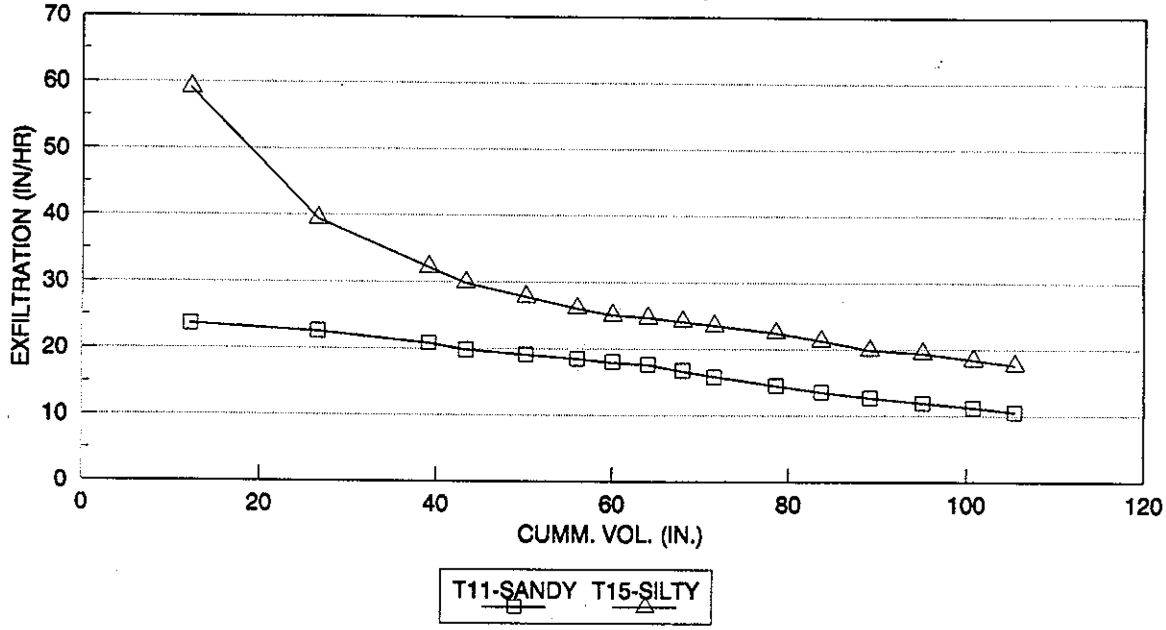



SANDY VS. SILTY SOIL
NONSETTLED, DRY CONDITION, 140N FABRIC
EXFILTRATION (IN/HR)
0
10
20
30
40
50
60
70
0
20
40
60
80
100
120
CUMM. VOL. (IN.)
T9-SANDY
T13-SILTY


SANDY VS. SILTY SOIL
700 XG
NONSETTLED, DRY CONDITION, 140N FABRIC
EXFILTRATION (IN/HR)
0
10
20
30
40
50
60
70
0
20
40
60
80
100
120
CUMM. VOL. (IN.)
T10-SANDY
T14-SILTY

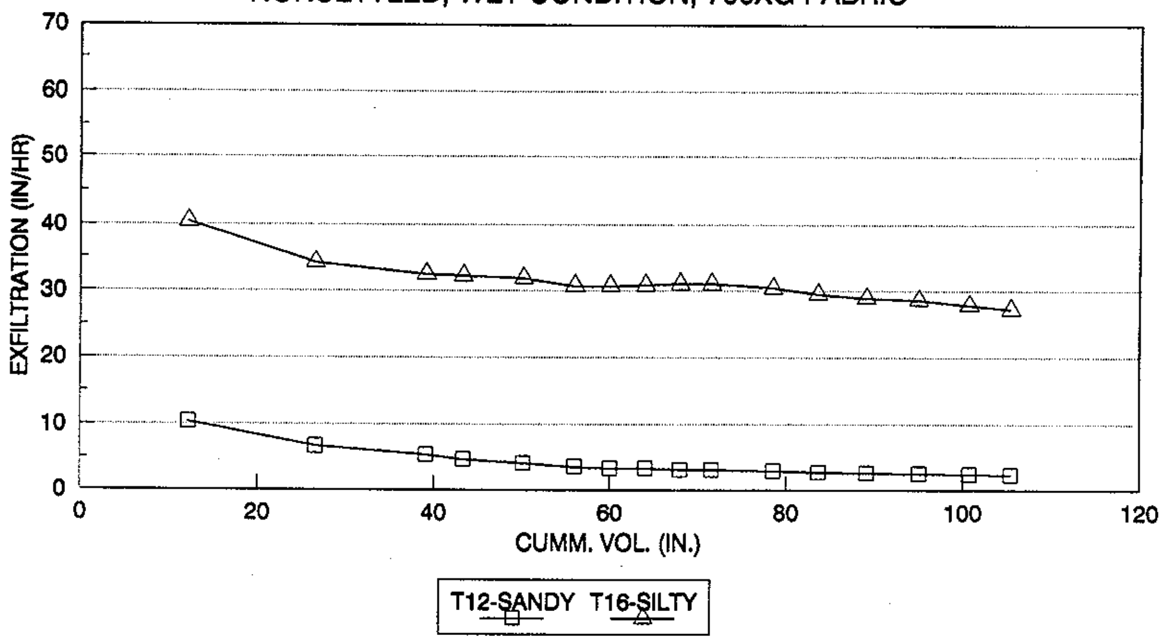
SANDY VS. SILTY SOIL

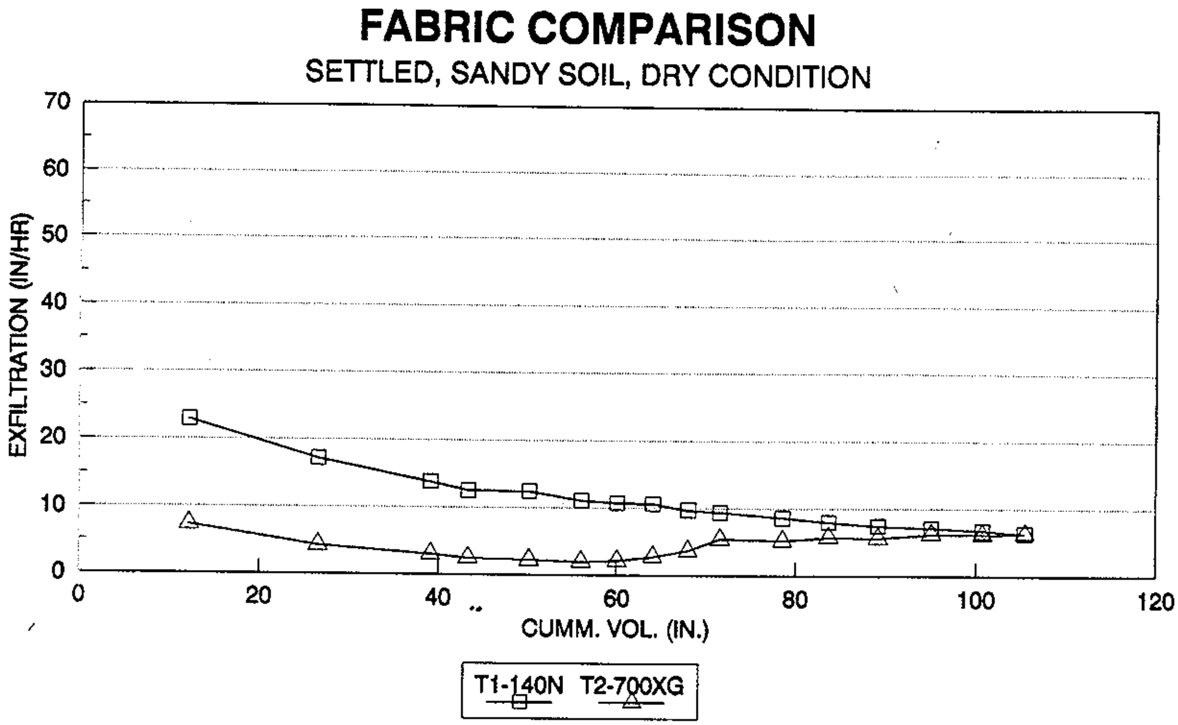
NONSETTLED, WET CONDITION, 140N FABRIC

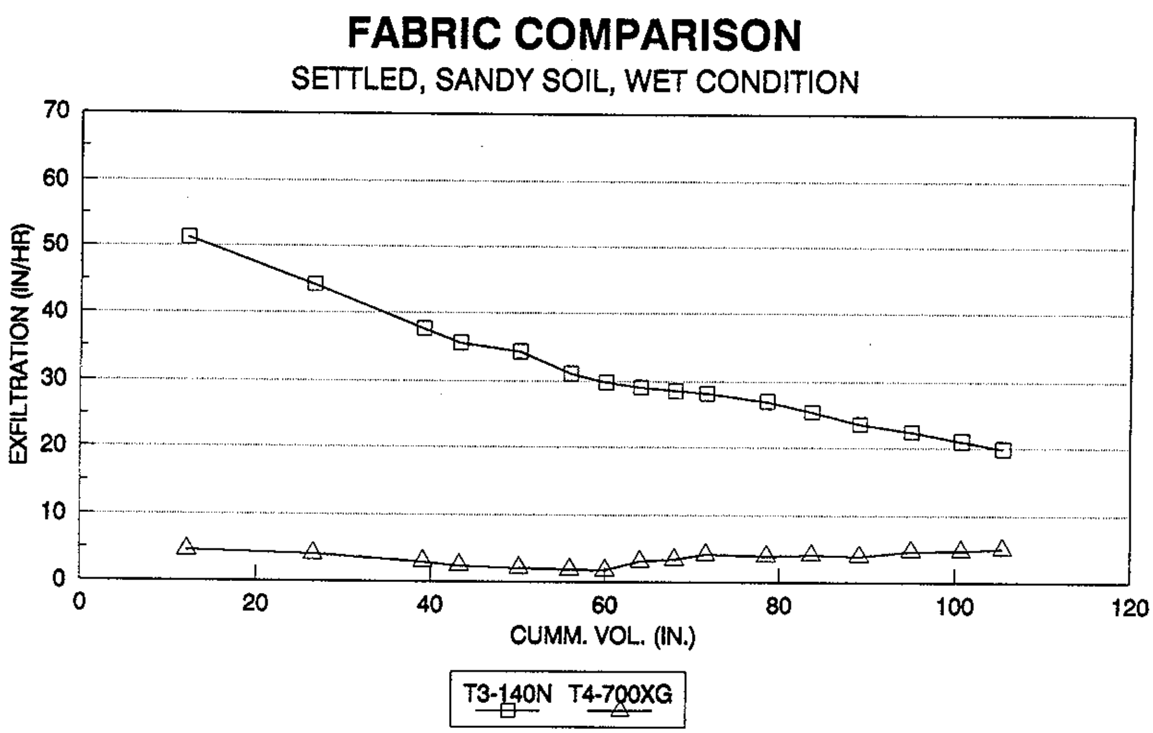


SANDY VS. SILTY SOIL

NONSETTLED, WET CONDITION, 700XG FABRIC

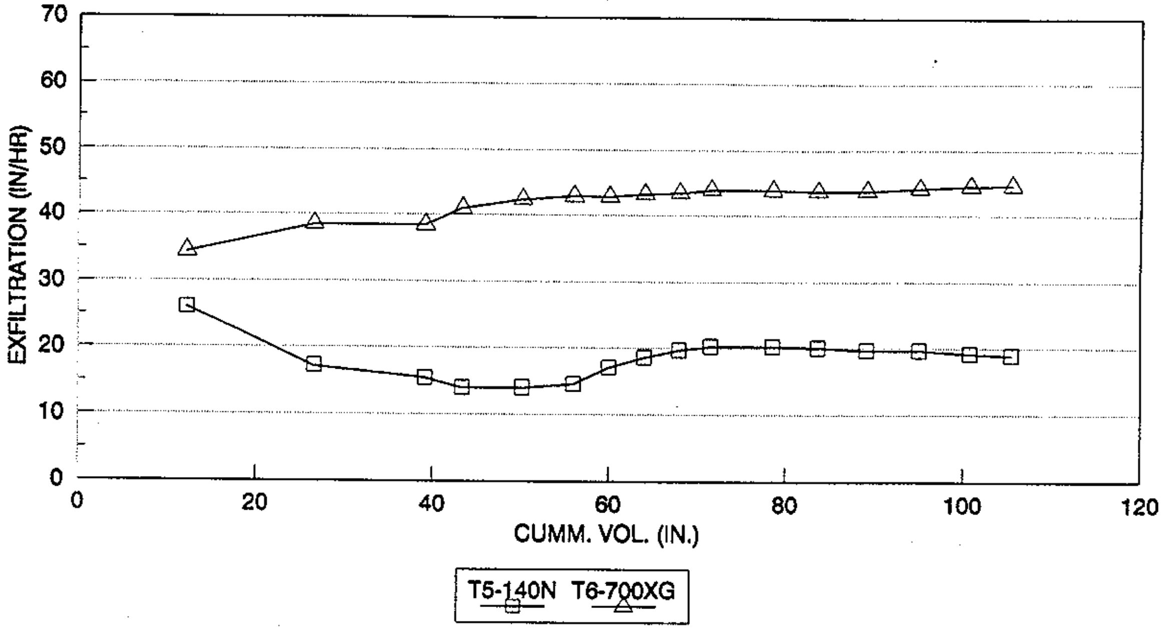



FABRIC COMPARISON
SETTLED, SANDY SOIL, DRY CONDITION
EXFILTRATION (IN/HR)
0
10
20
30
40
50
60
70
0
20
40
60
80
100
120
CUMM. VOL. (IN.)
T1-140N
T2-700XG


FABRIC COMPARISON
SETTLED, SANDY SOIL, WET CONDITION
EXFILTRATION (IN/HR)
0
10
20
30
40
50
60
70
0
20
40
60
80
100
120
CUMM. VOL. (IN.)
T3-140N
T4-700XG

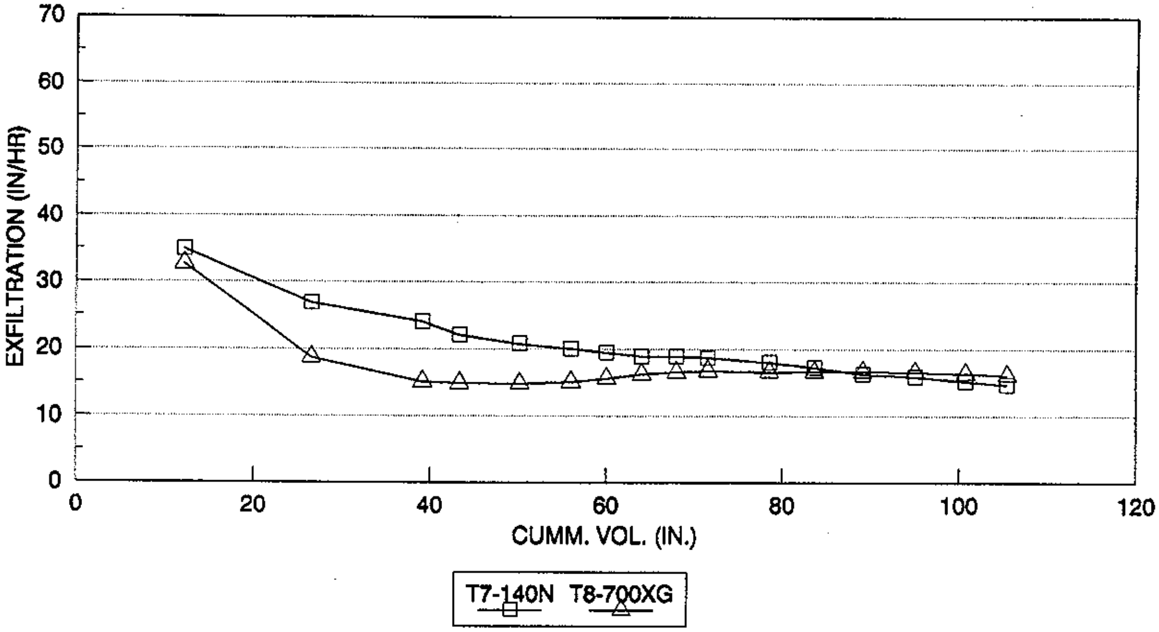
FABRIC COMPARISON

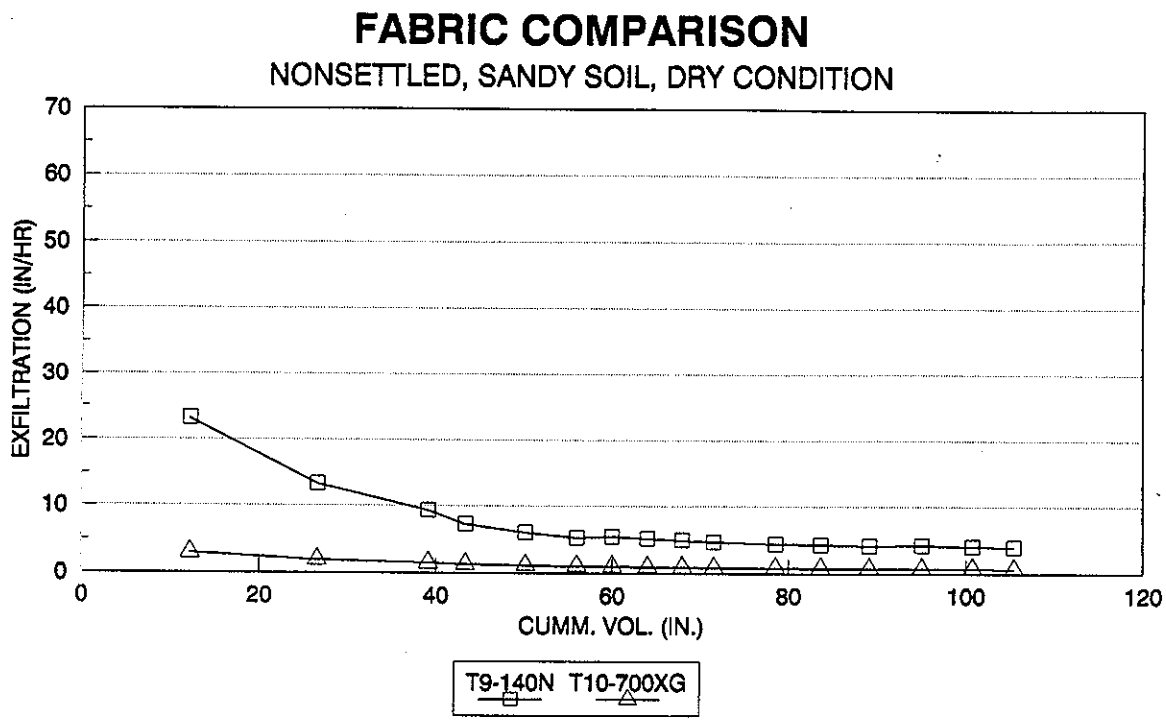
SETTLED, SILTY SOIL, DRY CONDITION



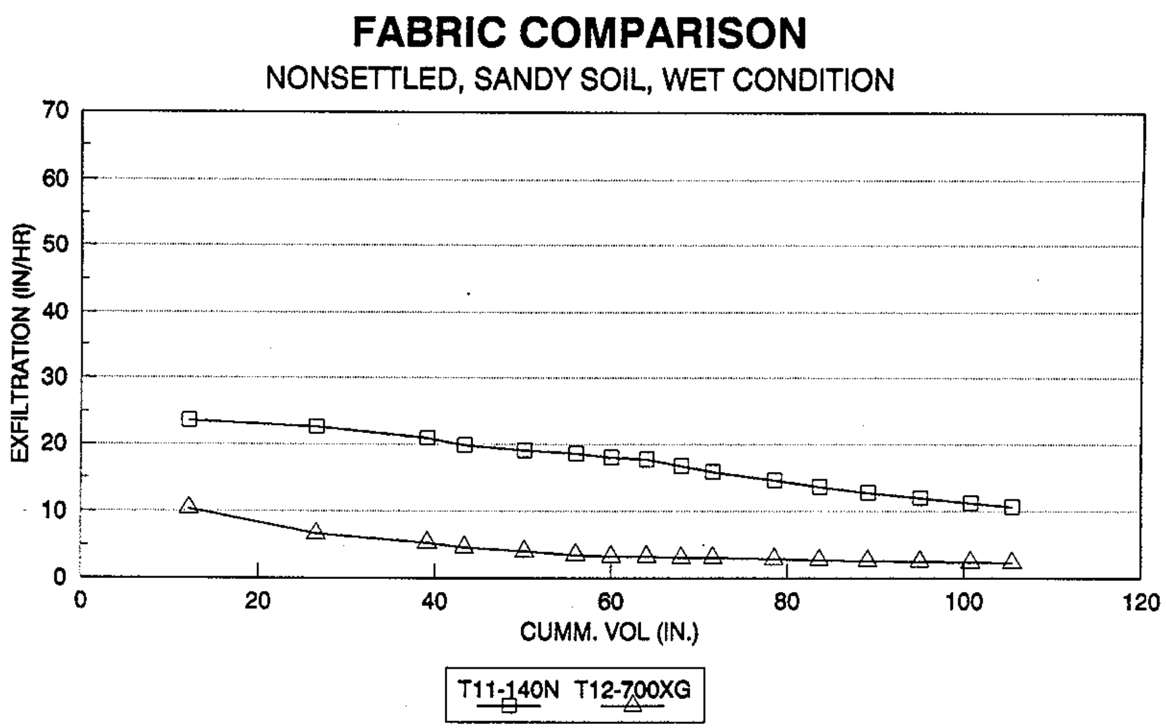
FABRIC COMPARISON

SETTLED, SILTY SOIL, WET CONDITION





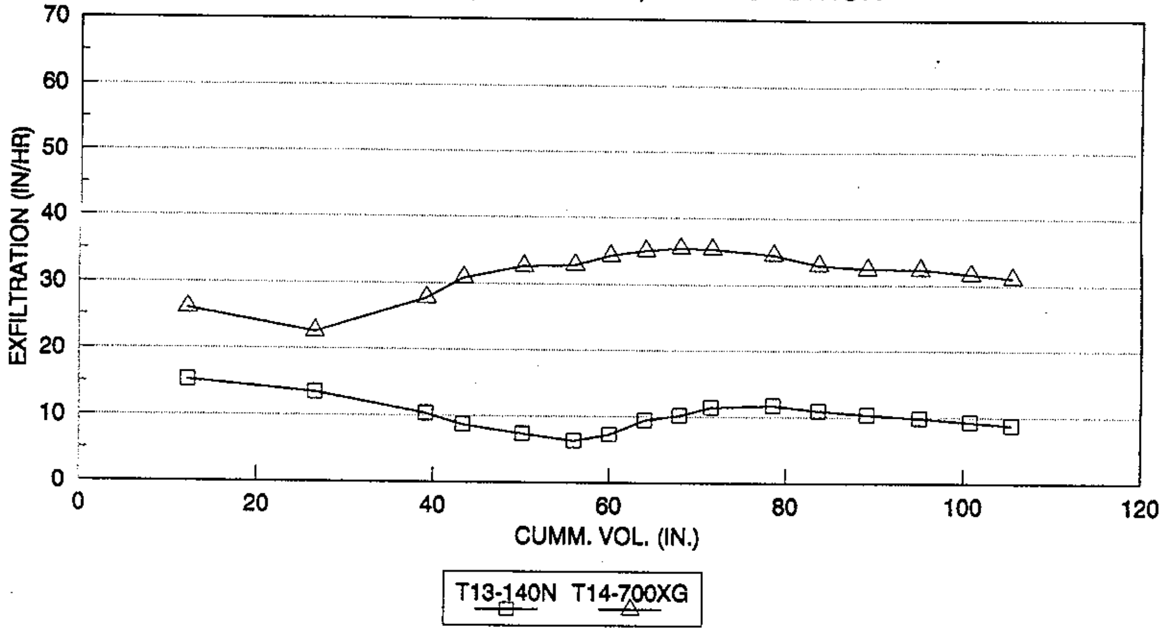
FABRIC COMPARISON
NONSETTLED, SANDY SOIL, DRY CONDITION
EXFILTRATION (IN/HR)
70
60
50
40
30
20
10
0
0
20
40
60
80
100
120
CUMM. VOL. (IN.)
T9-140N
T10-700XG



FABRIC COMPARISON
NONSETTLED, SANDY SOIL, WET CONDITION
EXFILTRATION (IN/HR)
70
60
50
40
30
20
10
0
0
20
40
60
80
100
120
CUMM. VOL (IN.)
T11-140N
T12-700XG

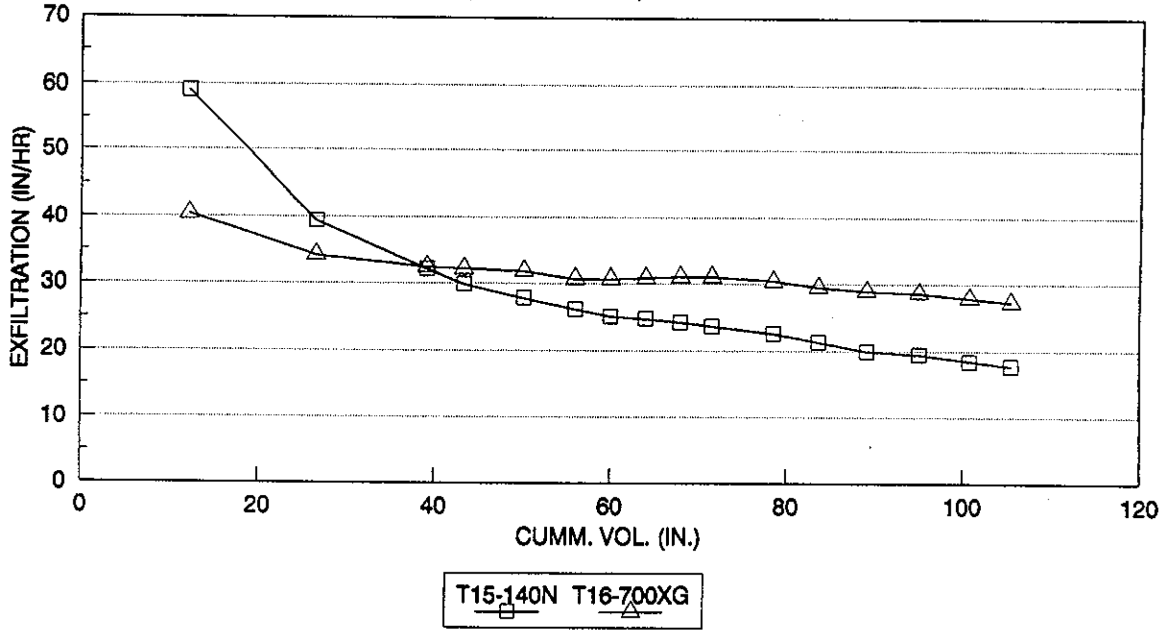
FABRIC COMPARISON

NONSETTLED, SILTY SOIL, DRY CONDITION

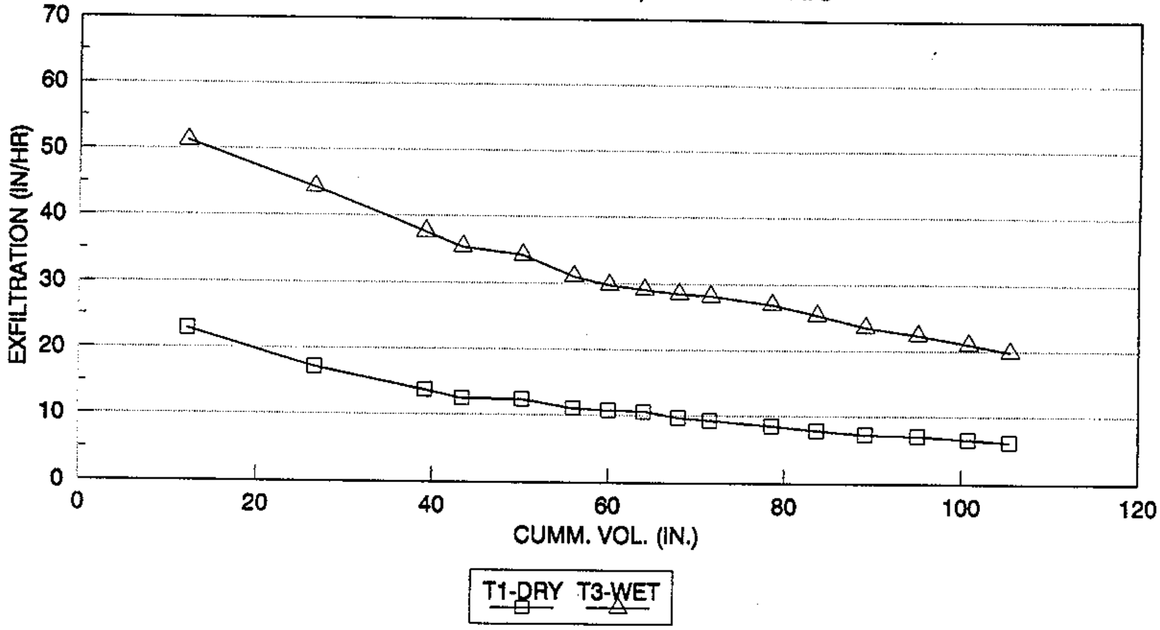


FABRIC COMPARISON

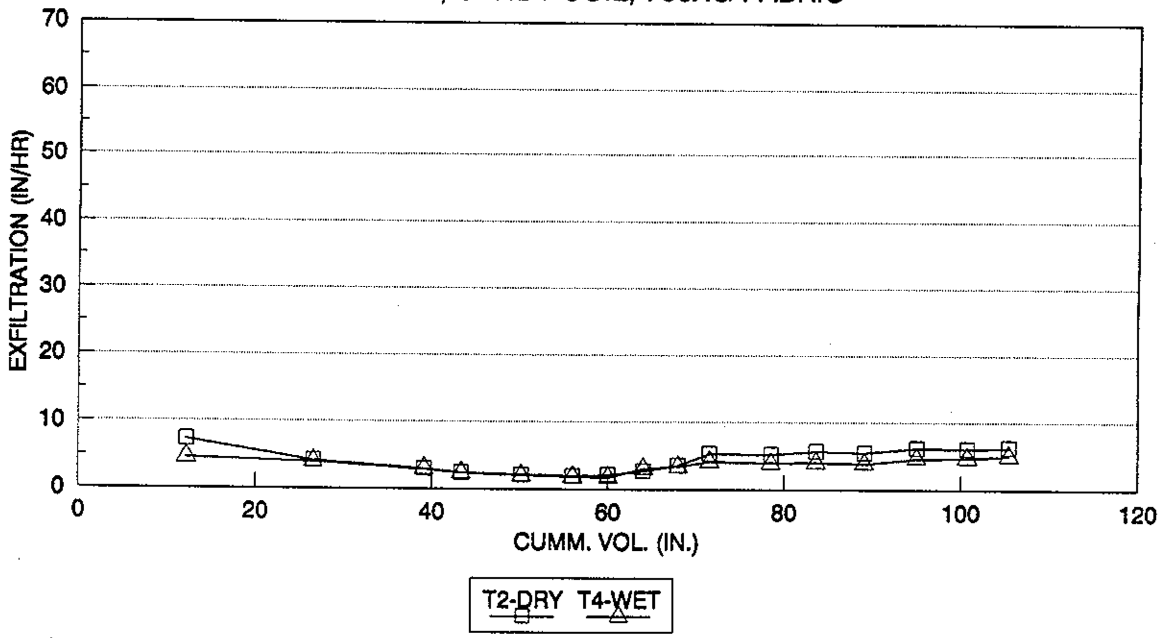
NONSETTLED, SITLY SOIL, WET CONDITION

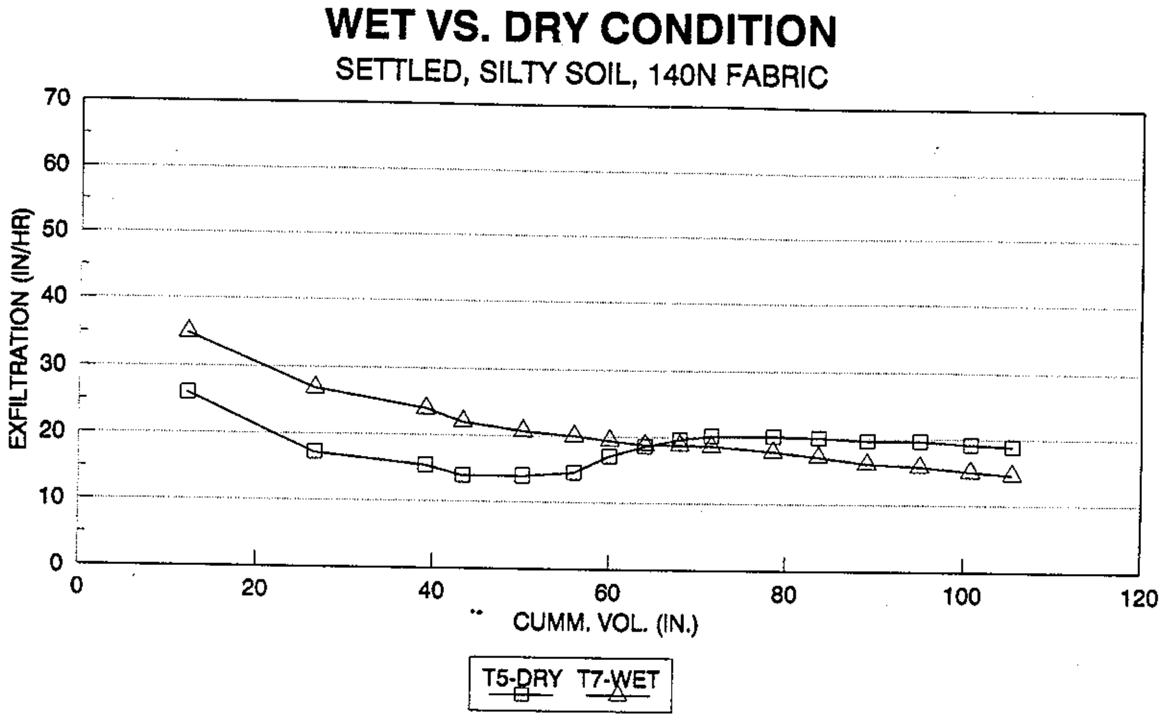


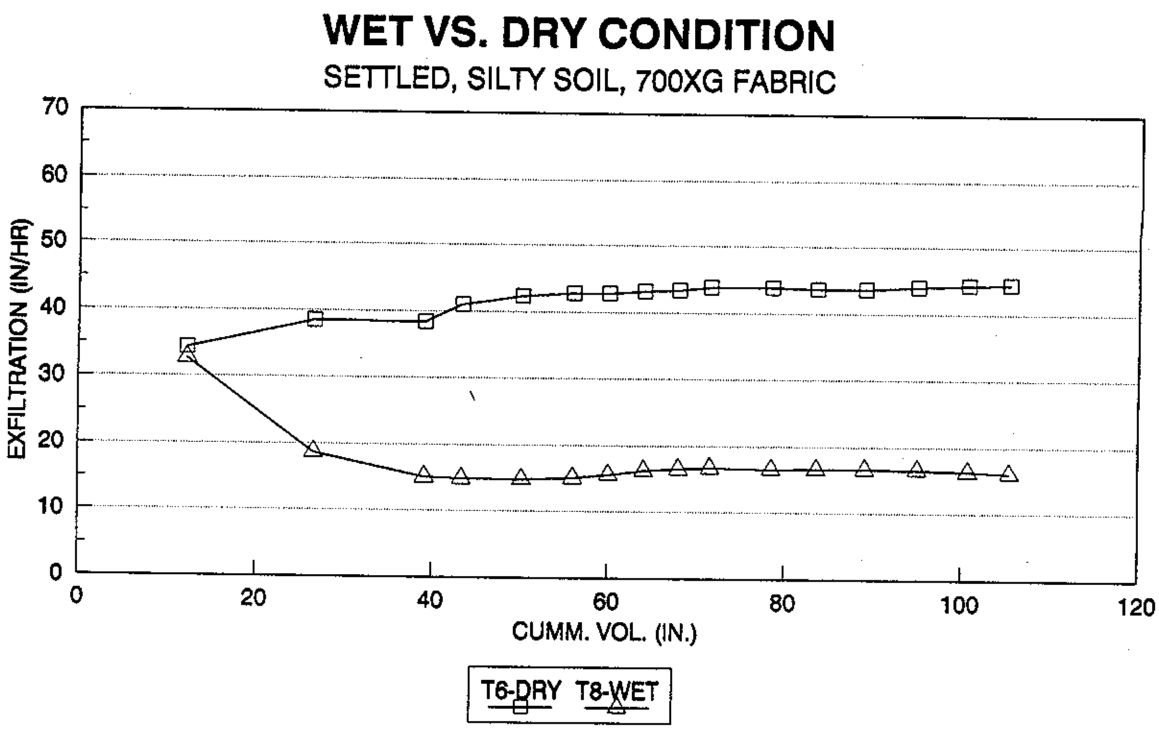
WET VS. DRY CONDITION
SETTLED, SANDY SOIL, 140N FABRIC



WET VS. DRY CONDITION
SETTLED, SANDY SOIL, 700XG FABRIC

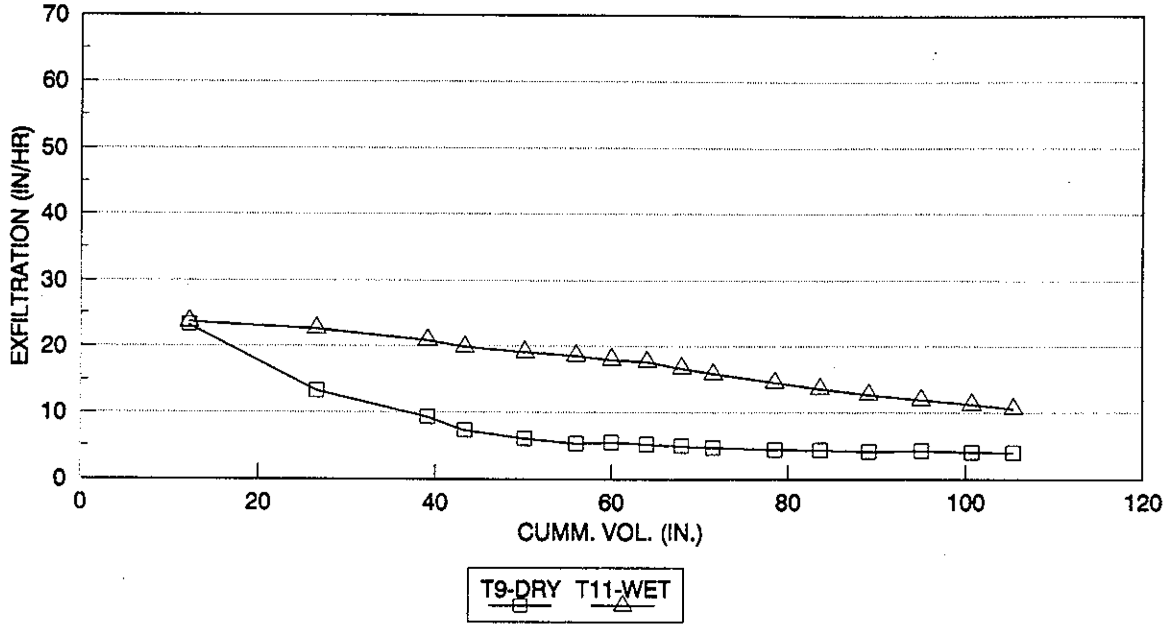



WET VS. DRY CONDITION
SETTLED, SILTY SOIL, 140N FABRIC
EXFILTRATION (IN/HR)
0
10
20
30
40
50
60
70
0
20
40
60
80
100
120
CUMM. VOL. (IN.)
T5-DRY
T7-WET


WET VS. DRY CONDITION
SETTLED, SILTY SOIL, 700XG FABRIC
EXFILTRATION (IN/HR)
0
10
20
30
40
50
60
70
0
20
40
60
80
100
120
CUMM. VOL. (IN.)
T6-DRY
T8-WET

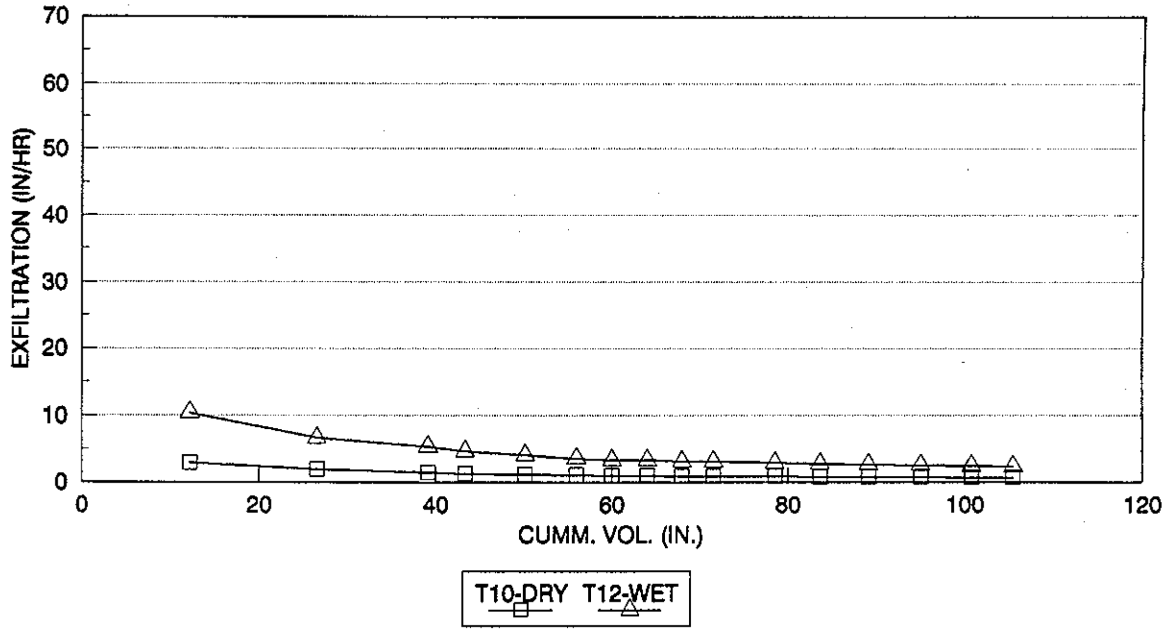
WET VS. DRY CONDITION

NONSETTLED, SANDY SOIL, 140N FABRIC



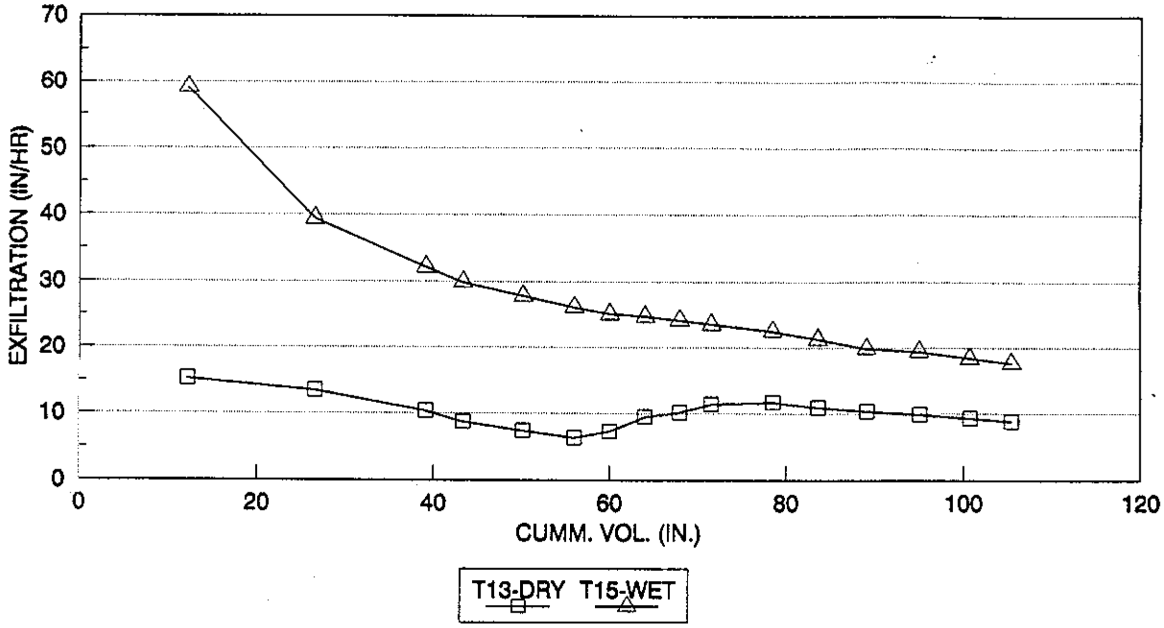
WET VS. DRY CONDITION

NONSETTLED, SANDY SOIL, 700XG FABRIC



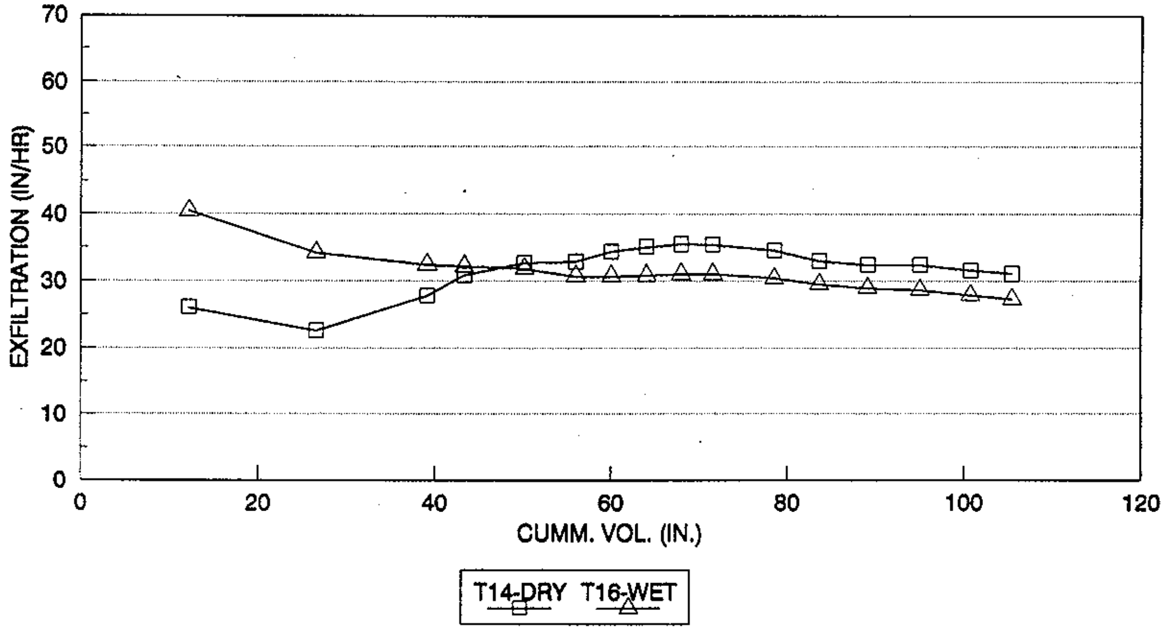
WET VS. DRY CONDITION

NONSETTLED, SILTY SOIL, 140N FABRIC



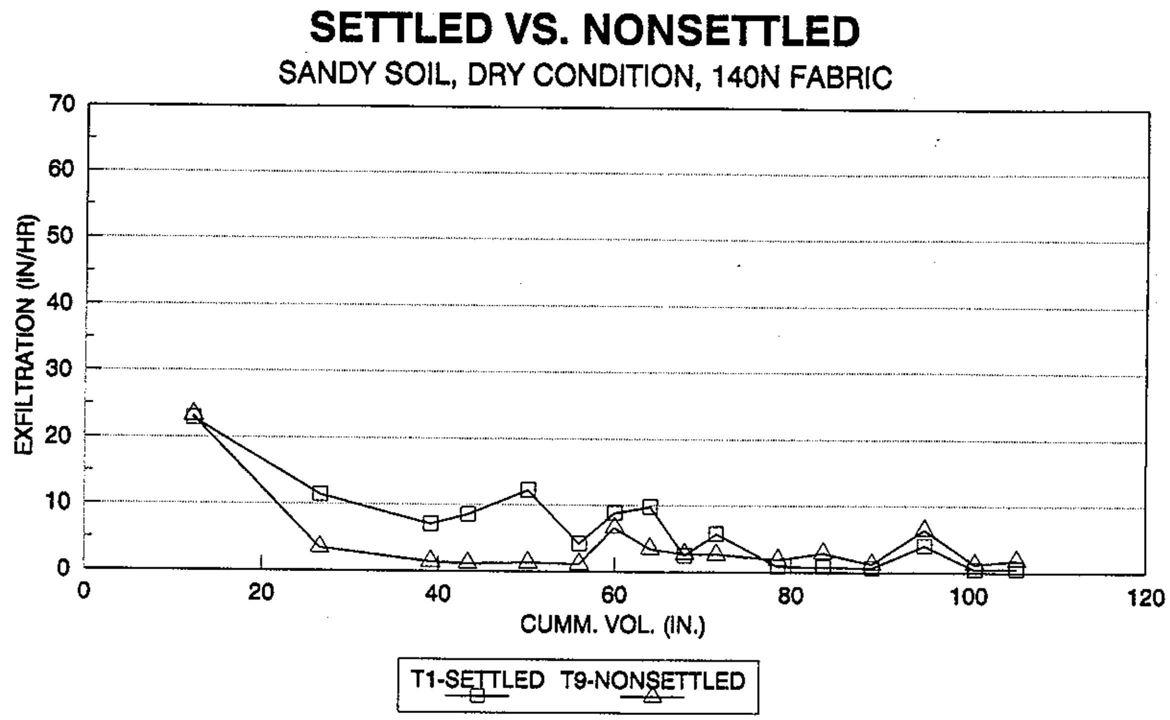
WET VS. DRY CONDITION

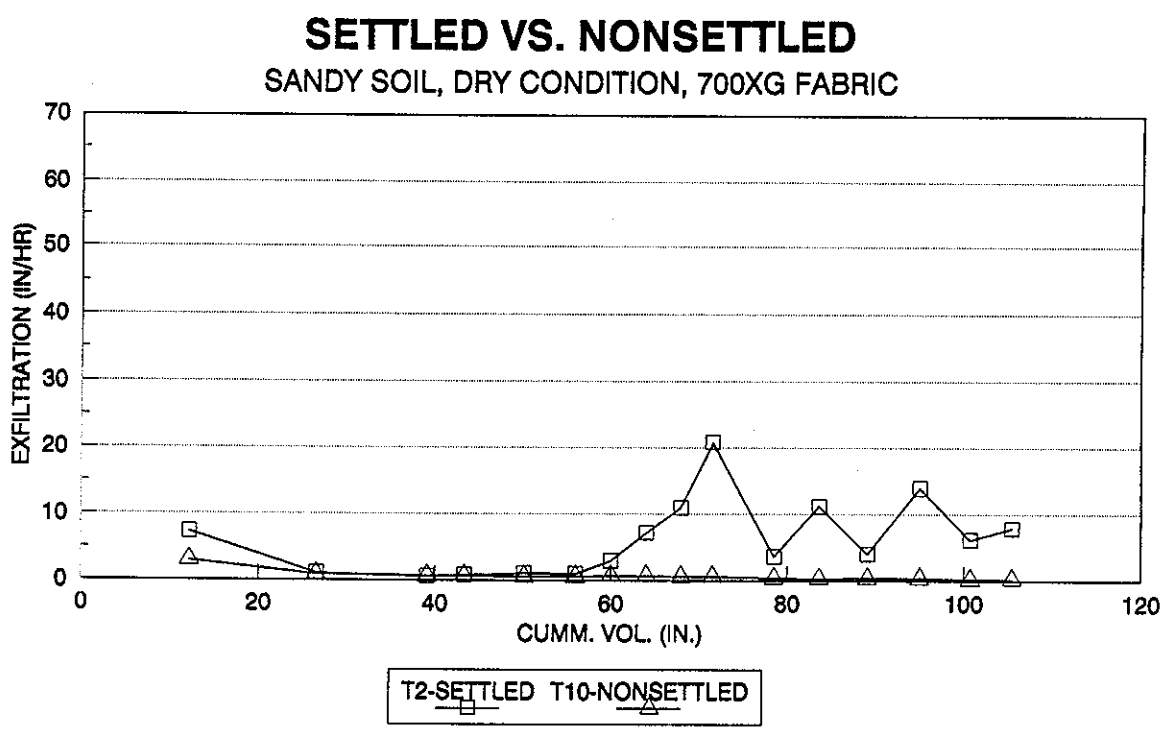
NONSETTLED, SILTY SOIL, 700XG FABRIC

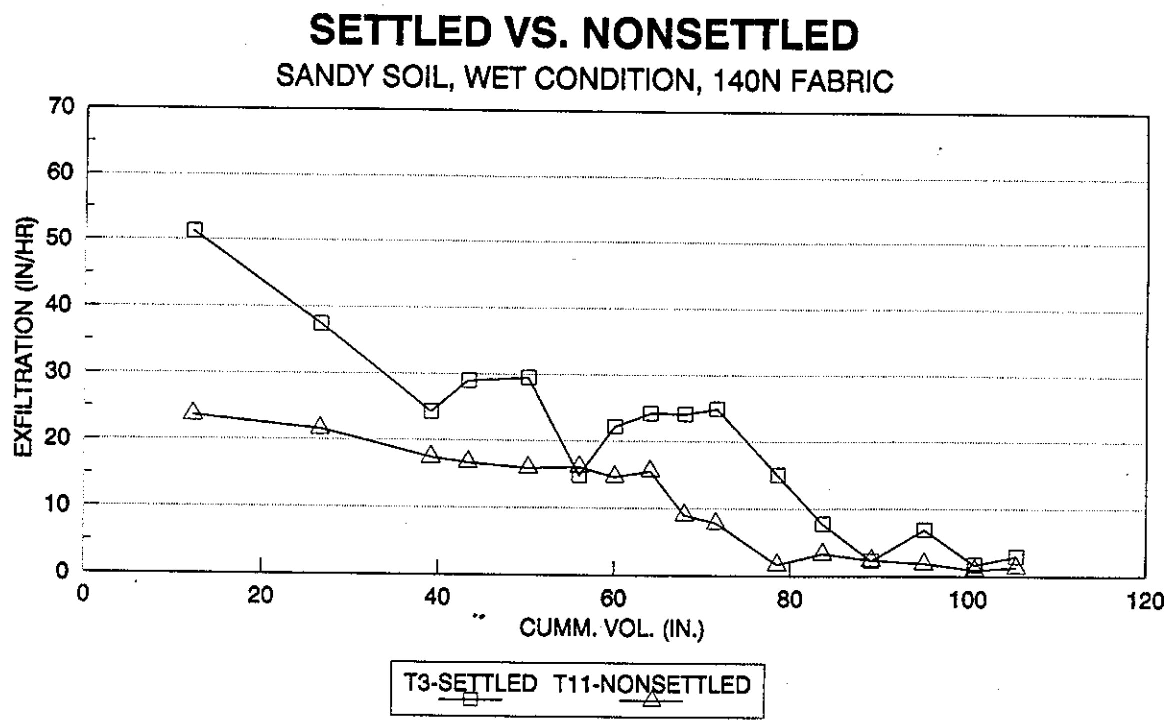


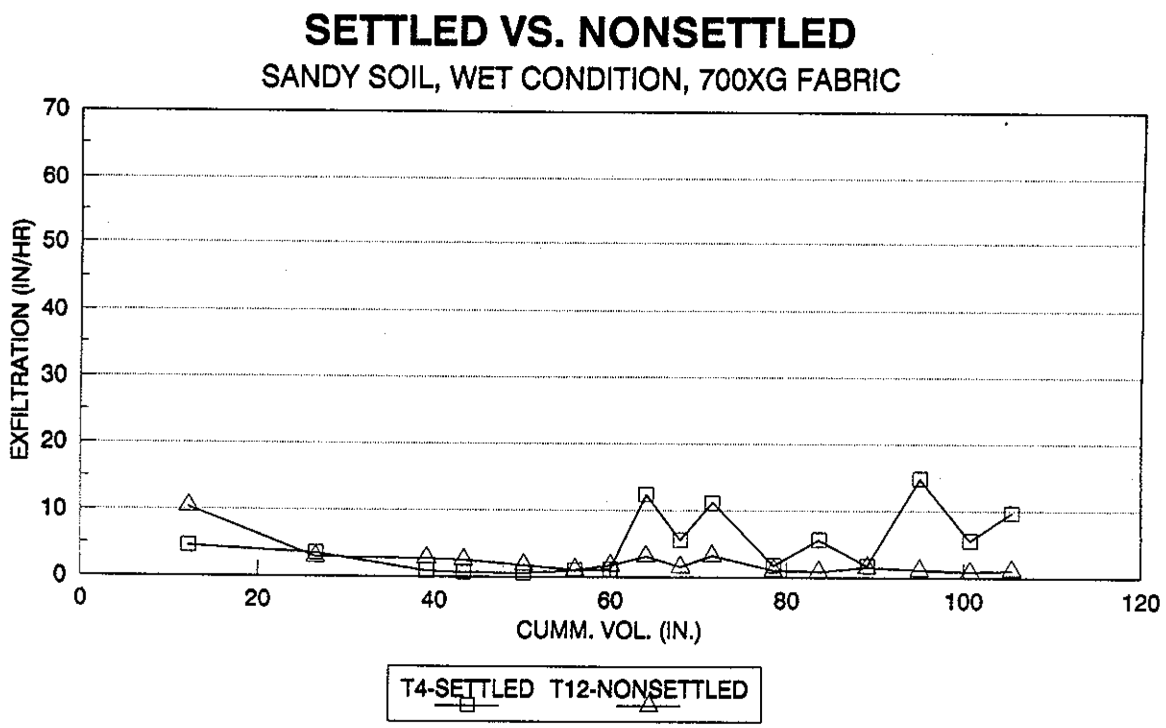
APPENDIX C-2

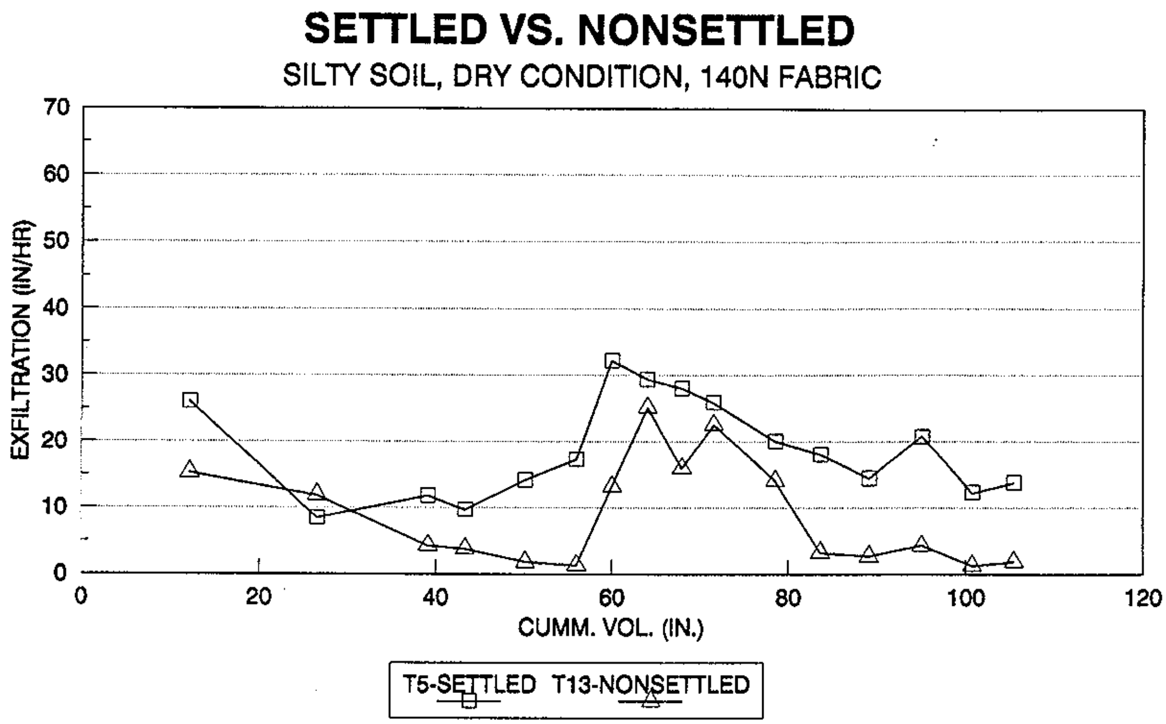
RAW DATA

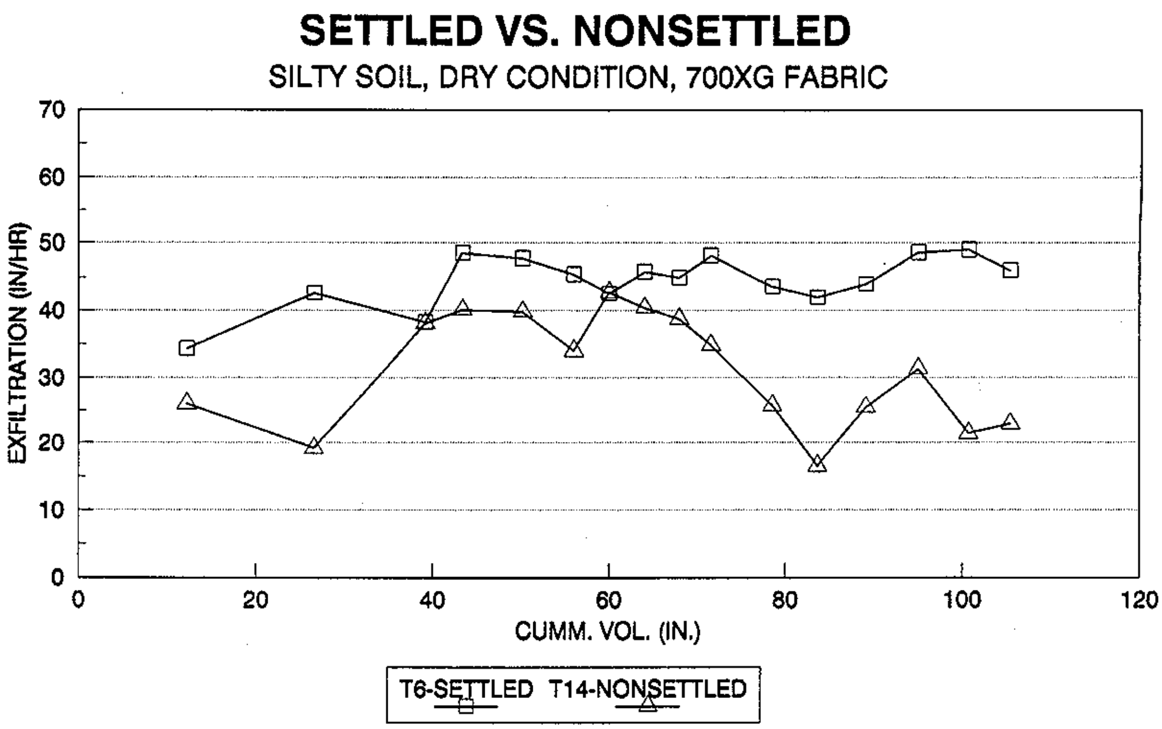

SETTLED VS. NONSETTLED
SANDY SOIL, DRY CONDITION, 140N FABRIC
EXFILTRATION (IN/HR)
0
10
20
30
40
50
60
70
0
20
40
60
80
100
120
CUMM. VOL. (IN.)
T1-SETTLED
T9-NONSETTLED

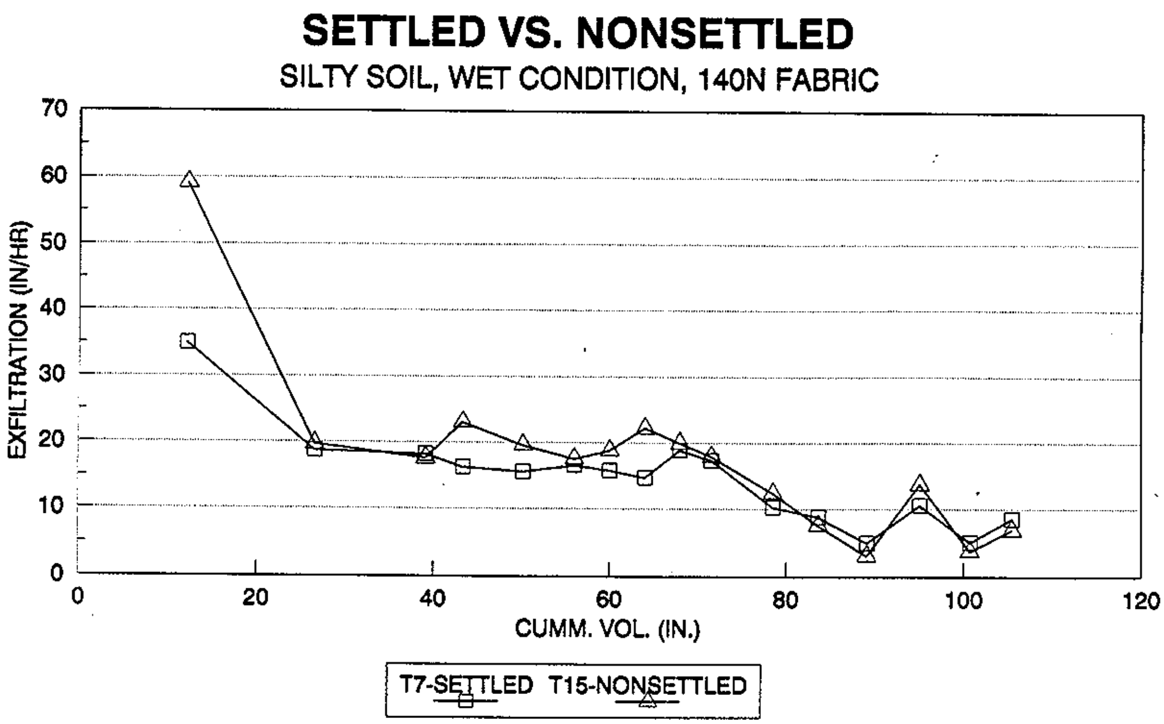

SETTLED VS. NONSETTLED
SANDY SOIL, DRY CONDITION, 700XG FABRIC
EXFILTRATION (IN/HR)
0
10
20
30
40
50
60
70
0
20
40
60
80
100
120
CUMM. VOL. (IN.)
T2-SETTLED
T10-NONSETTLED


SETTLED VS. NONSETTLED
SANDY SOIL, WET CONDITION, 140N FABRIC
EXFILTRATION (IN/HR)
0
10
20
30
40
50
60
70
0
20
40
60
80
100
120
CUMM. VOL. (IN.)
T3-SETTLED
T11-NONSETTLED

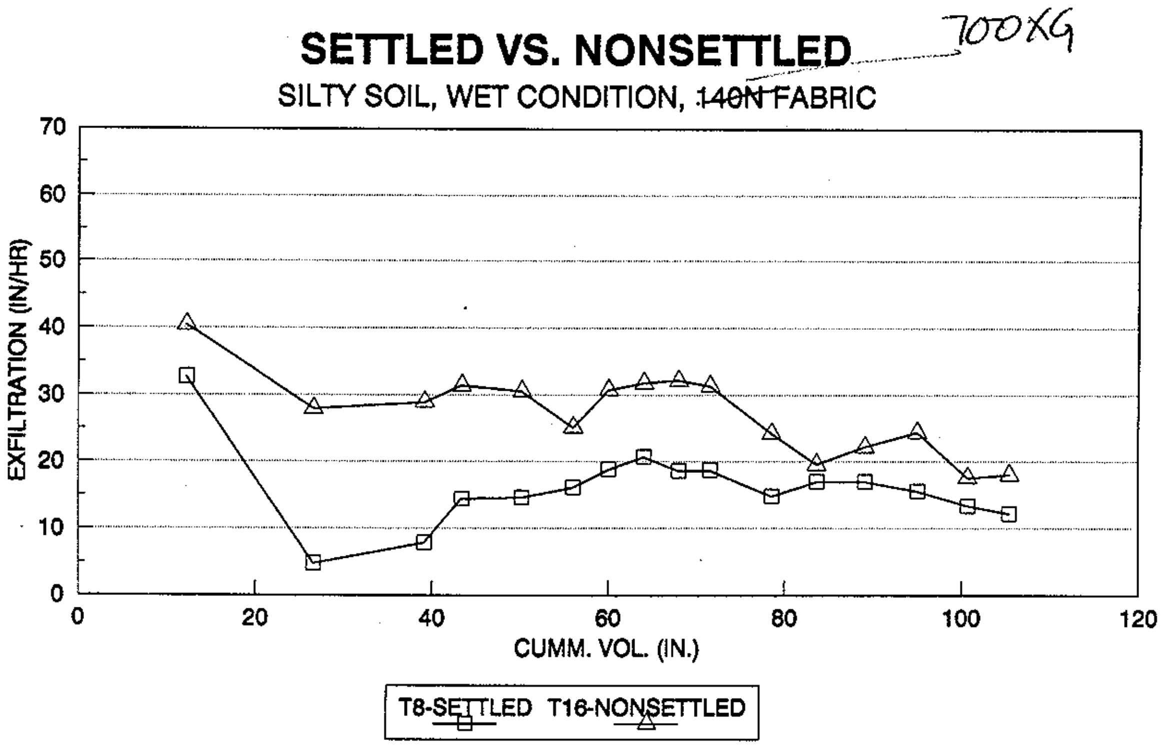

SETTLED VS. NONSETTLED
SANDY SOIL, WET CONDITION, 700XG FABRIC
EXFILTRATION (IN/HR)
0
10
20
30
40
50
60
70
0
20
40
60
80
100
120
CUMM. VOL. (IN.)
T4-SETTLED
T12-NONSETTLED


SETTLED VS. NONSETTLED
SILTY SOIL, DRY CONDITION, 140N FABRIC
EXFILTRATION (IN/HR)
70
60
50
40
30
20
10
0
0
20
40
60
80
100
120
CUMM. VOL. (IN.)
T5-SETTLED
T13-NONSETTLED

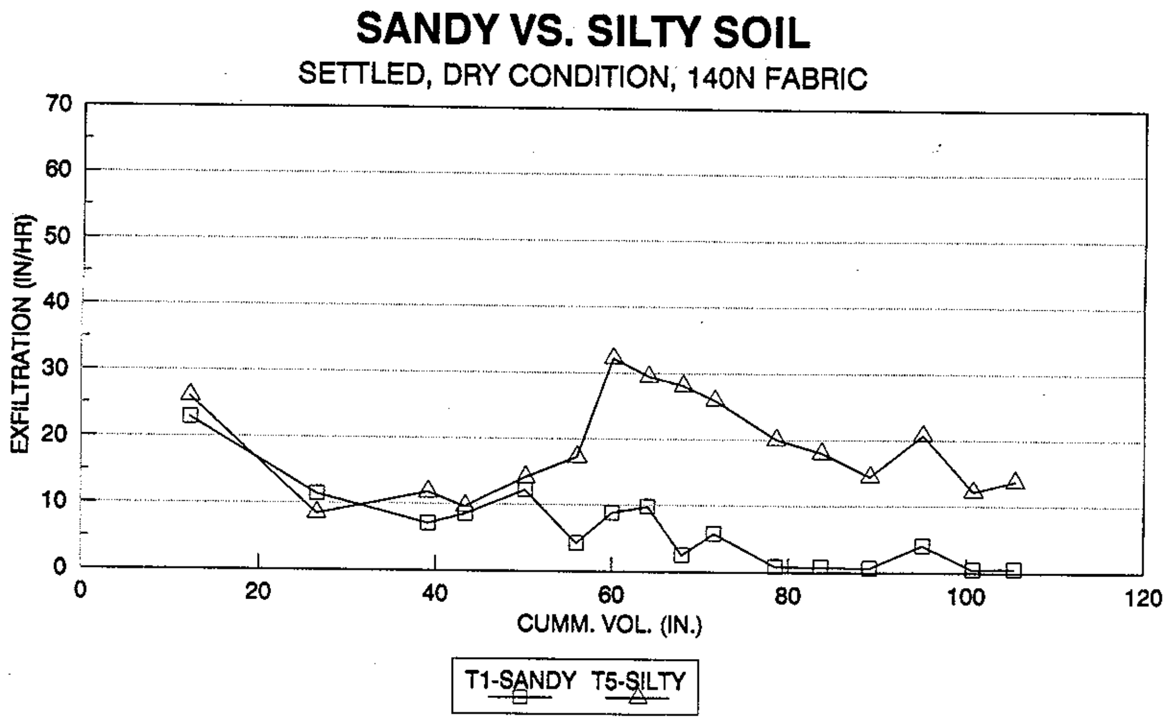

SETTLED VS. NONSETTLED
SILTY SOIL, DRY CONDITION, 700XG FABRIC
EXFILTRATION (IN/HR)
70
60
50
40
30
20
10
0
0
20
40
60
80
100
120
CUMM. VOL. (IN.)
T6-SETTLED
T14-NONSETTLED

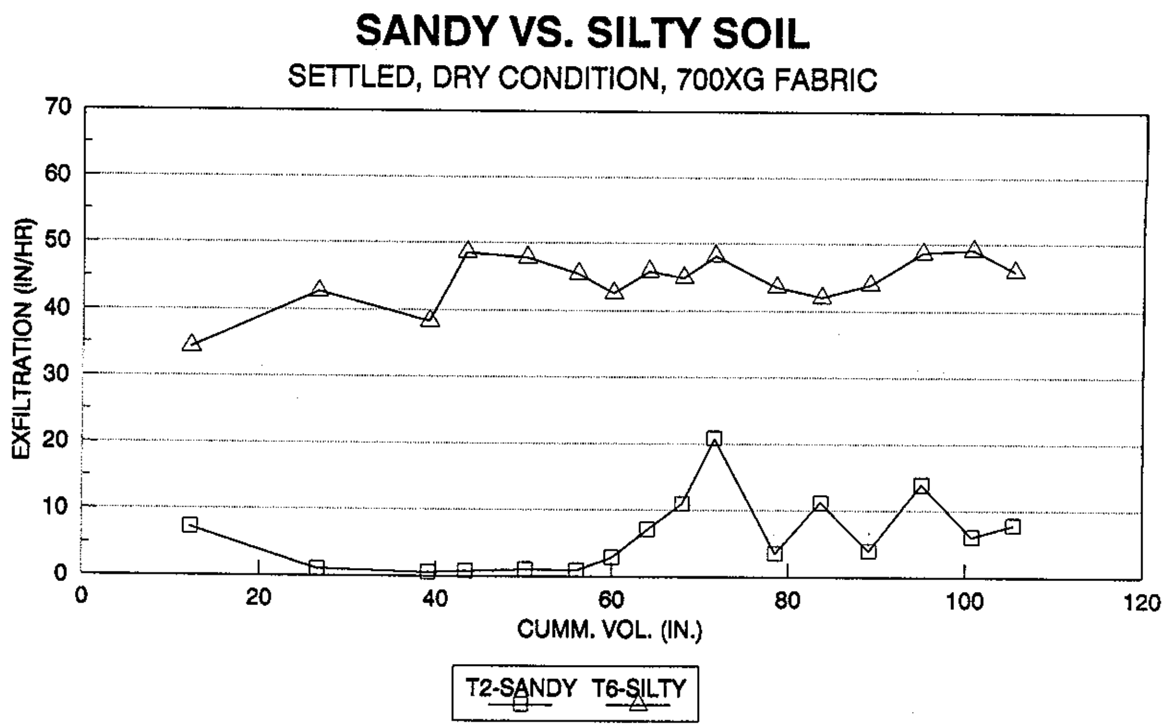


SETTLED VS. NONSETTLED
SILTY SOIL, WET CONDITION, 140N FABRIC
EXFILTRATION (IN/HR)
CUMM. VOL. (IN.)
T7-SETTLED
T15-NONSETTLED



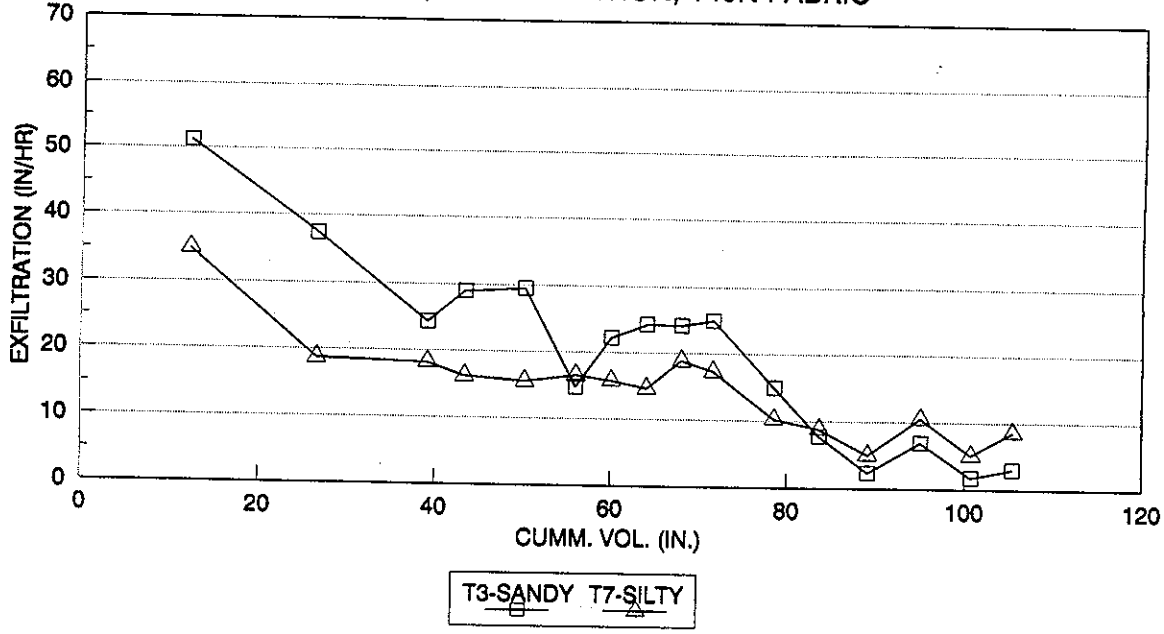
SETTLED VS. NONSETTLED
700XG
SILTY SOIL, WET CONDITION, 140N FABRIC
EXFILTRATION (IN/HR)
CUMM. VOL. (IN.)
T8-SETTLED
T16-NONSETTLED


SANDY VS. SILTY SOIL
SETTLED, DRY CONDITION, 140N FABRIC
EXFILTRATION (IN/HR)
0
10
20
30
40
50
60
70
0
20
40
60
80
100
120
CUMM. VOL. (IN.)
T1-SANDY
T5-SILTY


SANDY VS. SILTY SOIL
SETTLED, DRY CONDITION, 700XG FABRIC
EXFILTRATION (IN/HR)
0
10
20
30
40
50
60
70
0
20
40
60
80
100
120
CUMM. VOL. (IN.)
T2-SANDY
T6-SILTY

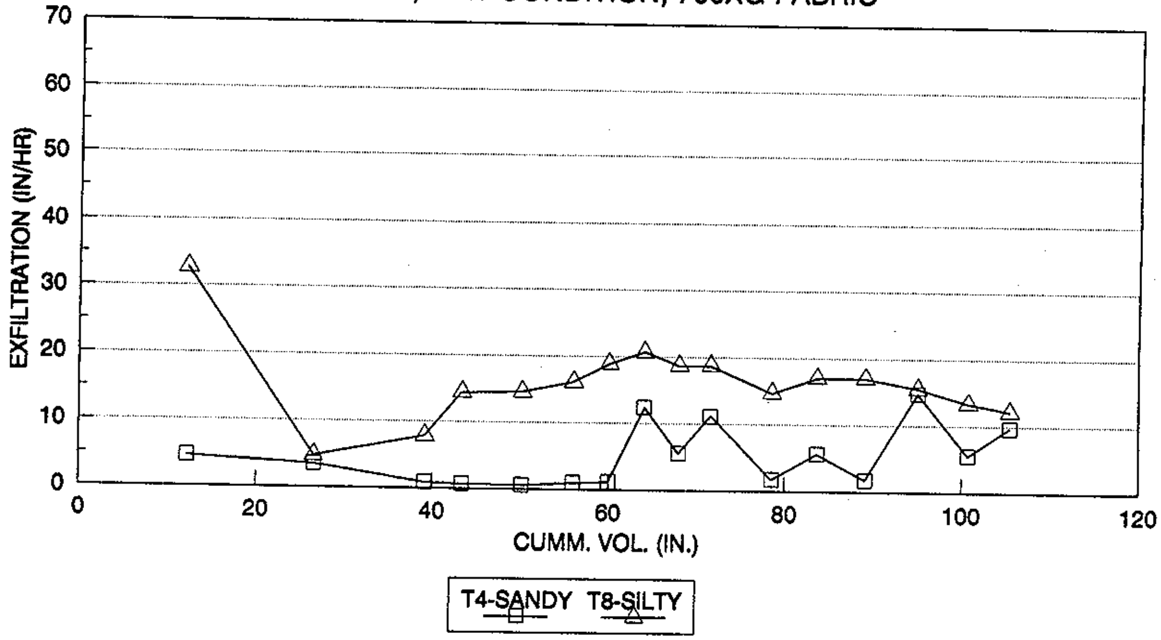
SANDY VS. SILTY SOIL

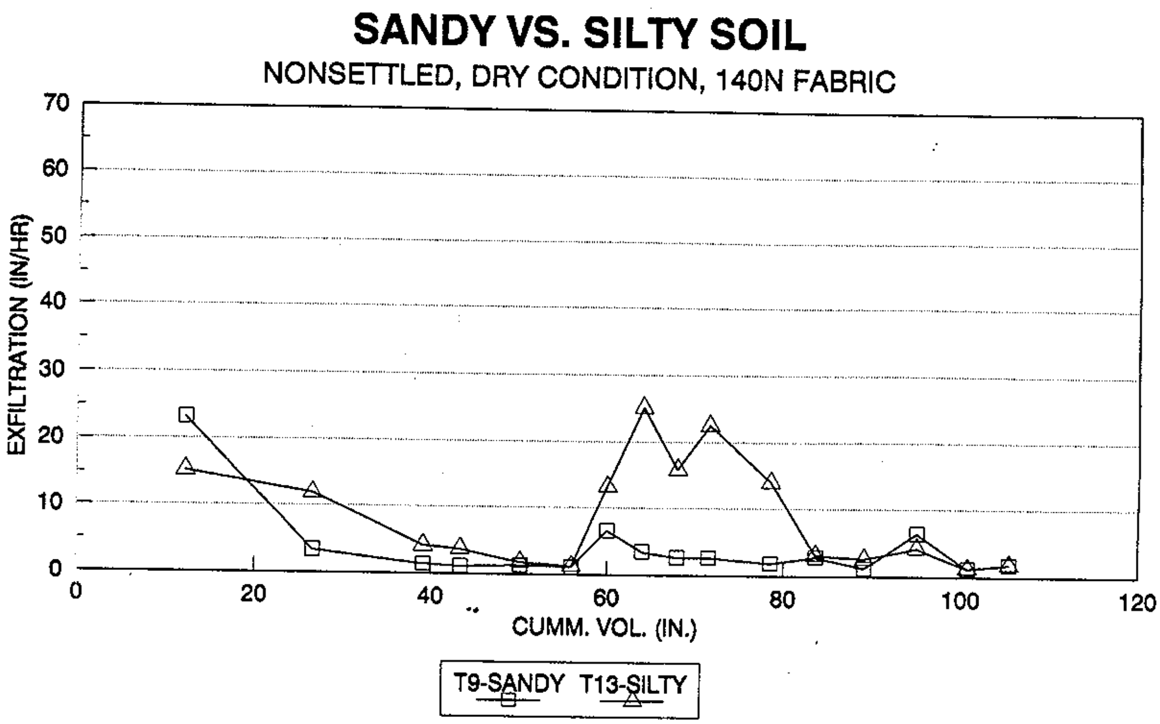
SETTLED, WET CONDITION, 140N FABRIC

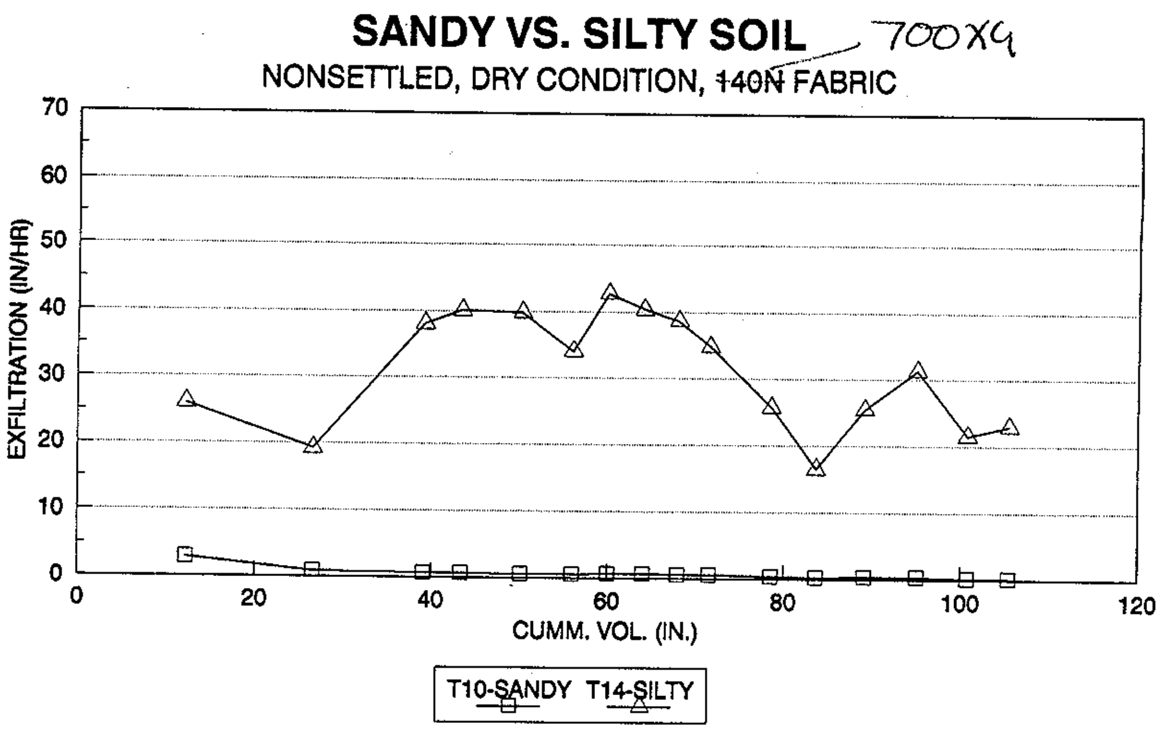


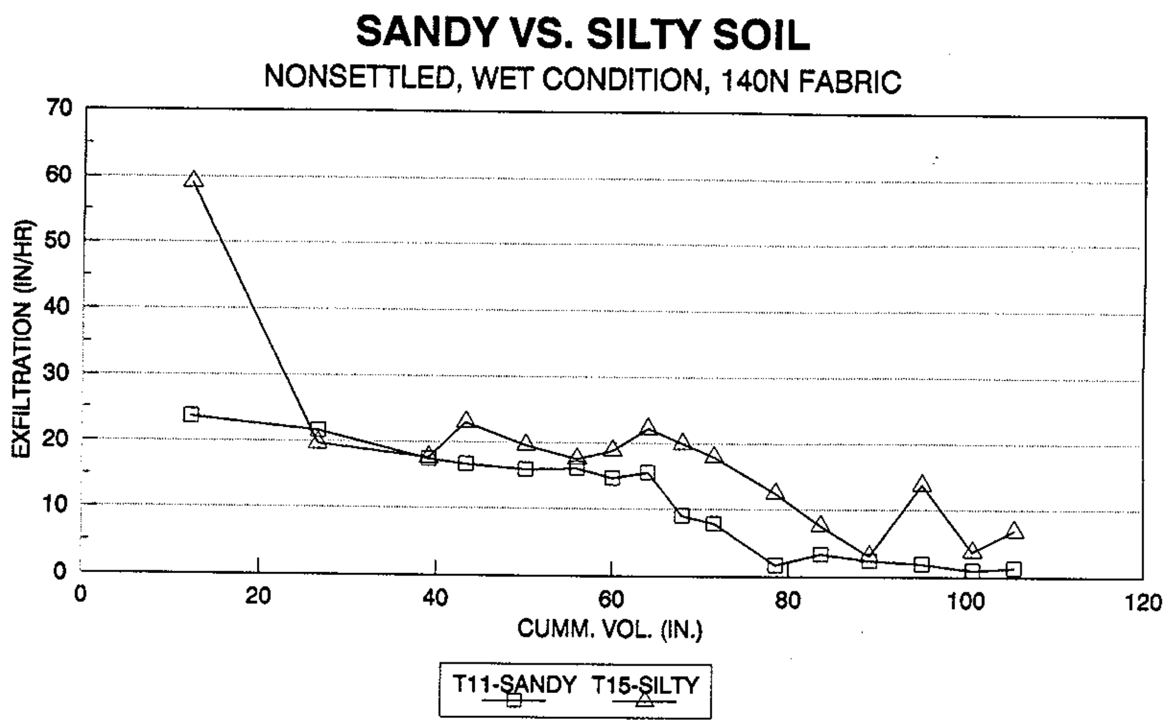
SANDY VS. SILTY SOIL

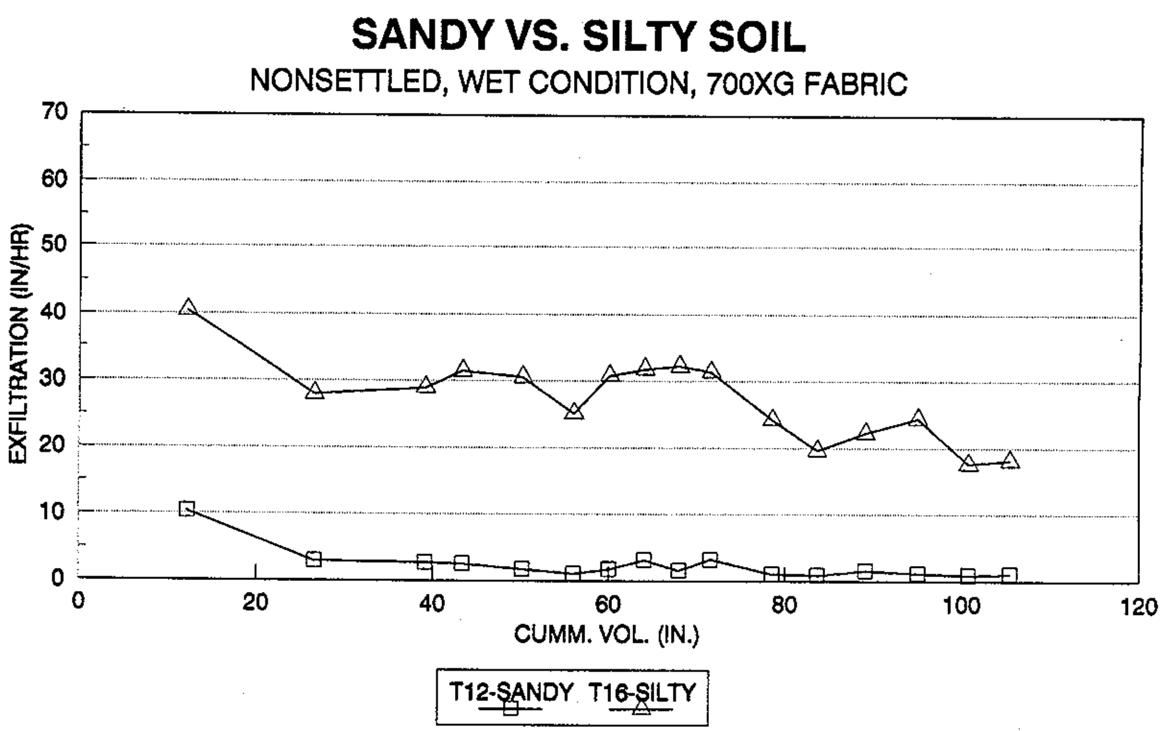
SETTLED, WET CONDITION, 700XG FABRIC




SANDY VS. SILTY SOIL
NONSETTLED, DRY CONDITION, 140N FABRIC
EXFILTRATION (IN/HR)
0
10
20
30
40
50
60
70
CUMM. VOL. (IN.)
0
20
40
60
80
100
120
T9-SANDY
T13-SILTY

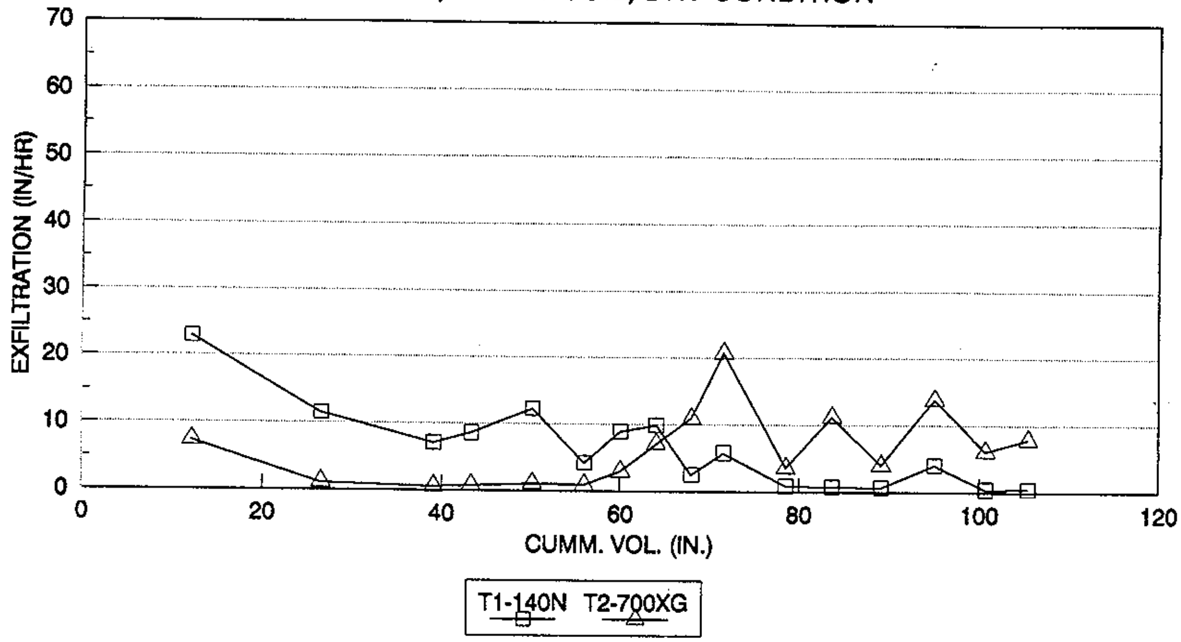

SANDY VS. SILTY SOIL
700X4
NONSETTLED, DRY CONDITION, 140N FABRIC
EXFILTRATION (IN/HR)
0
10
20
30
40
50
60
70
CUMM. VOL. (IN.)
0
20
40
60
80
100
120
T10-SANDY
T14-SILTY


SANDY VS. SILTY SOIL
NONSETTLED, WET CONDITION, 140N FABRIC
EXFILTRATION (IN/HR)
70
60
50
40
30
20
10
0
0
20
40
60
80
100
120
CUMM. VOL. (IN.)
T11-SANDY
T15-SILTY


SANDY VS. SILTY SOIL
NONSETTLED, WET CONDITION, 700XG FABRIC
EXFILTRATION (IN/HR)
70
60
50
40
30
20
10
0
0
20
40
60
80
100
120
CUMM. VOL. (IN.)
T12-SANDY
T16-SILTY

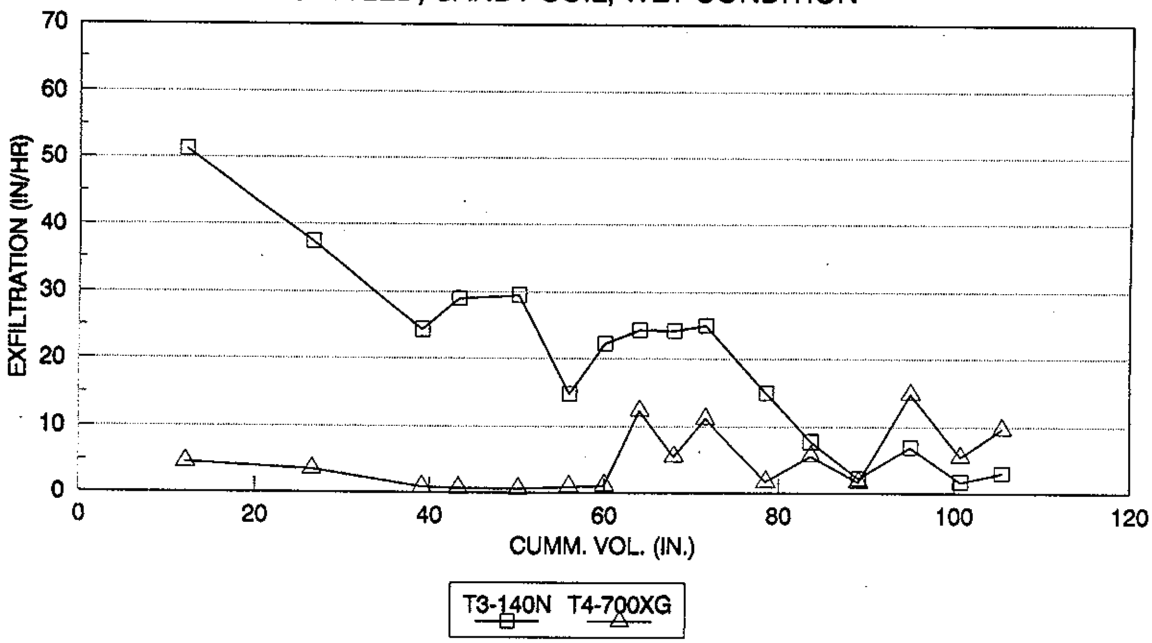
FABRIC COMPARISON

SETTLED, SANDY SOIL, DRY CONDITION



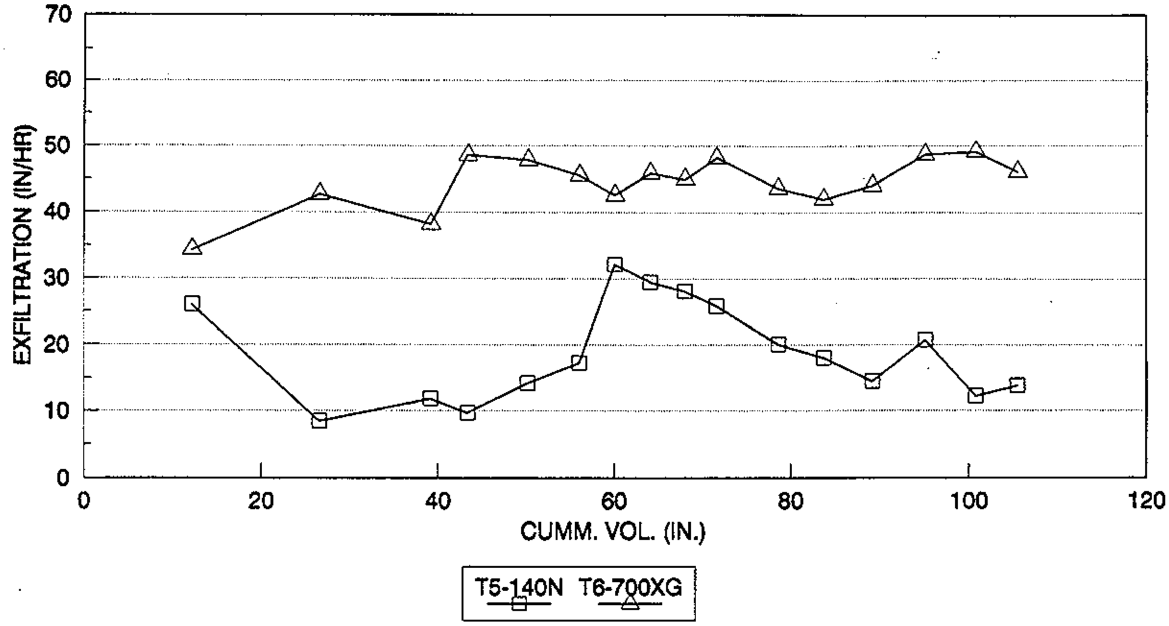
FABRIC COMPARISON

SETTLED, SANDY SOIL, WET CONDITION



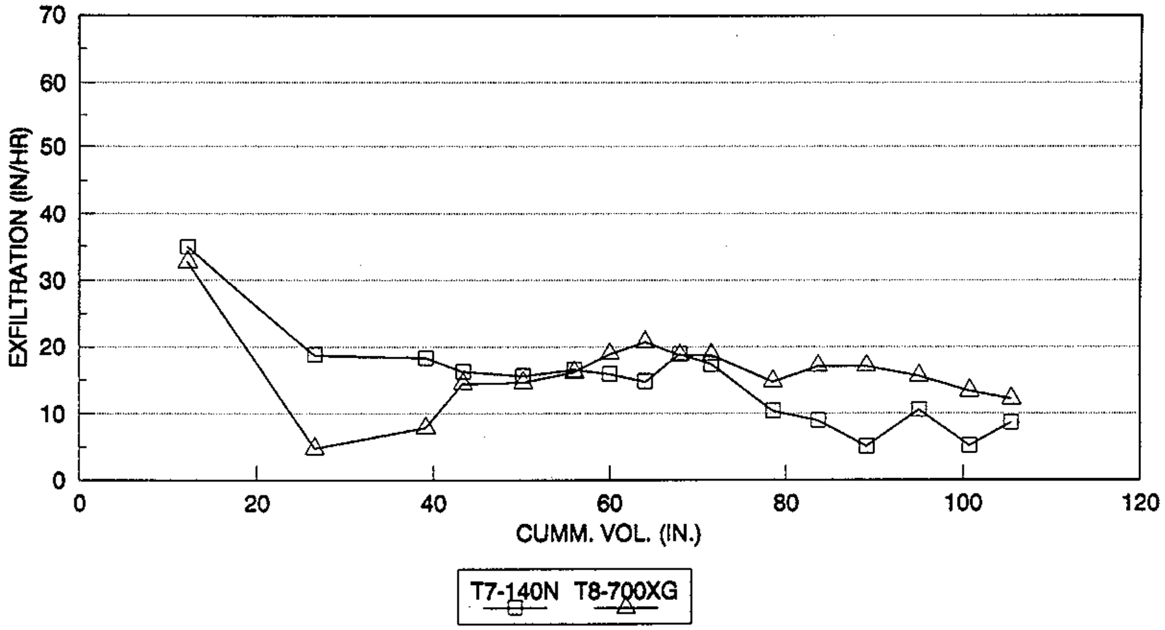
FABRIC COMPARISON

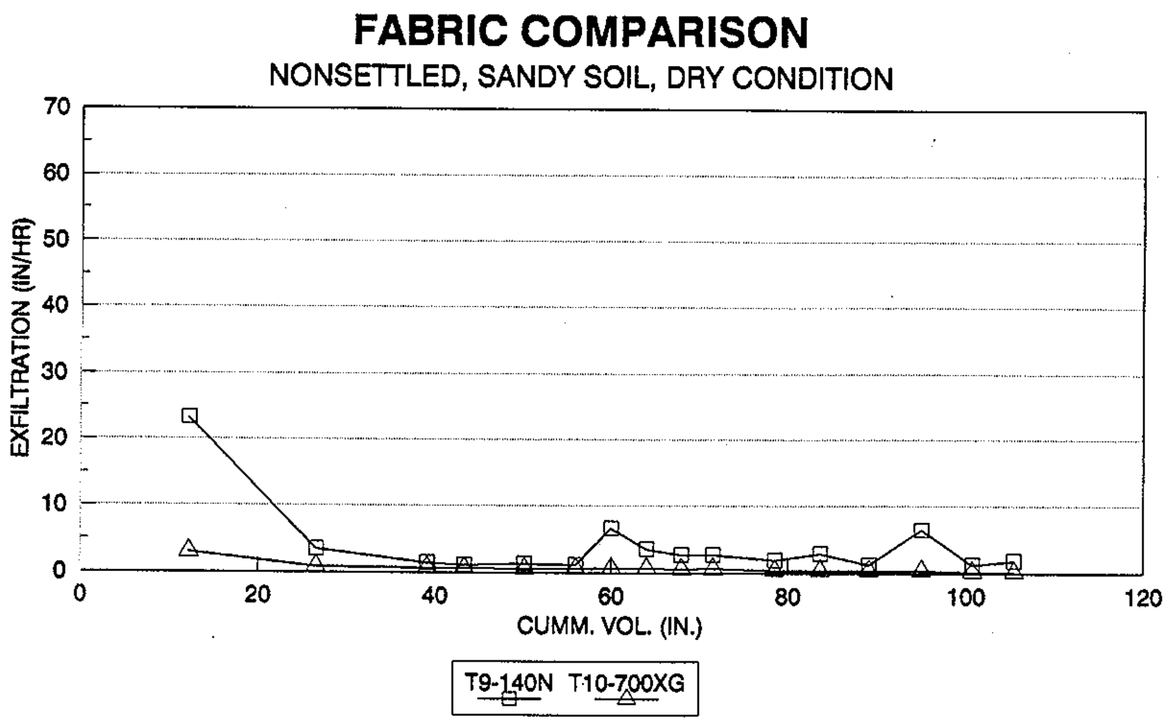
SETTLED, SILTY SOIL, DRY CONDITION

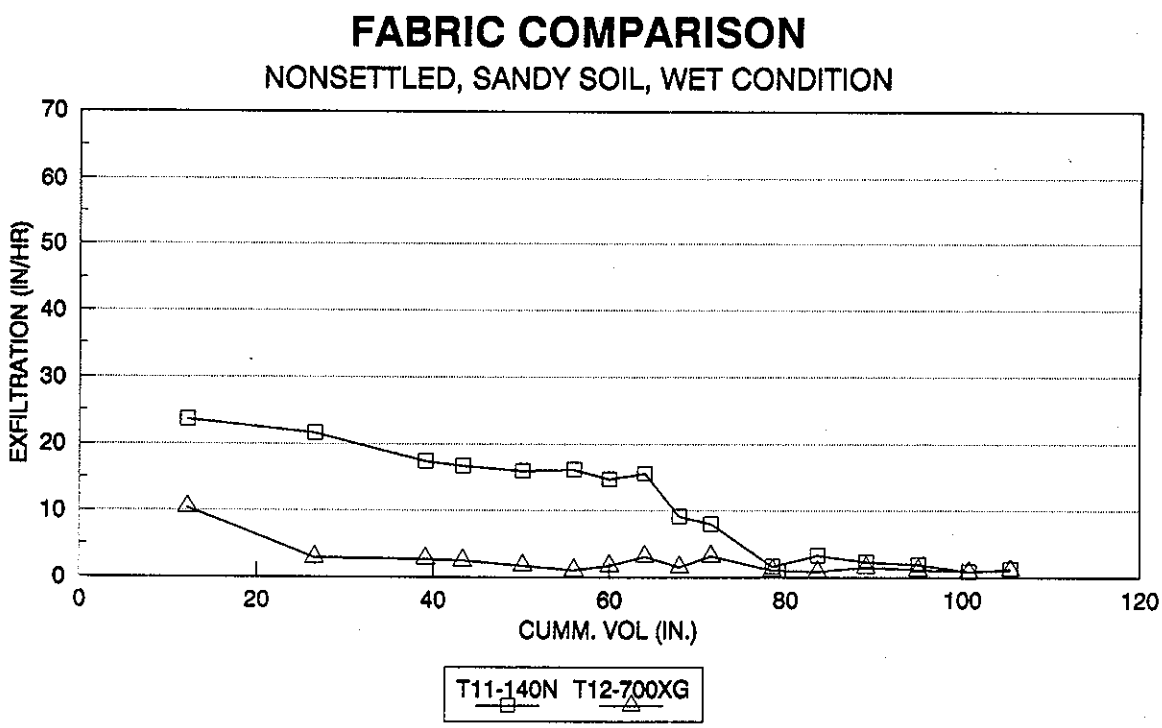


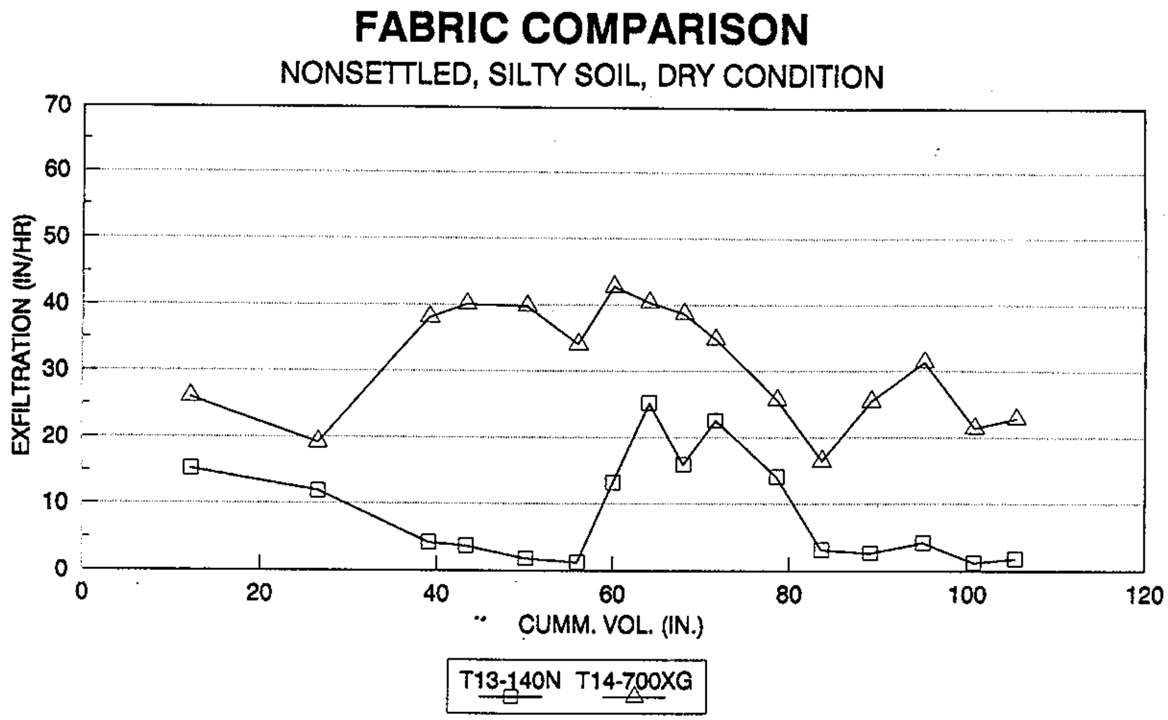
FABRIC COMPARISON

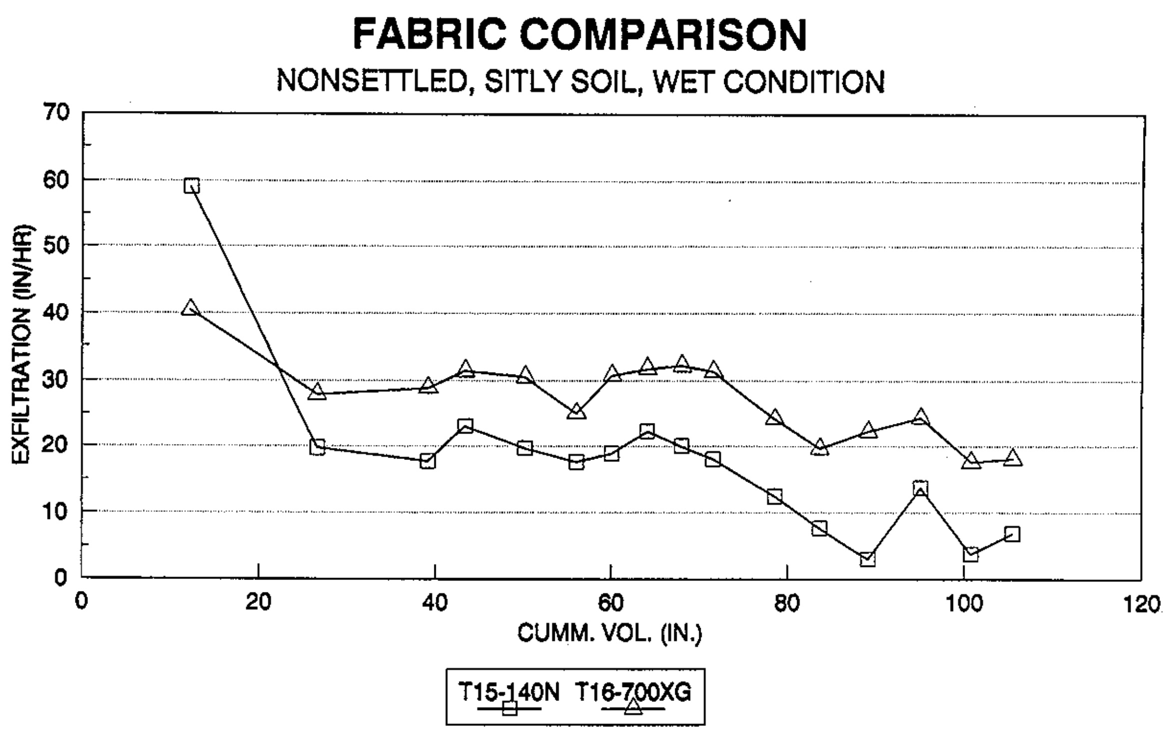
SETTLED, SILTY SOIL, WET CONDITION

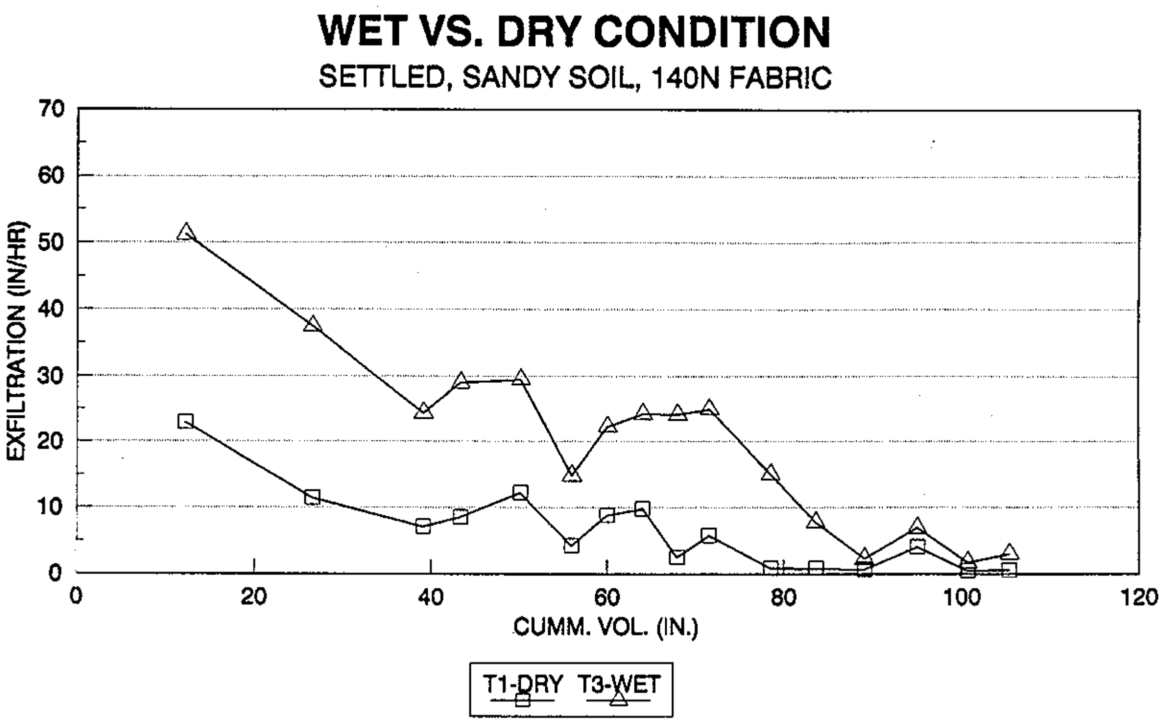


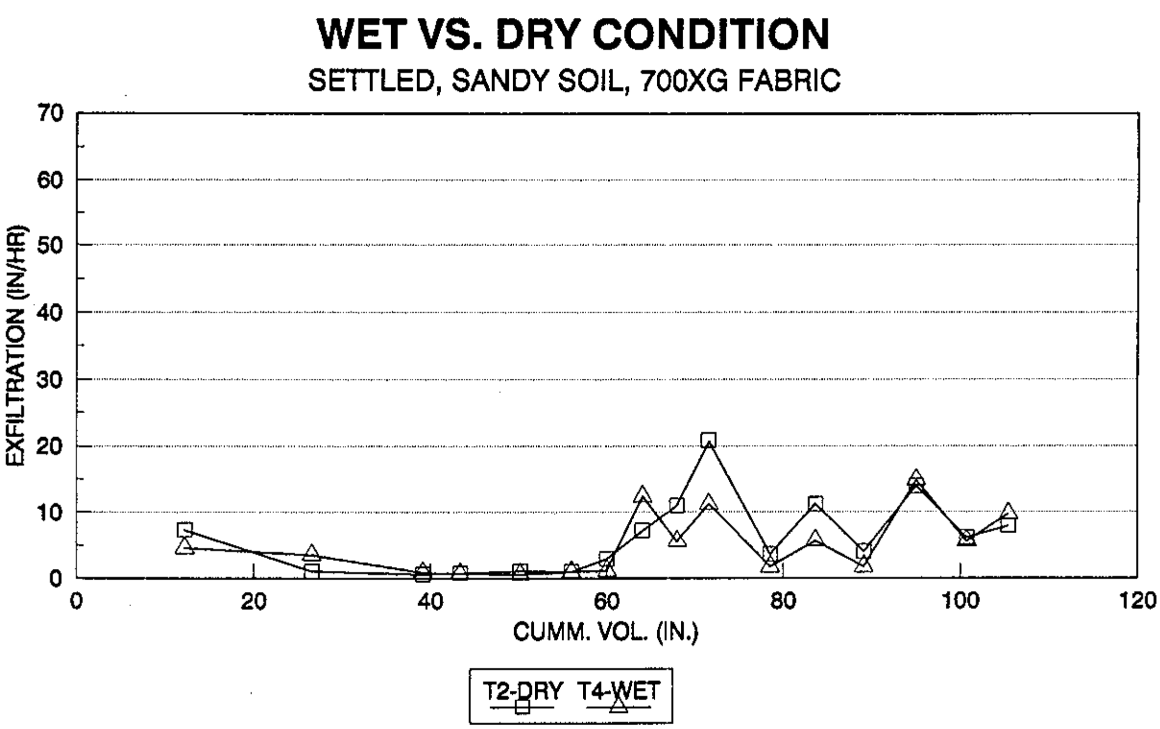

FABRIC COMPARISON
NONSETTLED, SANDY SOIL, DRY CONDITION
EXFILTRATION (IN/HR)
0
10
20
30
40
50
60
70
0
20
40
60
80
100
120
CUMM. VOL. (IN.)
T9-140N
T10-700XG


FABRIC COMPARISON
NONSETTLED, SANDY SOIL, WET CONDITION
EXFILTRATION (IN/HR)
0
10
20
30
40
50
60
70
0
20
40
60
80
100
120
CUMM. VOL (IN.)
T11-140N
T12-700XG


FABRIC COMPARISON
NONSETTLED, SILTY SOIL, DRY CONDITION
EXFILTRATION (IN/HR)
70
60
50
40
30
20
10
0
0
20
40
60
80
100
120
CUMM. VOL. (IN.)
T13-140N
T14-700XG

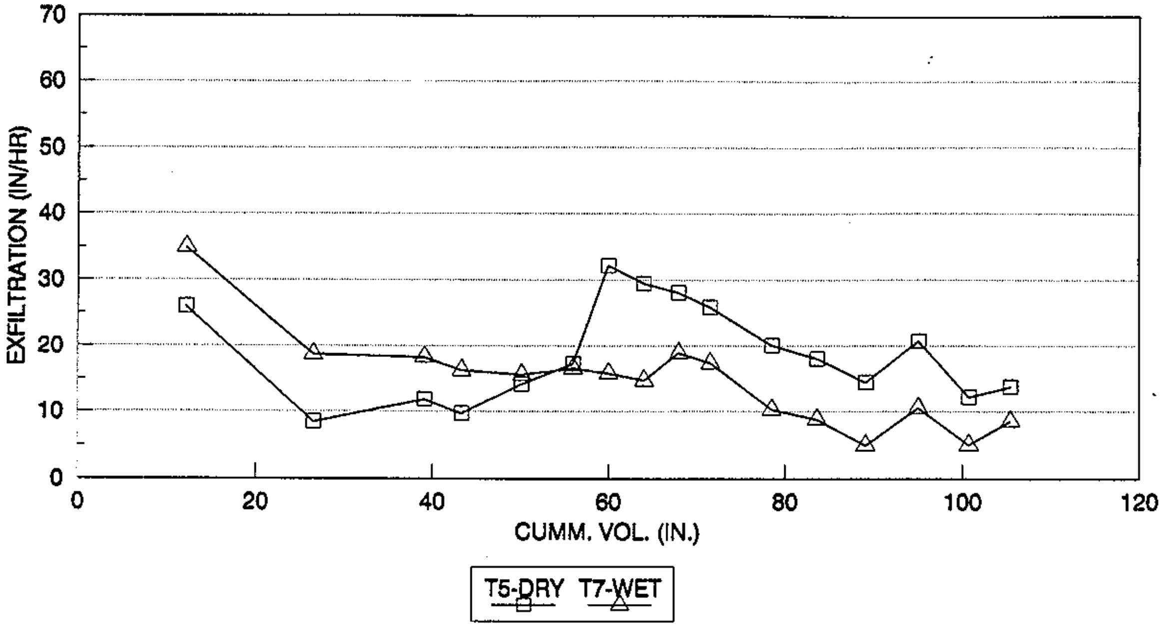

FABRIC COMPARISON
NONSETTLED, SITLY SOIL, WET CONDITION
EXFILTRATION (IN/HR)
70
60
50
40
30
20
10
0
0
20
40
60
80
100
120
CUMM. VOL. (IN.)
T15-140N
T16-700XG


WET VS. DRY CONDITION
SETTLED, SANDY SOIL, 140N FABRIC
70
60
50
40
30
20
10
0
EXFILTRATION (IN/HR)
0
20
40
60
80
100
120
CUMM. VOL. (IN.)
T1-DRY
T3-WET


WET VS. DRY CONDITION
SETTLED, SANDY SOIL, 700XG FABRIC
70
60
50
40
30
20
10
0
EXFILTRATION (IN/HR)
0
20
40
60
80
100
120
CUMM. VOL. (IN.)
T2-DRY
T4-WET

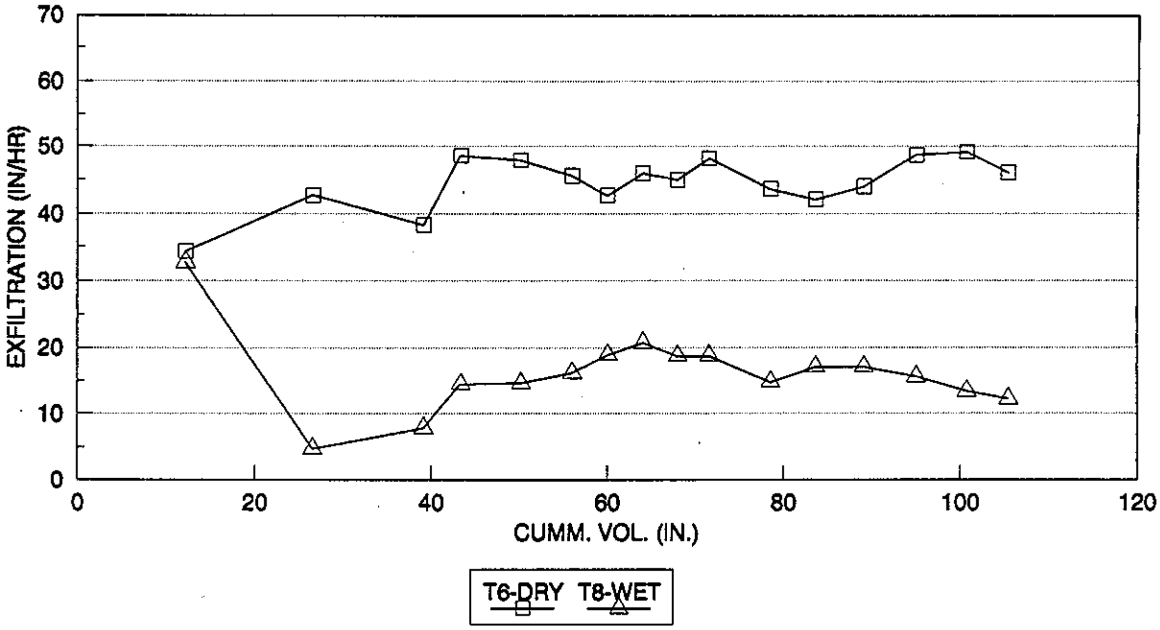
WET VS. DRY CONDITION

SETTLED, SILTY SOIL, 140N FABRIC



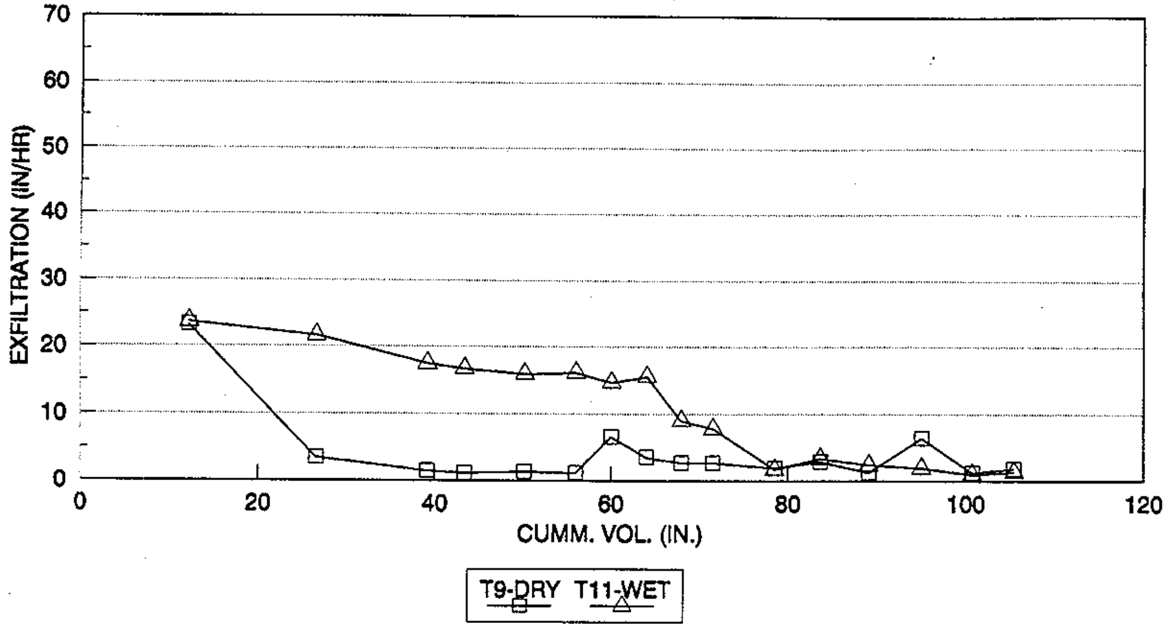
WET VS. DRY CONDITION

SETTLED, SILTY SOIL, 700XG FABRIC



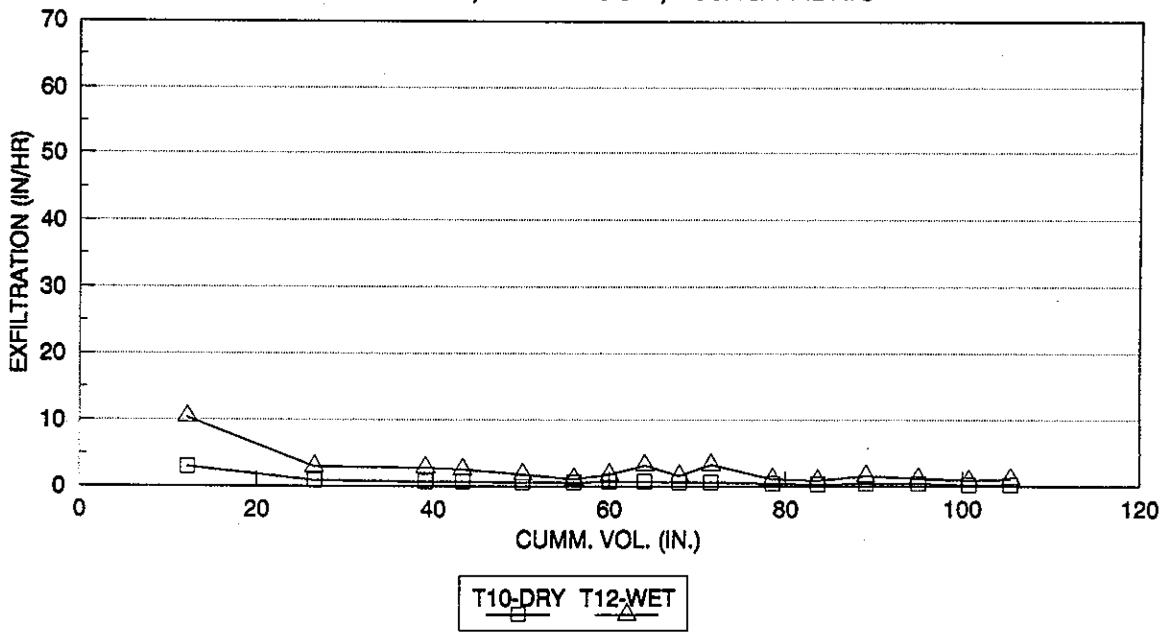
WET VS. DRY CONDITION

NONSETTLED, SANDY SOIL, 140N FABRIC



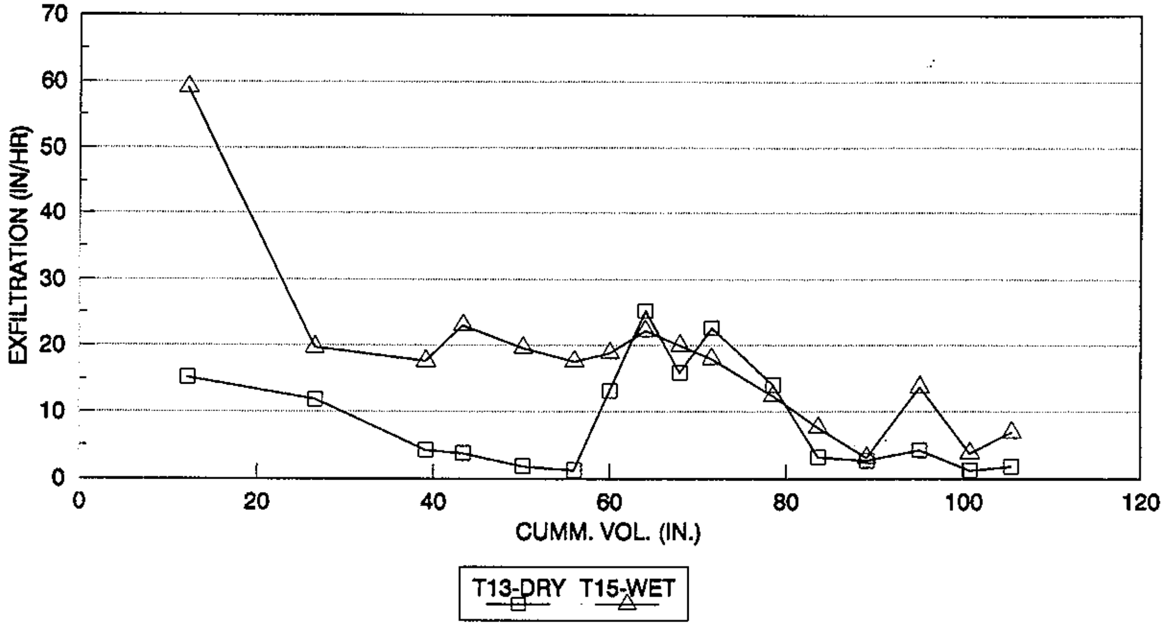
WET VS. DRY CONDITION

NONSETTLED, SANDY SOIL, 700XG FABRIC



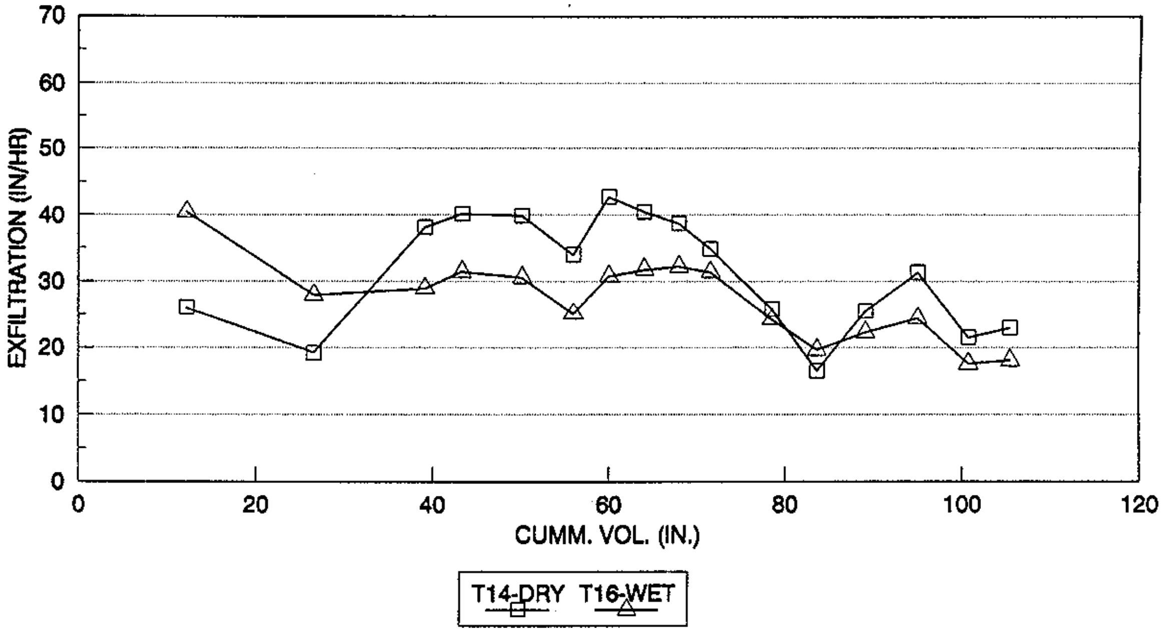
WET VS. DRY CONDITION

NONSETTLED, SILTY SOIL, 140N FABRIC



WET VS. DRY CONDITION

NONSETTLED, SILTY SOIL, 700XG FABRIC



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REFERENCES

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