VTRC
Virginia Transportation Research Council

We Bring Innovation to Transportation

Evaluation of the Filtration Effectiveness of Dewatering Bags and Assessment of Potential Improvements

http://www.virginiadot.org/vtrc/main/online_reports/pdf/21-r17.pdf

LEWIS N. LLOYD
Research Scientist

Final Report VTRC 21-R17

VIRGINIA TRANSPORTATION RESEARCH COUNCIL
530 Edgemont Road, Charlottesville, VA 22903-2454
vtrc.virginiadot.org

Standard Title Page - Report on Federally Funded Project

1. Report No.: FHWA/VTRC 21-R17	2. Government Accession No.:	3. Recipient's Catalog No.:
4. Title and Subtitle: Evaluation of the Filtration Effectiveness of Dewatering Bags and Assessment of Potential Improvements		5. Report Date: April 2021
		6. Performing Organization Code:
7. Author(s): Lewis N. Lloyd		8. Performing Organization Report No.: VTRC 21-R17
9. Performing Organization and Address: Virginia Transportation Research Council 530 Edgemont Road Charlottesville, VA 22903		10. Work Unit No. (TRAIS):
		11. Contract or Grant No.: 114309
12. Sponsoring Agencies' Name and Address: Virginia Department of Transportation 1401 E. Broad Street Richmond, VA 23219	Federal Highway Administration 400 North 8th Street, Room 750 Richmond, VA 23219-4825	13. Type of Report and Period Covered: Final
		14. Sponsoring Agency Code:
15. Supplementary Notes: This is an SPR-B report		

16. Abstract:

Geotextile dewatering bags are used on construction sites to treat sediment-laden construction discharge water pumped from excavations or behind cofferdams. Although these bags have become popular because of their small footprint on the construction site, recent observations have revealed that in some cases, fine sediment can pass through these bags, causing an increase in the turbidity of receiving waters.

The Virginia Department of Transportation (VDOT) has approved a number of geotextiles for use as dewatering bags based on the geotextiles' physical characteristics such as permittivity and apparent opening size. Because of the concerns with fine sediment, questions regarding the filtration effectiveness of these dewatering bags have been raised. The purpose of this study was to evaluate the filtration effectiveness of dewatering bags approved for use by VDOT and selected dewatering bags that are not currently approved by VDOT but are claimed to provide a higher level of filtration performance. In addition, a preliminary investigation of methods of improving the filtration effectiveness of dewatering bags including the use of straw bales and anionic polymer flocculants was conducted.

The results of the study indicated that the filtration effectiveness of geotextile dewatering bags can be highly variable based on the soil characteristics of the construction site. Specifically, sites with soils categorized as "fine-grained" performed poorly compared to sites with coarser soil gradations. An evaluation of VDOT's specifications and those from other states indicated that VDOT's material specifications are appropriate for maximizing the retention of sediments. However, VDOT's implementation guidance for dewatering bags, provided in Specification EC-8 of VDOT's Road and Bridge Standards, needs to be updated to include the proper methods for sizing, siting, and monitoring dewatering bags.

Evaluations of secondary sediment barriers (i.e., straw bales) and flocculants, though limited by the study's testing apparatus, showed promising results when used to improve the retention of fine sediments by dewatering bags as a system. These potential improvements were further supported by the literature.

An evaluation of a dewatering bag not approved for use by VDOT constructed from a woven geotextile showed that when treating the same volume of construction discharge water with similar sediment concentrations and characteristics, it was capable of maintaining a higher flow rate for a longer period of use compared to nonwoven geotextile dewatering bags. However, woven geotextile dewatering bags provided a lower degree of sediment retention during the initial stages of use.

Last, dewatering bags constructed from nonwoven geotextiles showed a degree of stretching with use. It is hypothesized that this stretching could be used to indicate when a dewatering bag is nearing rupture in the field.

17 Key Words: Dewatering bags, erosion and sediment control, flocculant, turbidity	18. Distribution Statement: No restrictions. This document is available to the public through NTIS, Springfield, VA 22161.

19. Security Classif. (of this report): Unclassified	20. Security Classif. (of this page): Unclassified	21. No. of Pages: 41	22. Price:

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

FINAL REPORT

EVALUATION OF THE FILTRATION EFFECTIVENESS OF DEWATERING BAGS AND ASSESSMENT OF POTENTIAL IMPROVEMENTS

Lewis N. Lloyd
Research Scientist

In Cooperation with the U.S. Department of Transportation
Federal Highway Administration

Virginia Transportation Research Council
(A partnership of the Virginia Department of Transportation
and the University of Virginia since 1948)

Charlottesville, Virginia

April 2021
VTRC 21-R17

DISCLAIMER

The contents of this report reflect the views of the author, who is responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Virginia Department of Transportation, the Commonwealth Transportation Board, or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation. Any inclusion of manufacturer names, trade names, or trademarks is for identification purposes only and is not to be considered an endorsement.

ABSTRACT

Geotextile dewatering bags are used on construction sites to treat sediment-laden construction discharge water pumped from excavations or behind cofferdams. Although these bags have become popular because of their small footprint on the construction site, recent observations have revealed that in some cases, fine sediment can pass through these bags, causing an increase in the turbidity of receiving waters.

The Virginia Department of Transportation (VDOT) has approved a number of geotextiles for use as dewatering bags based on the geotextiles' physical characteristics such as permittivity and apparent opening size. Because of the concerns with fine sediment, questions regarding the filtration effectiveness of these dewatering bags have been raised. The purpose of this study was to evaluate the filtration effectiveness of dewatering bags approved for use by VDOT and selected dewatering bags that are not currently approved by VDOT but that are claimed to provide a higher level of filtration performance. In addition, a preliminary investigation of methods of improving the filtration effectiveness of dewatering bags including the use of straw bales and anionic polymer flocculants was conducted.

The results of the study indicated that the filtration effectiveness of geotextile dewatering bags can be highly variable based on the soil characteristics of the construction site. Specifically, geotextile bags used at sites with soils categorized as "fine-grained" performed poorly compared to those used at sites with coarser soil gradations. An evaluation of VDOT's specifications and those from other states indicated that VDOT's material specifications are appropriate for maximizing the retention of sediments. However, VDOT's implementation guidance for dewatering bags, provided in Specification EC-8 of VDOT's *Road and Bridge Standards*, needs to be updated to include the proper methods for sizing, siting, and monitoring dewatering bags.

Evaluations of secondary sediment barriers (i.e., straw bales) and flocculants, though limited by the study's testing apparatus, showed promising results when used to improve the retention of fine sediments by dewatering bags as a system. These potential improvements were further supported by the literature.

An evaluation of a dewatering bag not approved for use by VDOT constructed from a woven geotextile showed that when treating the same volume of construction discharge water with similar sediment concentrations and characteristics, it was capable of maintaining a higher flow rate for a longer period of use compared to nonwoven geotextile dewatering bags. However, woven geotextile dewatering bags provided a lower degree of sediment retention during the initial stages of use.

Last, dewatering bags constructed from nonwoven geotextiles showed a degree of stretching with use. It is hypothesized that this stretching could be used to indicate when a dewatering bag is nearing rupture in the field.

FINAL REPORT

EVALUATION OF THE FILTRATION EFFECTIVENESS OF DEWATERING BAGS AND ASSESSMENT OF POTENTIAL IMPROVEMENTS

Lewis N. Lloyd
Research Scientist

INTRODUCTION

As water accumulates in an excavation or behind a coffer dam, it must be pumped out to allow crews (and equipment) safe and easy access to the construction site. In many instances, the water that is pumped out of these areas, hereinafter referred to as "construction discharge water" (CDW), can be heavily laden with sediment, requiring that it first be treated to reduce its turbidity before being released back into surface waters.

Treatment of CDW can be achieved in a number of ways, including the use of sedimentation basins. However, this practice requires a significant amount of space to be effective. Because of this, geotextile (GTX) dewatering bags have seen widespread use on projects where space is at a premium.

Dewatering bags consist of a GTX material sewn into a closed bag. Sediment-laden water from the construction site is pumped into the GTX bag. This acts to filter suspended particles from the CDW, allowing clear water to pass through the pores of the bag and discharge back into the receiving water. Previous research has shown that a number of factors can have an impact on the performance of GTX dewatering bags. These include sediment characteristics such as particle size distribution; sediment load in the CDW; and GTX characteristics including apparent opening size (AOS) and permittivity (Kutay and Aydilek, 2004; Soltz and Deli, 2019; Yee and Lawson, 2012). Because of this wide array of variables, accurately predicting the general filtration effectiveness of dewatering bags can be a challenge.

At the time of this study, VDOT had seven dewatering bag products approved for use on its Approved Products List (APL). These products are listed in Table 1 along with the specific GTX used to construct them. In some instances, more than one type of GTX can be used by the manufacturer to construct these dewatering bags.

Table 1. Dewatering Bags Approved for Use by VDOT Including the Specific Geotextile Name

Manufacturer and Product Name	Geotextile
• Colonial Silt Bags—series • Frank Roberts & Sons GTF-FB series • Geo Products Filter Bags • L&M Supply Q10 Dewatering Bag	Thrace-LINQ 245EX
ACF Dirtbag 55	SKAPS GT110
	Propex 1001
Hanes TerraTex N10 Series	Hanes N10
SKAPS GT110 Dewatering Bag	SKAPS GT110

Data from VDOT (2020b).

VDOT requires that the GTXs listed in Table 1 meet the physical specifications provided in Table 2 (VDOT, 2020a). VDOT specifications also require that only nonwoven GTXs be used to fabricate dewatering bags. Of the specifications provided in Table 2, the AOS and permittivity of the GTX are the characteristics most directly related to the ability of the material to filter out sediments when used as a dewatering bag (Kutay and Aydilek, 2004; Muthukumaran and Ilamparuthi, 2006; Yee and Lawson, 2012). The AOS of a GTX is a measure of the approximate diameter of the largest particle that would pass through the material, sometimes referred to as O_{95} (ASTM International [ASTM], 2017b; Koerner and Koerner, 2014). In nonwoven GTXs, the AOS of the material is primarily a function of the diameter of the needle used for the needle punching process during manufacturing. However, because of the nature of nonwoven GTXs, some of these openings will be larger and some will be smaller than the specified AOS.

VDOT specifies a maximum AOS of a No. 100 U.S. sieve or 0.149 mm. This means that the smallest particle that will be retained by a new, unused dewatering bag will have a diameter greater than 0.149 mm (ASTM, 2017b). Particles smaller than this will generally pass through the GTX.

The permittivity of a GTX represents the volumetric flow rate of water per unit cross-sectional area per unit head in the normal (perpendicular) direction through a GTX (ASTM, 2012). It is important to differentiate this characteristic from permeability, which when referring to GTXs represents the general rate of fluid flow through the GTX (ASTM, 2012). The primary difference between these characteristics is that with permittivity the thickness of the GTX is taken into account and with permeability it is not. By specifying the GTX permittivity rather than permeability, the user is provided with a characteristic that can be directly compared to other GTXs of any thickness. When GTXs are specified for use as silt fences and dewatering bags, the common guidance from GTX manufacturers is to specify lower permittivity and smaller AOS values for finer sediment sizes.

During the initial stages of use, sediment retention (i.e., filtration) is primarily provided by the GTX alone (Stoltz et al., 2019; Yee and Lawson, 2012). As the dewatering bag is used, sediment will begin to collect along the inner wall of the bag and form what is commonly referred to as a filter cake (Muthukumaran and Ilamparithi, 2006; Stoltz et al., 2019; Yee and Lawson, 2012).

Table 2. Geotextile Specifications for Dewatering Bags Used on VDOT Projects

Physical Property	Test Method	Requirements
Grab Strength at Elongation > 50% (CRE/Dry)	ASTM D4632	Min. 250 lb
Seam Strength	ASTM D4632	90% specified grab strength
Puncture	ASTM D4833	Min. 150 lb
Flow Rate	ASTM D4491	Min. 0.189 $ft^3/sec/ft^2$
Permittivity	ASTM D4491	Min. 1.2 sec^{-1}
UV Resistance	ASTM D4355	Min. 70% at 500 hr
Apparent Opening Size	ASTM D4751	Max. No. 100 sieve

Data from the Virginia Department of Transportation (2020a).

Depending on the characteristics of the sediment present in the CDW, the resulting filter cake will typically have a lower permittivity and provide a greater degree of filtration compared to the GTX alone (Muthukumaran and Ilamparuthi, 2006; Yee and Lawson, 2012). CDW containing primarily coarser sediment sizes will lead to the development of a filter cake with a higher permittivity than CDW containing primarily fine silts and clays.

Once a filter cake has been established, it can account for the majority of the filtration provided by the dewatering bag (Kutay and Aydilek, 2004; Stoltz et al., 2019). Although this has the added benefit of increasing the ability of the dewatering bag to filter out finer particles, it also has the potential to reduce the flow rate of the dewatering bag system significantly over time. As this continues, pressure inside the bag will increase as more and more sediment is collected, causing the filter cake to increase in thickness, decreasing the permittivity of the overall system (i.e., filter cake and GTX). As a result, the flow rate out of the dewatering bag system will continue to decrease (Stoltz et al., 2019). In addition, the pores of the GTX itself will begin to clog with particles, a process commonly referred to as blinding (Muthukumaran and Ilamparuthi, 2006). Although reductions in flow rate caused by filter cake formation can be reversed by disturbing the filter cake, reductions in flow rate caused by blinding are typically permanent.

Much of the literature regarding GTX dewatering bags focuses on their application for dewatering fly ash slurries or dredged harbor sediment. These studies break the dewatering process into three stages: (1) filling, (2) settling/dewatering, and (3) dewatering (Yee and Lawson, 2012). These stages are repeated as additional material is collected and pumped into the bag. VDOT's application differs slightly in that CDW typically is continually pumped into the bag over the course of the day to maintain a dry working area. This can prevent or postpone the formation of a filter cake as influent water disturbs any accumulated sediment.

Previous studies have shown that clogging of GTX pores and the development of a filter cake can be readily detected through observation of the change in discharge (or flow response) from the dewatering bag. Research evaluating the flow response of a woven GTX when harbor sediment and fly ash are being treated was conducted by Muthukumaran and Ilamparuthi (2006). They found that the flow response for the GTX tested with both harbor sediment and fly ash could be broken into two phases. The authors characterized the first phase as a significant decrease in flow rate governed by filter cake formation, compaction, and blinding (Muthukumaran and Ilamparuthi, 2006). The second phase can be identified by the development of an essentially constant flow rate (Koerner and Ko, 1982). Transition from the first to the second phase of flow response marks the completion of filter cake formation (Koerner and Ko, 1982; Muthukumaran and Ilamparuthi, 2006).

Flocculants

Flocculants have seen widespread use in a number of industries, including wastewater treatment and the oil and gas industry, and in erosion and sediment control on construction sites. These materials can have a positive (cationic), negative (anionic), or neutral net charge (Kang and McLaughlin, 2016). Although anionic polymer flocculants have been approved by the U.S.

Environmental Protection Agency (U.S. EPA) to treat turbid water discharging directly into surface waters, positively charged cationic flocculants have been found to be toxic to aquatic environments (U.S. EPA, 2013). Because of this, cationic flocculants are primarily used in the wastewater treatment industry where they can be removed prior to discharge.

Anionic polyacrylamide (PAM) flocculants are available in a number of different forms including granular, solid, liquid, and semi-hydrated blocks. Kang et al. (2014) evaluated the material's effectiveness at reducing the turbidity of concentrated runoff from construction sites. The authors investigated the effectiveness of granular and semi-hydrated PAM blocks at reducing the turbidity and the concentration of total suspended solids (TSS) in runoff confined to a shallow trench lined with jute netting and containing evenly spaced silt wattles. Tests were conducted with granular PAM applied directly to the jute netting and/or silt wattles while semi-hydrated PAM blocks were placed directly uphill from the silt wattles (Kang et al., 2014). In all configurations, the intent was for the PAM to be dissolved (essentially activating it) into the runoff as it traveled down the trench. This type of application of flocculant is commonly referred to as a passive application. With the PAM in solution, sediment particles clump together, forming flocs. These denser flocs will more readily fall out of suspension, becoming caught in the jute netting or settling out behind one of the check dams (Kang et al., 2014).

Kang et al. (2014) found that the addition of PAM flocculants produced a 38% to 67% reduction in turbidity depending on the tested configuration. The greatest reductions were found when granular PAM was applied directly to the jute netting rather than to the wattle (Kang et al., 2014). TSS concentrations showed similar results, with reductions ranging from 59% to 67%. Again, the most effective configuration consisted of granular PAM applied directly to the netting rather than the wattle (Kang et al., 2014). The authors attributed the increased effectiveness of granular PAM applied to the jute netting to the increased interaction/mixing between the PAM and the water caused by the jute netting compared to tests with PAM applied to the silt wattles or those with semi-hydrated PAM blocks. The increased interaction allowed the PAM flocculant to dissolve more readily into the runoff and interact with suspended particles (Kang et al., 2014).

It can also be assumed that increasing the length of the channel used to convey and treat this runoff would also produce greater reductions in turbidity and TSS. Testing by Kang et al. (2014) was conducted using a 79-ft trench, a distance much longer than what is commonly seen between a dewatering bag and the receiving water body. Because of this, the effectiveness of this method of passive dosing when used with a dewatering bag is not known.

Other studies have evaluated the effectiveness of using PAM flocculants to increase the effectiveness of dewatering bags. Notably, Kang and McLaughlin (2016) evaluated the use of both dissolved PAM and solid blocks of chitosan (a biopolymer also used for flocculation) in conjunction with dewatering bags (Kang and McLaughlin, 2016). Dissolved PAM was injected into the influent water at a flow-weighted rate of 1 mg L^{-1}, and passive treatment of chitosan was tested by placing blocks of the material in the flow path of the influent water. Test water with a turbidity from 2,000 to 3,500 NTU was fed into the bag through a corrugated pipe. The corrugations in the pipe helped to increase mixing of the flocculant and the interaction (collision) between sediment particles (Kang and McLaughlin, 2016). The study found that although the dewatering bag alone reduced effluent turbidity by 70%, the addition of flocculants increased this to up to 97% (Kang and McLaughlin, 2016).

In addition, solid PAM flocculant tablets can be added directly into dewatering bags, where they are dissolved into solution. Although active dosing of liquid flocculants requires a series of jar tests to determine the proper concentration / dosing rate, passive dosing of flocculants (using tablets, blocks, or granular application downslope) typically does not.

Field observations by VDOT personnel have noted that in some instances, discolored/turbid water has been seen discharging from these dewatering bags. This has raised concerns regarding the effectiveness of these bags in retaining fine sediment, especially near sensitive environments.

PURPOSE AND SCOPE

The purpose of this study was to determine the filtration effectiveness of dewatering bags approved for use on VDOT construction projects. Further, select dewatering bag products that had shown promise but were not currently approved for use were also evaluated. Dewatering bags were evaluated based on their ability to reduce the turbidity and TSS of synthetically generated CDW. Observations and water quality sampling of dewatering bags in use in the field were also conducted.

In addition, a preliminary investigation of methods of improving the filtration effectiveness of dewatering bags was conducted. This investigation included determining the effectiveness of using straw bales and flocculants in reducing the turbidity of effluent water. Straw bales are commonly used in conjunction with dewatering bags to increase their performance; however, the effectiveness of this practice is not well understood. The U.S. EPA (2013) has approved the use of only anionic polymer flocculants for stormwater applications that discharge into surface waters. Because of this, only the use of anionic flocculant was investigated in this study.

METHODS

Literature Review

A literature search was conducted to identify the specifications of other states (either their DOT or other state regulatory agencies) regarding the use of dewatering bags and the type of GTX approved for dewatering bag use. Peer reviewed scientific journals were also reviewed to identify prior research regarding the filtration effectiveness of GTX dewatering bags and methods of increasing their filtration effectiveness.

Literature searches were conducted using a number of tools including Web of Science, Google Scholar, and Google Search. State dewatering bag specifications and guidance documents were identified by searching the state DOT specifications and then the state environmental regulatory agency documents. The latter search was conducted only if no information was provided by the DOT.

Along with the scientific literature and state documents, standard testing procedures regarding GTX dewatering bags were collected from the ASTM International Compass. This search was targeted at identifying existing testing procedures for determining the sediment retention capabilities of GTXs used for a broad array of applications (such as silt fences) and dewatering bags specifically.

Identification and Collection of Test Bags

Samples of dewatering bags approved for use on VDOT projects were procured from various manufacturers. Typically, dewatering bag dimensions range from 4 ft x 6 ft to 15 ft x 15 ft depending on the amount of water that needs to be treated and the size of the pump used. However, in order to reduce the amount of water needed for testing, the bag dimensions were scaled down so that the designed flow rate of the bag equaled about 2 times the peak discharge of the falling head tank used as the water source for the study. This resulted in the bags having dimensions of 1 ft x 2 ft, providing a flow rate from 160 to 170 gpm depending on the GTX being tested. The specific GTXs tested in this study included Crown Resources TNS R100 GTX and Hanes TerraTex N10 GTX. These materials represent GTXs commonly used for the manufacture of dewatering bags and have characteristics that are similar to, if not the same as, those of the other GTXs on VDOT's APL. Table A2 in the Appendix provides a complete listing of these specifications. All of the listed products have identical AOS and permittivity values.

In addition to the nonwoven GTXs on VDOT's APL, the Pump-It Tube manufactured by Flo-Water, LLC, was tested. The Pump-It Tube is manufactured using a monofilament woven GTX with a much larger AOS equal to that of a No. 60 sieve (0.250 mm) and higher flow rate (192 gpm/ft^2). This product also has a reported filtering efficiency of 91% when tested in accordance with ASTM D5141. ASTM D5141 calls for the use of soil with the gradations provided in Table 3 when not testing with site-specific material (ASTM, 2018). However, it should be noted that this method was written to "determine the filtering efficiency and flow rate of the filtration component of a sediment retention device, such as a silt fence, silt barrier, or inlet protector" (ASTM, 2018). Although this test does have some applicability to the testing of GTXs used to construct dewatering bags, it is not capable of replicating the types of conditions encountered by dewatering bags in the field. Specifically, the test is not designed to replicate conditions such as the amount of water that is intended to be treated and the overall geometry of dewatering bags compared to silt fences.

Table 3. Default Soil Characteristics Specified in ASTM D5141 for Testing the Filtering Efficiency of Silt Fences

Percent Passing	Sieve Size (opening size, mm)
100	No. 10 (2.0 mm)
80-100	No. 40 (0.420 mm)
70-90	No. 100 (0.149 mm)
50-70	No. 200 (0.075 mm)

Testing Apparatus

The testing apparatus was constructed to replicate ideal field conditions as closely as possible. ASTM provides one test method, ASTM D7880, Standard Test Method for Determining Flow Rate of Water and Suspended Solids Retention From a Closed Geosynthetic Bag (also known as the pillow test), which is similar in nature to the methods used in this study. However, this method does not provide the ability to test the bags over a longer period of time as do the methods used for this study. It should be noted that a second common test method, ASTM D7701 (commonly called the hanging bag test), was removed from use as of July 2020 (ASTM, 2020).

As can be seen in Figure 1, the testing setup consisted of four primary components: (1) the supply tank, (2) the drainage frame, (3) the approach section, and (4) the H-flume. Artificial CDW of a known concentration was kept constantly mixed in the 118-gal supply tank using a mixing rod and drill attached to the top of the tank. The artificial CDW was gravity fed into the dewatering bag resting on top of a drainage frame. Samples of effluent water were collected from directly underneath the drainage frame. A similar apparatus was used in 2016 by Kang and McLaughlin in a similar study to evaluate the effectiveness of using flocculants in combination with a GTX dewatering bag (Kang and McLaughlin, 2016).

Discharge from the bag was measured using a 0.5-ft H-flume from Open Channel Flow combined with a Campbell Scientific SR50A ultrasonic distance sensor. Water depth in the H-flume was measured by the distance sensor every 3 sec and recorded using a Campbell Scientific CR-1000 datalogger. The approach section not only collected and directed the water leaving the bag, but it also provided an area for surface turbulence to dissipate, allowing the ultrasonic distance sensor to make an accurate reading of the water depth.

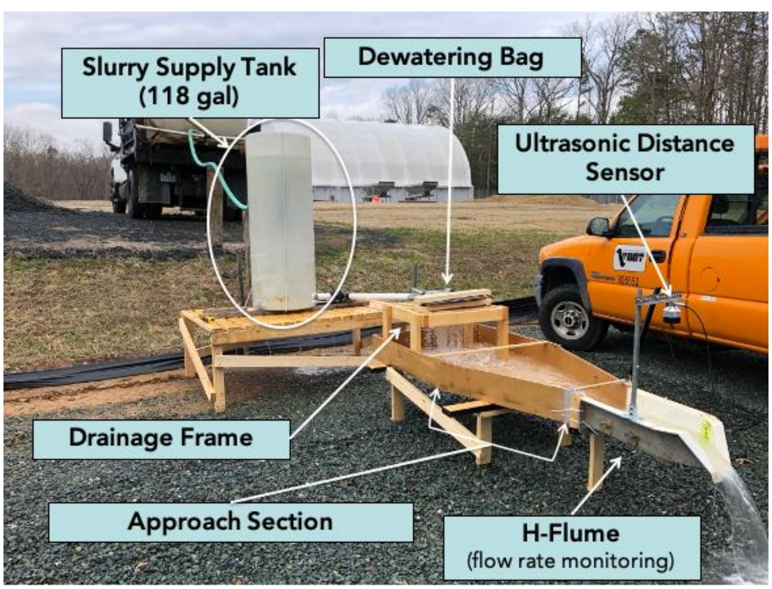


Figure 1. Dewatering Bag Testing Apparatus Used During Laboratory Testing

Using the curve fitting equation (Eq. 1) provided by the manufacturer for the H-flume, water-depth measurements were converted to discharge values in units of gallons per minute.

$$Discharge\ (GPM) = (0.000112 - 0.00195 \times H\hat{}0.5 + 0.167309 \times H\hat{}1.5 + 1.62001 \times H\hat{}2.5) \times 448.8312 \qquad \text{[Eq. 1]}$$

Collection and Characterization of Construction Discharge Water

Three construction projects actively using dewatering bags were identified for observation and sample collection. The locations of these sites are shown in Figure 2. The objective of this phase of the study was to determine the field conditions commonly encountered when these bags are used. Relevant conditions recorded included the particle size characteristics of the native soil, type of pump feeding into the bag, and influent and effluent turbidity and TSS of the CDW treated by the bag. Samples were also taken of the receiving waters at points upstream, downstream, and directly adjacent to the dewatering bag in order to identify any impacts to receiving waters.

When effluent water samples were collected from dewatering bags in the field, care was taken to ensure that any developed filter cake inside the bag or sediment that had accumulated on the surface of the bag was not disturbed. As was discovered during the sampling of Site 3, any disturbance to the filter cake or accumulated sediment on the surface of the bag can cause a significant increase in the turbidity of the effluent water.

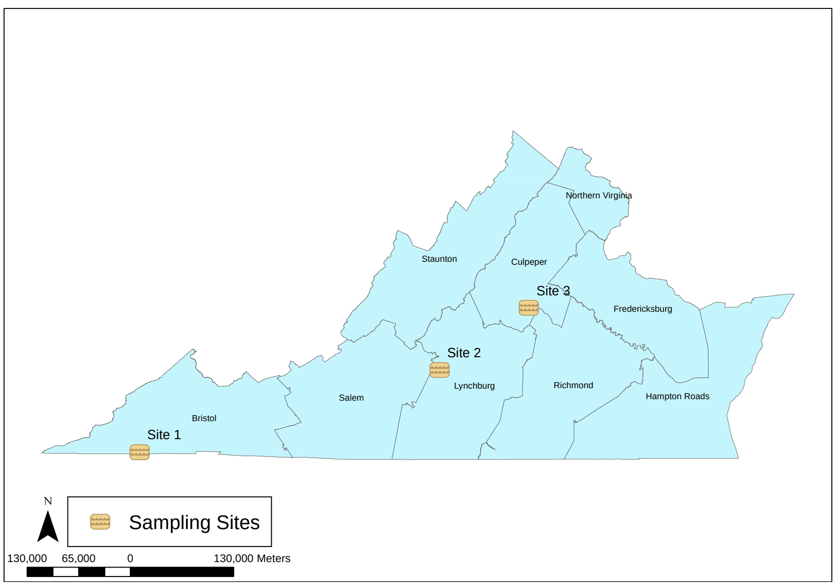


Figure 2. Locations of Dewatering Bags Selected for Field Sampling

Dewatering Bag Testing

Prior to sediment being introduced into the system, three tank volumes (118 gal each) of clear water were passed through the bag to determine the average peak discharge of the dewatering bag, hereinafter termed "background peak discharge." This also allowed the GTX to be fully saturated with water prior to filtration testing. After background peak discharge tests, tests using artificial CDW were conducted.

Testing Conditions

Artificial CDW was mixed using soil collected from Site 2 in Figure 2, a pipe jacking project located in central Virginia. Material from this site was selected based on previous field observations showing the release of fine sediment from CDW treated with dewatering bags. This ensured there would be a measurable amount of sediment in the discharge during laboratory testing. Particle size distribution of this material is provided in Table 4 and was tested in accordance with ASTM D6913 (ASTM, 2009).

Each tank volume of artificial CDW was mixed to achieve a final soil concentration of about 1000 mg/L, requiring about 450 g of soil per tank. This yielded average TSS and turbidity starting values of 405 mg/L and 370.3 NTU, respectively.

Four tank volumes of artificial CDW were passed through each of the dewatering bags tested. At the start of each tank, a sample was taken directly from the supply tank to determine the starting turbidity and TSS concentration. Samples of effluent water were collected based on the rate of discharge from the bag. For example, samples were taken more frequently during periods of high discharge and less frequently during periods of low discharge. In order to compute flow-weighted concentrations, the time was noted at the start and end of each sample collection period.

Table 4. Particle Size Distribution of Soil Used for Artificial Construction Discharge Water

Percent Passing	Sieve Size (opening size, mm)
100	¾ in, 19
95.1	3/8 in, 9.5
90.2	No. 4, 4.75
83.5	No. 8, 2.36
72.2	No. 30, 0.6
69.3	No. 40, 0.425
66.2	No. 50, 0.3
62.2	No. 100, 0.15
51.5	No. 200, 0.075

Total Suspended Solids and Turbidity Sample Analysis

Effluent water samples were collected in 1-liter low-density polyethylene bottles. The number of samples collected ranged from 21 to 36, depending on the total duration of each test. Collected samples were stored at 40˚F for no longer than 7 days before analysis to prevent any incidental biological growth. Prior to analysis, each sample was shaken vigorously to ensure a homogenous mixture. All turbidity and TSS tests were run in triplicate for each sample to ensure reliability of results.

Turbidity measurements were taken using a Thermo Orion AQ3010 AQUAfast turbidity meter in accordance with EPA Method 180.1, Determination of Turbidity by Nephelometry (U.S. EPA, 1996). Prior to each use, the turbidity meter was calibrated using 0.02, 20.0, 100, and 800 NTU calibration standards. This calibration was confirmed after every 10 samples using the 100 NTU calibration standard.

TSS concentrations were determined in accordance with EPA Method 160.2, Residue, Non-Filterable (U.S. EPA, 1971). A 100-mL portion of each sample was used for this analysis. This volume was increased to 200 mL for samples that produced less than 0.01 g of residual sediment when a 100-mL portion was used so that a measurable amount of residual sediment was collected.

Data Analysis Using Flow-Weighted Concentrations

In order to account for the change in discharge and back pressure caused by the use of a falling head tank, changes in TSS and turbidity for each tank volume were calculated using flow-weighted results. This was achieved using Equation 2 where C represents TSS concentration or turbidity; Q represents the average discharge over the sampling period; and t represents the time interval over which the sample was taken.

$$Flow - Weighted\ Concentration = \frac{\sum C_i Q_i t_i}{\sum Q_i t_i} \qquad \text{[Eq. 2]}$$

Percent reductions in TSS and turbidity for each tank volume were determined by comparing measurements of the influent water taken at the start of the test run to the flow-weighted values calculated using Equation 2.

Changes in peak discharge were determined by comparing the average background peak discharge, determined at the start of the test, to the highest discharge measured over the course of a tank volume.

Evaluation of Methods of Increasing Filtration Effectiveness

A preliminary investigation of two methods of increasing the filtration effectiveness of dewatering bags was conducted during this study. The methods were (1) the use of straw bales, and (2) the use of straw bales treated with granular anionic PAM flocculant (see Figure 3). Tests were conducted using the same testing apparatus described previously with the addition of a straw bale directly under the dewatering bag and on top of the drainage frame. For tests that included flocculants, 133 g of granular H30 PAM provided by Carolina Hydrologic was evenly spread along the top of the straw bale, directly underneath the bag. This mass of H30 PAM was selected based on the manufacturer's recommendations for direct land application.

Figure 3. Straw Bale Treated With Granular H30 Polyacrylamide Flocculant (Left) and Dewatering Bag Test Conducted With the Addition of a Straw Bale Alone (Right)

In an ideal scenario, straw bales would be placed underneath and around the perimeter of the dewatering bag, forming a “corral” around the bag. Because of the physical limitations of the testing apparatus used for this study, only one straw bale was able to be used for each test.

RESULTS AND DISCUSSION

Literature Review

A number of states have DOT and environmental agency specifications for the GTXs used to construct dewatering bags and how they are to be implemented. The following sections provide an overview of these specifications, identified during the literature review. This information was divided into two categories: (1) material specifications of the GTX fabric used, and (2) general dewatering bag implementation guidance.

Geotextile Specifications From Other States

Many of the GTX specifications used by VDOT are also in use by other states. These include minimum grab tensile strength (Alaska Department of Transportation and Public Facilities [hereinafter “Alaska DOT”], 2016; Pennsylvania Department of Transportation [hereinafter “PennDOT”], 2020; Georgia DOT, 2001; New York State Department of Environmental Conservation [hereinafter “New York State”], 2016; Wisconsin DOT, 2020b); puncture resistance (PennDOT, 2020; Georgia DOT, 2001; New York State, 2016; Wisconsin DOT, 2020b); AOS (Alaska DOT, 2016; PennDOT, 2020; Georgia DOT, 2001; New York State, 2016; Wisconsin DOT, 2020b); ultraviolet (UV) resistance (Alaska DOT, 2016; PennDOT, 2020; Georgia DOT, 2001; New York State, 2016); flow rate (Alaska DOT, 2016; Georgia DOT, 2001; New York State, 2016); and permittivity (Alaska DOT, 2016; Georgia DOT, 2001; Wisconsin DOT, 2020b). Table A1 in the Appendix provides the specifications of state DOTs and environmental agencies that were identified in the literature review.

Several states have approved the use of both nonwoven and woven GTX for dewatering bag applications. One of these states, Maine, specifies that the selection of a woven or nonwoven GTX should be made based on the "size of soil particles to be trapped (i.e., woven material for coarse particles and nonwoven material for finer particles)" (Maine Department of Environmental Protection, 2014). Maine does not provide additional details as to the specific particle size at which a nonwoven GTX should be used. The only other state identified with specifications of this nature was South Carolina. The South Carolina DOT (2011) breaks the state into two operating regions; Lower State and Upper State. Establishing these regions was originally intended to help guide seed mixture selection on DOT projects (South Carolina DOT, 2016). The dividing line between these regions represents the geological fall line between the Piedmont and Coastal Plain regions and the transition from primarily clay soils to sandy soils (South Carolina Geological Survey, 2005).

Along with the type of GTX (woven/nonwoven), permittivity is another criterion for which VDOT's specifications differ from those of a number of other states. VDOT specifies that GTXs have a permittivity equal to 1.2 sec^{-1} (VDOT, 2020). This is a similar value to values used by states such as Alaska and California (both 1 sec^{-1}) (Alaska DOT, 2016; California DOT, 2018) and Georgia (1.3 sec^{-1}) (Georgia DOT, 2018) but much greater than what is specified by Wisconsin (0.04-0.12 sec^{-1} depending on application) (Wisconsin DOT, 2020b). These variations could be attributable to differences in soil characteristics or perhaps could indicate that other states rely more on AOS specifications to determine filtration performance.

GTX AOS was identified as another criterion for which VDOT's specifications differed from those of other states. As noted previously, VDOT requires that all GTXs used for dewatering bag applications have an AOS equal to that of a No. 100 sieve. In comparison to the majority of state specifications identified, this is a much smaller opening size than what is commonly required. For example, New York (New York State, 2016), California (California DOT, 2018), Alaska (Alaska DOT, 2016), and Wisconsin (Wisconsin DOT, 2020a) all specify GTXs with an AOS larger than VDOT's requirement (No. 40-80, No. 30-50, No. 70, and No. 30, respectively). The reason for this wide variety of AOS specifications is not readily apparent from the information provided in the specifications. However, the most likely explanation could again be variations in soil gradations across the United States.

Dewatering Bag Implementation Guidance From Other States

Along with material specifications, many agencies provide guidance on the proper implementation of GTX dewatering bags in the field. This guidance can be broken into five general categories including (1) bag siting, (2) bag foundation, (3) bag sizing, (4) secondary sediment barriers, and (5) signs of a clogged or full bag. The guidance identified in each of these categories is summarized in the following sections.

Bag Siting

Many states provide guidance on the proper siting or location of GTX dewatering bags on the construction site. For example, New York specifies that the "bag should be placed in a location that is vegetated, relatively level, and provides for ease of access by heavy equipment, cleanout, disposal of trapped sediment, and proper release of filtered water" (New York State, 2016). New York also states that bags should be placed at least 50 ft from surface waters or wetlands.

PennDOT (2020) specifies locating bags in well-vegetated (stabilized) areas. In the event a suitable area is not available, PennDOT specifies lining the flow path with GTX meeting their Class 4, Type A, specifications (PennDOT, 2020). Further, PennDOT prohibits the placement of a bag on an area with a slope steeper than 5% (PennDOT, 2020). Maine's specifications require consultation prior to the use of a dewatering bag if the project will be located within 75 ft of a sensitive environment (Maine Department of Environmental Protection, 2014).

These specifications are intended to achieve two goals. The first is to prevent erosion caused by the effluent water from the bag, hence requiring level ground and vegetation. The second is to increase the dewatering bag system's effectiveness at removing sediment from CDW. By increasing the distance effluent water must travel through dense vegetation before re-entering receiving waters, it is anticipated that a level of treatment similar to that of a vegetated filter strip can be achieved. However, as mentioned previously, this requires additional space, which might not be available.

Dewatering Bag Bed

Along with properly locating the bag on the construction site, state agencies provide guidance and specifications for properly constructing a bed or platform on which to place the bag. New York specifies placing the bag on a 2-in-thick gravel bed, 4-in-thick straw mat, or vegetated filter strip (New York State, 2016). Similarly, the Georgia DOT (2001) specifies placing the bag on a bed of No. 57 stone, and the Alaska DOT (2016) specifies a bed of well-graded, clean 4-in-minus rock, straw, or other non-erodible barrier if the native soil does not allow percolation.

Maine provides more detailed guidance, specifying a 6-in-thick layer of 0.75-to-1.5-in-diameter crushed stone placed under the bag and on top of an additional GTX layer. This additional GTX layer is not intended to improve the bag's function but rather to make removal of the bag easier at the end of its service life. The specification also indicates that the stone bed should extend 3 ft on either side of the bag parallel to the flow and at least 5 ft on the downslope edge (Maine Department of Environmental Protection, 2014). Figure 4 provides plan and side view drawings of these specifications.

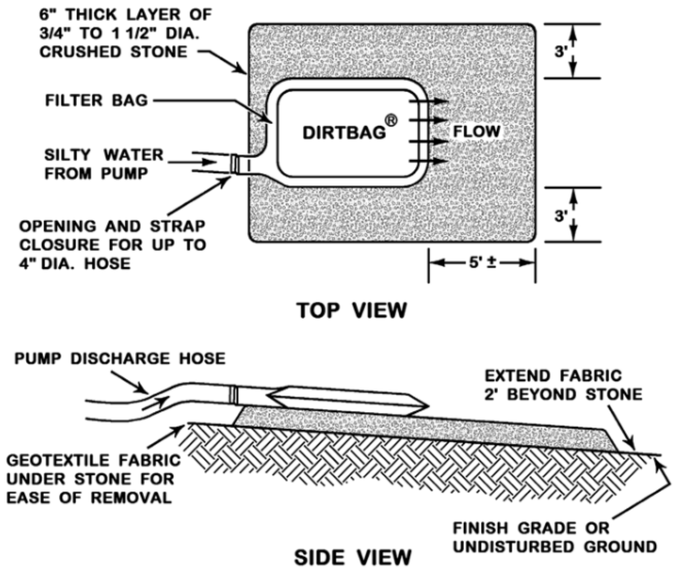


Figure 4. Geotextile Dewatering Bag Placement Specifications From Maine's *Erosion and Sediment Control Practices Field Guide for Contractors.* Used with permission of the Maine Department of Environmental Protection.

Generally, these specifications are written not only to prevent erosion of the soil underneath and downslope of the bag but also to allow the bag to function properly. Placement of a bag directly on poorly draining soils, such as clay, can prevent water from discharging through the bottom of the bag (Wisconsin DOT, 2020b). This effectively reduces the flow rate of the bag by one-half, potentially leading to bag failure even if it is properly sized. This topic is covered further in the following section.

Dewatering Bag Sizing

In general, proper sizing is critical to maintaining the effectiveness and service life of dewatering bags. In order to determine the proper dewatering bag size, three variables need to be considered: (1) the elevation difference between the pump and water level in the excavation (defined as the total hydraulic head); (2) peak discharge of the pump at the given hydraulic head conditions; and (3) the specified flow rate of the GTX used to construct the bag. This information can readily be collected from site inspections to measure the hydraulic head that the pump must lift; pump curves provided by the pump manufacturer; and GTX specifications also provided by the manufacturer.

State agencies provide additional guidance regarding the sizing of dewatering bags. For example, Wisconsin requires that dewatering bags have a minimum surface area of at least 100 ft^2 (Wisconsin DOT, 2020b). Bags smaller than 100 ft^2 are permitted only when discharge from the site is less than 100 ft^3 total (Wisconsin DOT, 2020b). Wisconsin's specifications provide further sizing guidance directing users to apply the following correction factors: (1) "reduce specified GTX flow rate by 50% to account for clogging," and (2) "for filter bags and basins, do not consider the bottom GTX surface area unless the bag or basin is placed on permeable bedding material (e.g., open graded) that will not impede or reduce the flow through the GTX" (Wisconsin DOT, 2020b). PennDOT (2020) provides similar guidance, specifying a dewatering bag size of 225 ft^2 and a maximum pump rate of 750 gpm or 50% of the maximum as specified by the manufacturer, whichever is less. New York State (2016) simply specifies that the bag "shall be sized in accordance with the manufacturers recommendations based on the pump discharge rate."

Secondary Sediment Barriers

Secondary sediment barriers refer to straw bales, silt fences, filter socks, or other practices installed around and/or under the perimeter of the dewatering bag to increase the retention of sediment. These can be useful near sensitive environments where increases in turbidity at or downstream of the project site can have adverse impacts on aquatic species.

PennDOT (2020) specifies the use of compost berms or filter socks in conjunction with dewatering bags that are located in sensitive areas (Penn DOT terms these areas as high quality or exceptional value watersheds); within 50 ft of receiving surface waters; or where a well-stabilized area to place the bag is not available. The Alaska DOT (2016) provides similar guidance, although they do not require their use, with the additional provision for the use of "contained Silt Control Systems . . . in place of sedimentation basins" when available space is limited.

Although these secondary barriers will increase the retention of sediments, little information is available in the literature regarding how much of an improvement they provide when used in conjunction with dewatering bags.

Signs of a Clogged or Full Bag

The identification of dewatering bags that have reached the end of their service life, because of either clogging or becoming full, is critical to their proper implementation. Typical guidance provided by other states identify this point using reductions in discharge from the bag (Alaska DOT, 2016; Georgia DOT, 2001; New York State, 2016; PennDOT, 2020).

Of the states identified that provide guidance, an observed reduction in flow rate of 50% is the most commonly used criterion to define this point (Alaska DOT, 2016; PennDOT, 2020). Other guidance defines this point as simply when the bag can no longer pass water or when the "bag flow area" has been reduced by 75% (Georgia DOT, 2001; New York State, 2016). Although the bag flow area is not explicitly defined, it can be assumed that it refers to the surface area of the bag that is still capable of discharging water. If so, this area can be identified in the right-hand image of Figure 5 as the black area of exposed GTX at the center of the dewatering bag.

Figure 5. Field Observations From Site 3 Showing an Increase in Discharge From Areas of the Bag Where the Accumulated Filter Cake Was Disturbed During Sampling

Although the guidance provided by other states is relatively consistent, when available, reliable methods for determining when these reductions in discharge have been met in the field are lacking. Generally, operators are directed to use visual observations to identify when flow out of the bag has been reduced sufficiently. However, this requires vigilant daily monitoring by the operator throughout the service life of the dewatering bag.

Field Evaluation

Three sites were selected for observation and sampling. Two were bridge replacement projects: the Route 23 Bridge over the North Fork Holston River in Weber City, Virginia (Site 1), and the Route 629 Deep Creek Road in Fluvanna County, Virginia (Site 3). The other site was a pipe jacking project at the Route 460 Vines Center in Lynchburg, Virginia (Site 2). The locations of these sites are shown in Figure 2.

Each of the sites used the same brand of dewatering bag, ACF Environmental's Dirtbag 55. It is important to note that manufacturers can produce dewatering bags with a number of different GTXs listed on VDOT's APL and it can be difficult, if not impossible, to determine the specific GTX used while in the field. Because of this, it is unknown if the Dirtbag 55s used at these three sites were manufactured using the same GTX. All of the bags had been in service for a number of days prior to sampling, although the exact duration each bag was in service or the amount of water that had been treated was unknown.

Reductions in turbidity and TSS concentrations of CDW treated by dewatering bags observed in the field ranged from 39% to 88% and 55% to 83%, respectively. Unfortunately, results from Site 3 were inconclusive because of errors in sample collection. Because of this, results from these field observations are limited to only two sites. It is suspected that accumulated sediment inside and on the surface of the bag (as shown in Figure 5) was disturbed and released during sample collection, causing an artificial increase in the turbidity and TSS of the effluent water. Sediment accumulation on the surface of the dewatering bag was a common observation that can be attributed to the accumulation of particles that settled out from the effluent water. This can be seen in the right-hand image of Figure 5 where the top center of the bag shows no signs of accumulated sediment. A closer inspection of the perimeter of the bag also showed that this area was not passing water. These observations would suggest that sediment had accumulated in the bag up to the same level as the observed sediment line. However, brushing this sediment off of the surface of the bag caused a visible increase in the flow rate from the cleared area (left-hand image of Figure 5). This would indicate that the level of sediment visible on the surface of the bag was more representative of the extent of filter cake development rather than of the remaining capacity of the bag.

These observations are consistent with informal guidance provided by some dewatering bag manufacturers directing users to use a broom to sweep sediment off of the walls of the bag to increase the flow rate. Although this practice will temporarily increase the flow rate of the dewatering bag, it can also allow a pulse of sediment to discharge from the bag. Although this sediment pulse could have potentially adverse impacts, it is a preferable outcome compared to a ruptured dewatering bag.

The far-right column of Table 5 shows the percent of the native soil from each site passing the No. 200 sieve. Based on definitions in ASTM D2487, soils with 50% or more of the material passing the No. 200 sieve are categorized as “fine-grained soils” (ASTM, 2017a). Considering this, it becomes apparent that native soils that can be categorized as fine-grained per the Universal Soil Classification System (USCS) can cause GTXs to perform less effectively with regard to filtration effectiveness. This result is somewhat to be expected given the AOS of the GTX. However, other factors could also be contributing to this variation in results. For example, the duration each bag had been in use prior to sampling plays an important role in the formation of a filter cake and the associated effects this has on sediment retention.

With regard to Site 1, the results provided in Table 5 provide further insight into the influence that site-specific characteristics, such as soil gradation, can have on the effectiveness of dewatering bags. Observations from a prior phase of the Site 1 construction project noted visible amounts of sediment discharging from the dewatering bag. At the time of these earlier observations, work was being conducted on the south bank of the river, noted by Points 6 and 7 in Figure 6.

Table 5. Turbidity and Total Suspended Solids: Field Results

Location	Influent Turbidity / TSS	Effluent Turbidity / TSS	Percent Turbidity Reduction	Percent TSS Reduction	Percent Passing No. 200 Sieve (Native Soil)
Site 1: Route 23 Bridge Over North Fork Holston River	203 NTU / 0.150 mg/L	25.3 NTU / 0.025 mg/L	88%	83%	19%
Site 2: Route 460 Vines Center	789 NTU / 933 mg/L	483 NTU / 420 mg/L	39%	55%	62%
Site 3: Route 629 Deep Creek Road	1035 NTU / NA	1474 NTU / NA	-30%	NA	49%

NA = not measured because of complications with sampling.

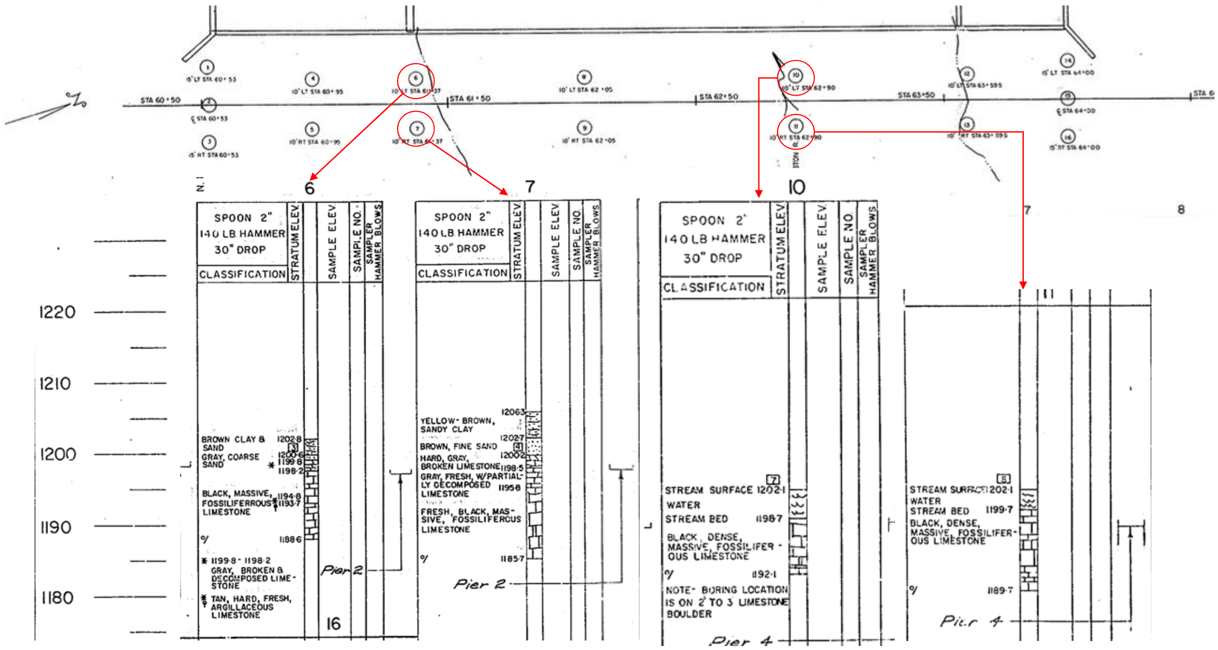


Figure 6. Location of Bore Holes Taken During the Initial Geotechnical Investigation of the Route 23 Bridge Project in Scott County, Virginia

The results in Table 5 for Site 1 represent samples taken from work being conducted in the middle of the river, noted by Points 10 and 11 in Figure 6. Referring to the geotechnical data collected at the time of the original bridge construction in 1960, it becomes apparent that the soil characteristics change across the width of the river.

The geotechnical data collected from Points 6 and 7 showed layers of clay and sand followed by limestone. Data from Points 10 and 11 showed that the stream bed consisted primarily of limestone with little, if any, fine material present. These geotechnical data provide some insight into why so much variability in dewatering bag effectiveness was seen in the same project area. They also highlight how geotechnical data collected during the planning stages of a project could be used to predict complications associated with the use of a dewatering bag.

Although field tests discussed previously can be effective in determining how well a dewatering bag will function at a given site, CDW collected from the site is necessary to conduct them. In many instances, this would mean that work at the site was already well underway. If the results of the field tests proved to be unfavorable, it could be difficult or infeasible to pivot to another method of managing the CDW generated on the site.

Another interesting field observation was the variety of pump types and sizes and the number of pumps used at these sites. Site 2 used a small sump pump to move water out of the excavation; Site 1, requiring the removal of a much larger quantity of water, implemented a number of 6-in trash pumps capable of pumping liquid mixed with solids. Based on observations from field personnel, one dewatering bag was used to treat the discharge from multiple pumps in a number of instances. Site 3 used a combination of a 4-in trash pump initially to draw the water down in the excavation and then a smaller sump pump to maintain a dry working environment.

These pumps produce very different discharge rates. For example, a 4-in engine-driven trash pump is capable of producing up to 550 gpm of discharge (American Machine and Tool Company, 2012). This is 5 times greater than the discharge rate the typical 1.5-in electric sump pump is capable of producing. Although the difference in pump size will have an impact on the size of dewatering bag that should be used, it is unclear what impact, if any, it will have on the filtration performance of the bag.

Dewatering bags that are undersized can undergo premature failure because of over-pressurization. Reports from the field indicate that in these instances, the GTX itself can rip open, releasing significant amounts of collected sediment onto the worksite. This observation is of interest because it notes that the GTX itself is failing rather than the seam around the perimeter of the bag. This could be attributable to variances in the thickness or density of nonwoven GTX inherent in the manufacturing process (Moo-Young et al., 2002).

Laboratory Evaluation

Total Suspended Solids and Turbidity Reductions

Table 6 provides the flow-weighted average TSS and turbidity measurements and the associated percent reduction for each of the GTX dewatering bags evaluated. As can be seen, all of the bags tested reduced effluent turbidity and TSS to a certain degree for all tank volumes except for the bag constructed with R100 GTX during Tank Volume 4. In this case, the flow-weighted average turbidity and TSS increased 32% and 16%, respectively, indicating that the bag was actually releasing sediment during Tank Volume 4. This result could be attributable to a disturbance in the filter cake occurring during the preparation of Tank Volume 4.

Table 6. Total Suspended Solids and Turbidity Starting Measurements, Flow-Weighted Averages, and Percent Reductions for the Three Geotextiles Examined During This Study

Geotextile	Tank Volume	Starting Turbidity (NTU)	Flow-Weighted Average Turbidity (NTU)	Percent Turbidity Reduction	Starting TSS (mg/L)	Flow-Weighted Average TSS (mg/L)	Percent TSS Reduction	Percent Peak Discharge Reduction
R100	1	357.7	286.2	24%	388.3	179.3	54%	1.4%
	2	409.0	192.9	53%	441.7	126.3	71%	32%
	3	429.3	61.9	86%	408.3	16.1	96%	77%
	4	411.0	541.2	-32%	418.3	484.4	-16%	95%
N10	1	424.3	204.4	52%	478.3	129.1	73%	10%
	2	382.7	77.8	80%	470.0	40.6	91%	69%
	3	327.0	247.2	24%	398.3	176.6	56%	91%
	4	386.3	321.8	17%	435.0	245.0	44%	94%
Pump-It Tube[a]	1	346.0	316.4	9%	411.7	216.5	47%	-15%
	2	330.3	171.9	48%	401.7	113.1	72%	-34%
	3	246.3	195.8	21%	270.0	125.7	53%	41%
	4	344.0	177.0	49%	373.3	104.0	72%	68%

TSS = total suspended solids.

[a] The Pump-It Tube is not currently listed on VDOT's Approved Products List.

As can be seen in Figure 7, aside from the expected peak in discharge at the beginning of Tank Volume 4, the discharge out of the R100 GTX bag remained very low and constant. Further, the peak discharge for the same tank volume was 95% lower than the average background discharge. Although these factors indicate the formation of a filter cake, the increase in effluent turbidity and TSS could also be a result of sediment accumulation on the surface of the bag washing into the sample container. This would be an effect similar to what was observed during the field sampling efforts, occurring naturally, however, rather than as a result of a physical disturbance during sample collection.

The dewatering bag constructed from the N10 GTX showed its greatest reduction in TSS and turbidity during Tank Volume 2 of CDW with 91% and 80% reductions, respectively. These reductions corresponded to a 69% reduction in peak discharge. Subsequent tank volumes produced up to a 94% reduction in peak discharge; however, with lower reductions in TSS and turbidity (44% and 17%, respectively, by Tank Volume 4). The general trend of these results is similar to those for the R100 GTX bag.

The results from tests conducted with the Pump-It Tube showed a relatively consistent reduction in TSS and turbidity between each tank volume. Further, peak discharge decreased the least overall of the three GTXs evaluated (68% maximum reduction by Tank Volume 4). This was most likely related to the woven GTX for this bag having a much larger AOS in comparison to the other nonwoven GTXs tested.

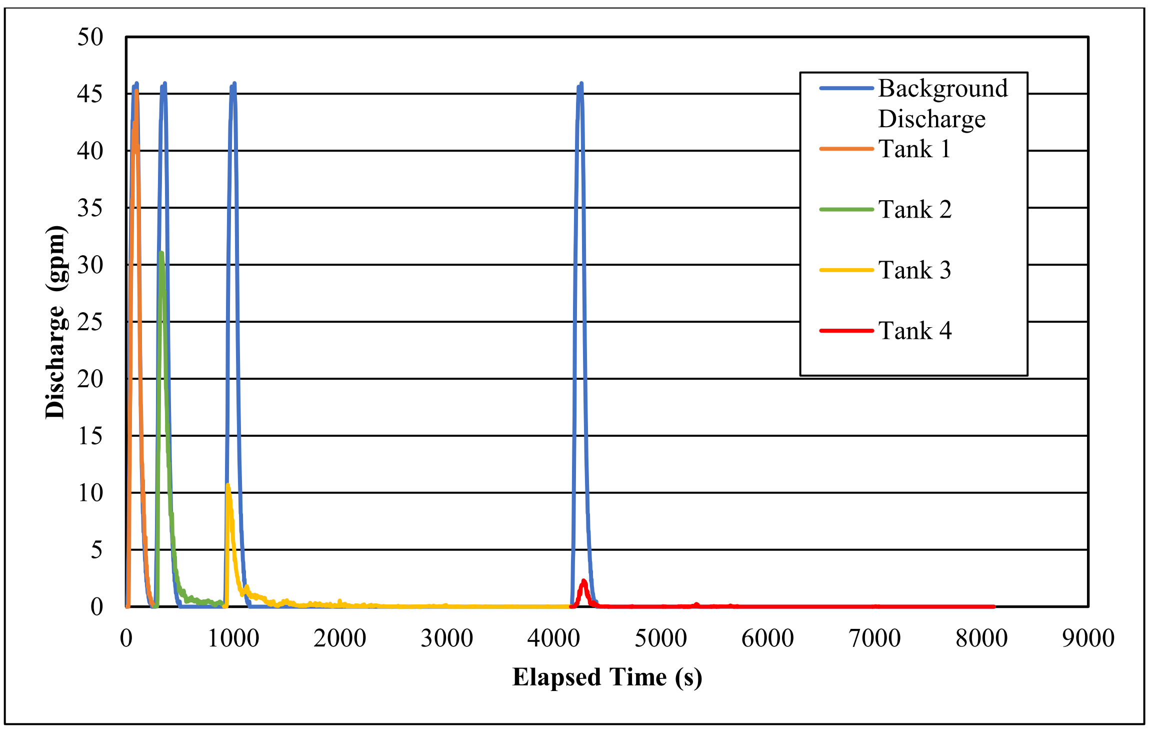


Figure 7. Changes in Discharge Rate Over the Course of Testing the R100 Geotextile Dewatering Bag. For the purposes of this figure, "background discharge" represents the average of the three background discharge tests transposed over time so that the background peak discharge aligns with the peak discharge measured during each tank volume.

With all other variables being held constant, GTXs with a larger AOS generally take longer to develop a filter cake. Because of this, although they do not provide the same turbidity/TSS reductions as those provided by GTXs with a tighter AOS (i.e., nonwoven GTXs), they are capable of maintaining a constant discharge for a longer period, potentially lengthening their service life.

Reductions in Peak Discharge

Reductions in peak discharge compared to the background discharge for each tank volume are also provided in Table 6. All of the GTXs showed the same general trend of decreasing peak discharge with additional tank volumes. However, there was a marked difference in the rate of decrease between the two nonwoven GTXs evaluated and the woven GTX. As noted, compared to the nonwoven materials, the woven GTX was able to maintain a higher flow rate throughout the course of testing while maintaining relatively constant effluent TSS and turbidity values. This can be most directly related to the AOS and flow rate of the woven GTX being significantly higher (192 gpm/ft^2) than those of the nonwoven GTXs tested (all equal to 80 gpm/ft^2) and the propensity for nonwoven GTX to blind at a higher rate than woven GTX (Yee and Lawson, 2012).

Previous research has shown that along with sediment characteristics, a GTX's AOS and permittivity characteristics are primarily responsible for a GTX's capacity to retain sediments (Kutay and Aydilek, 2004). Kutay and Aydilek (2004) evaluated the dewatering effectiveness and retention of fines of dewatering bags constructed of woven GTX, nonwoven GTX, and a combination of both materials (i.e., a double-walled bag with woven GTX on the outside and nonwoven GTX inside), which were used to dewater fly ash slurry and dredged materials at various water contents ranging from 80% to 1600%. Dewatering effectiveness here refers to the material's ability to reduce the water content of the influent slurry after a period of resting.

Kutay and Aydilek (2004) found that as the AOS and permittivity of the GTX (both woven and nonwoven) increased, the soil retention of the dewatering bag system decreased. This was especially the case at higher water contents. Interestingly, the authors found that GTX AOS and permittivity had no impact on the dewatering efficiency of either the fly ash or dredged sediment. The authors stated that this was because dewatering efficiency was primarily a function of the filter cake developed inside the bag rather than GTX characteristics (Kutay and Aydilek, 2004). Since dewatering takes place at later stages of a dewatering bag's use cycle (i.e., when the pumps have been turned off at the end of the day), this makes sense—since a fully formed filter cake should be present and providing the majority of sediment retention. The results from Kutay and Aydilek (2004) also indicate that the properties of the filter cake are not influenced by the properties of the GTX but rather by the characteristics of the CDW being treated.

From the results from the current study, it would appear that AOS and permittivity of the GTX have an impact on how long it takes for the filter cake to develop, with smaller-AOS, lower-permittivity GTXs developing a filter cake earlier in their service life compared to the larger-AOS, higher-permittivity GTXs representative of woven GTXs. This can be seen when the changes in TSS, turbidity, and peak discharge reductions are compared with each tank volume. The two nonwoven GTXs showed greater reductions in TSS and turbidity for Tank Volumes 1 and 2 compared to the woven GTX. After Tank 2, discharge rates from the bags dropped significantly for the nonwoven GTXs (reaching up to a 95% reduction in peak discharge), indicating the formation of a filter cake. For the woven GTX, it would appear that by Tank Volume 4, filter cake formation was in its early stages, as can be noted by the additional 27% reduction in peak discharge compared to Tank Volume 3.

Although the observed reductions in peak discharge over time would indicate that a filter cake was able to form during testing, the corresponding decrease in percent reductions of TSS and turbidity for the nonwoven GTXs needs further clarification. As noted previously, a potential explanation for this result could be the accumulation and shedding of fine sediment on the outside of the bag. As the rate of discharge from the bag decreases, sediment suspended in the effluent water is more prone to settling out and accumulating on the outer surface of the bag. This process can continue until no more sediment can be accumulated or there is some change in the pressure inside the bag (i.e., shutting down pumps). At this point, the surface of the bag will begin to shed some of the accumulated sediment, increasing the turbidity and TSS of the effluent water. This would explain why decreases in TSS and turbidity were observed with no increase in discharge (indicative of a disturbance in the filter cake).

Geotextile Stretching

Length and width measurements of each bag tested were taken before and after testing to determine the amount of stretching resulting from use. The results of these measurements are provided in Table 7. Length measurements represent the dimensions of the bag parallel to the inlet hose. As can be seen from the data, the Pump-It Tube, manufactured from a woven GTX, exhibited no stretching in length or width whereas the nonwoven GTXs showed some degree of stretching. This result can most likely be attributed to the Pump-It Tube's higher grab tensile strength and percent grab elongation (297 lb and 58%, respectively, in the machine direction) compared to the other nonwoven GTXs tested (both equal to 250 lb and 50%, respectively) (Flo-Water, LLC, 2017; Hanes Geo Components, 2016; US Fabrics, Inc., 2016).

The two nonwoven GTXs showed signs of stretching. The R100 GTX stretched in both directions (length and width), and the N10 GTX stretched only along the bag's width. This result was likely due to the construction of the dewatering bags. Specifically, the bags constructed with the R100 GTX had stitched seams around the entire perimeter of the bag whereas the N10 bags were constructed from one piece of GTX folded in half and stitched along each side. The stitched seams likely prevented or reduced the elongation of the GTX because of the thread used or the increased amount of material present in the area because of folding at the seam.

Table 7. Stretching Observed With Each Geotextile Tested Before and After Testing

Geotextile	Dimensions Pre-Test (Length x Width)	Dimensions Post-Test (Length x Width)	Percent Change (Length x Width)	Percent Change for Total Area
R100	26.5 in x 18 in	27.5 in x 19.875 in	4% x 9%	13%
N10	22.875 in x 13.75 in	22.875 in x 15.375 in	0% x 11%	11%
Pump-It Tube[a]	20 in x 8 in (approx.)	20 in x 8 in (approx.)	No change	No change

[a] Results from the Pump-It Tube are approximate because the clamps slipped during testing.

Although GTX stretching was observed, its impact on TSS and turbidity reductions is still unknown. A further investigation of how GTX stretching affects the AOS and subsequent filtration performance would need to be conducted to understand better the impacts associated with these results. Methods such as the bubble point test (ASTM D6767) could be used to determine not only the AOS of the GTX before and after use but also the size distribution of all of the openings present in the GTX (ASTM, 2016; Elton and Hayes, 2007). This would also provide further information on the clogging characteristics of the GTX when exposed to different CDW characteristics.

The primary focus of the current study was to evaluate the filtration performance of these dewatering bags. However, after discussions with VDOT personnel, it was discovered that the rupturing of the dewatering bags was also a topic of concern. Field observations have indicated that dewatering bags most commonly rupture because of failure of the GTX fabric itself (i.e., tearing) rather than failure at the stitched seams. It is unknown if these ruptures were caused by improper use / overuse or were attributable to defects in manufacturing. Further research could be conducted to relate the GTX stretching observed during this study to grab tensile strength and, more specifically, grab elongation at break values (a physical characteristic readily available from the manufacturer) to predict better when a bag is nearing failure. This could include monitoring the changes in the dimensions of the bag during use. Once one of the dimensions of the bag has stretched past a certain percentage of its original length, personnel could determine if the bag needed to be replaced or other actions needed to be taken. However, more information regarding the GTXs' modulus of elasticity (how much the material can stretch before permanent deformation occurs) is needed first, along with other information.

Methods of Increasing Filtration Effectiveness

Previous research has evaluated a number of methods of improving the ability of GTX dewatering bags to retain sediment. As noted previously, some states provide guidance on a number of secondary sediment barriers that can be used in conjunction with dewatering bags to improve CDW quality. These secondary barriers typically consist of common erosion and sediment control techniques and products. The effectiveness of these products when used on their own to manage stormwater runoff is generally well understood. However, little quantitative information is available in the literature regarding their effectiveness when used in combination with a dewatering bag. This is important to note since these secondary barriers must remove CDW containing much finer sediment particles than what they were originally intended to remove.

Along with secondary barriers, the use of flocculants has received attention in the literature as a potential method of improving the filtration effectiveness of dewatering bags. These studies have investigated the application of flocculants directly into the dewatering bag either by dosing influent water (active treatment) or adding solid flocculant into the bag and applying the material to secondary barriers such as straw bales, wattles, or check dams (passive treatment).

When applied directly into dewatering bags, flocculants function by increasing the size of the particles present in the CDW, making the GTX more effective at retaining sediment.

However, depending on the flocculant dosing and characteristics of the CDW such as sediment concentration and particle size distribution, the addition of flocculants in this manner can also clog or blind the GTX prematurely. Because of this, direct application into the bag was not evaluated during this study.

When applied to secondary barriers, flocculants are intended to function by increasing the sedimentation rate of soil particles, again by increasing the average size and density of the particles (or flocs) in the CDW. As these secondary barriers primarily provide turbidity and TSS reductions by improving conditions for sedimentation, the increases in particle size and density allow these barriers to remove particles effectively that they would normally not be capable of removing. However, one of the criteria that is key to the effective use of these secondary barriers when combined with flocculants is the length of time the CDW remains in contact with the applied flocculants. Allowing enough time for the granular or block flocculant to dissolve into solution and mix with sediment particles and for those sediment particles to collide with each other is critical for the successful use of this material.

In a 2014 study, Kang et al. evaluated the effectiveness of jute netting and silt wattles treated with PAM flocculant (in granular and block form) at reducing TSS and turbidity levels in CDW. Turbid water was fed into a channel lined with GTX fabric to prevent erosion during testing. Six different treatment combinations were evaluated consisting of silt wattles with and without jute netting and with various combinations of flocculant application. Flocculant applications consisted of granular PAM applied to the jute netting or on the silt wattles and PAM blocks placed on the downslope side of the silt wattles. The study found that passive dosing of PAM flocculants proved to be an effective method of decreasing the turbidity and TSS levels of CDW. Of the six treatments tested, granular PAM applied to jute netting combined with silt wattles showed the greatest reductions in turbidity (67.1% reduction from 298 NTU) and TSS (74.6% reduction from 3669 mg L^{-1}).

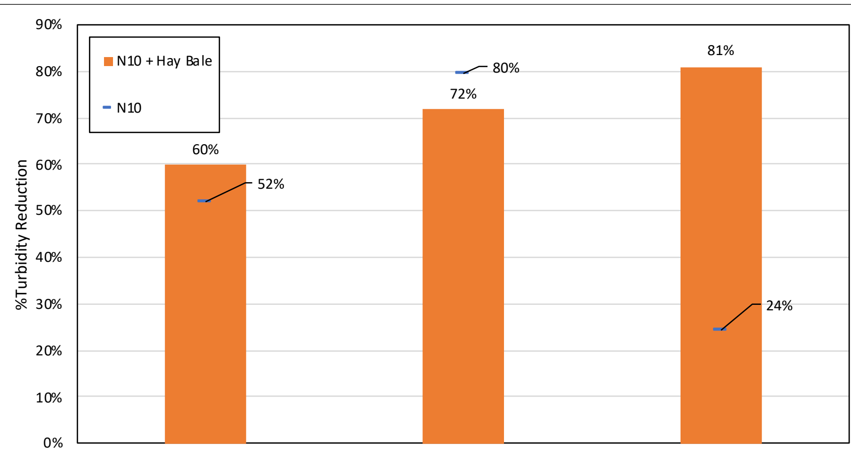
Kang et al. (2014) also evaluated how these treatments affected the particle size distribution of the sediment in suspension. Their results indicated that the use of jute netting combined with PAM flocculants produced a marked shift in particle size distribution. This shift was readily seen from the silt size (2 to 50 µm) up to the sand size (50 to 2000 µm). This result is of particular interest for the current study as the nonwoven GTXs currently used by VDOT all have an AOS equal to 149 µm. Because of this, particles in the discharge from dewatering bags will primarily be smaller than 149 µm. These finer fractions of sediment have been shown to contribute more to the turbidity of water than coarser particles do (Kang et al., 2014; Przepiora et al., 1998). The results from Kang et al. (2014) indicate that flocculants could be used effectively to increase the size of particles present in the water discharging from dewatering bags, potentially providing an improvement in turbidity immediately downstream of the dewatering bag. This reduction could be attributed not only simply to the increase in size of sediment particles in suspension but also to the increased sedimentation rate associated with larger particles.

Straw Bale Treatment

After discussions with a number of dewatering bag users and a review of the literature, the researcher identified straw bales as the most common of these traditional erosion and sediment control measures to be used with dewatering bags. Straw bales are commonly used to construct corrals around dewatering bags, with bales placed around the perimeter and underneath the bag. These straw bales act to remove sediment primarily through filtration.

Flow-weighted percent turbidity reductions from the N10 GTX dewatering bag when paired with a straw bale and previous reductions provided by the N10 bag alone are provided in Figure 8. Unfortunately, during the beginning of Tank Volume 4, the hose from the feed tank slipped out of the dewatering bag, allowing water and sediment that had accumulated inside the bag to be released. This caused a significant disturbance to any filter cake that might have begun to form, and because of this, results from this tank volume were omitted.

When the turbidity reductions produced by the N10 bag paired with the straw bale to those produced by the N10 bag alone were compared, an additional turbidity reduction of about 8% was seen in Tank 1. Tank 2 produced less turbidity reduction, about an 8% increase in turbidity, compared to the N10 bag alone. Tank 3, however, showed a significant (57%) increase in turbidity reduction when the straw bale was used compared to the bag alone.



Tank Volume	1	2	3
Influent Turbidity	366 NTU	397 NTU	347 NTU
Flow Weight Effluent Turbidity	147 NTU	112 NTU	66 NTU

Figure 8. Percent Turbidity Reduction Provided by the Terra Tex N10 Dewatering Bag on Its Own and With the Addition of a Straw Bale

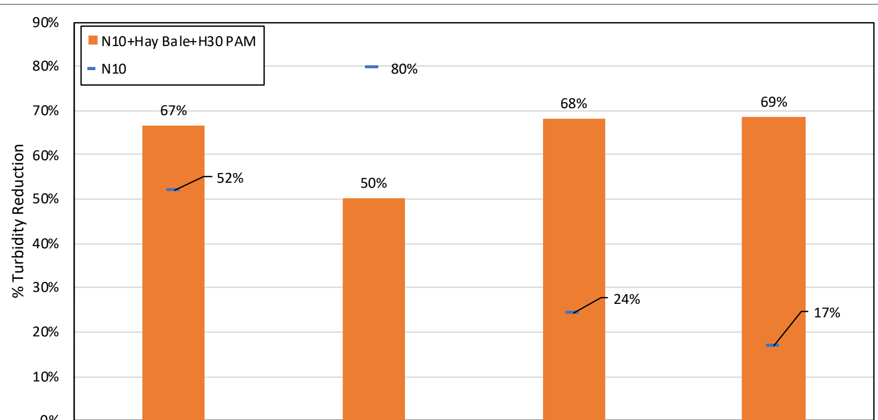
During testing, a number of visual observations were made. First, the testing apparatus allowed for only one straw bale to be placed under the bag. Because of this, it was anticipated that the majority of the discharge from the bag would flow around rather than through the straw bale, decreasing its impact on sediment retention. However, throughout the duration of the test, water was observed draining evenly from the bottom of the straw bale. This provided a good indication that water was passing through the bale, providing some form of treatment.

Second, there was a lack of sediment accumulation visible on the surface of the straw bale. This is likely an indicator that any sediment trapped by the straw bale took place within the body of the bale and not at the surface. Of course, it can be assumed that with prolonged use, a visible layer of sediment would accumulate on the surface.

Straw Bale + PAM Treatment

Along with the straw bale alone, tests were conducted with a straw bale treated with a granular PAM flocculant. The results of this test are shown in Figure 9. From these results it can be seen that although the addition of the straw bale treated with flocculant did increase the turbidity reductions, these reductions were generally lower than those provided by the addition of the straw bale alone.

This result could be attributable to a number of factors. For example, although water was observed passing through the entire cross section of the straw bale during the test conducted without the addition of flocculant, similar results were not seen during this test.



Tank Volume	1	2	3	4
Influent Turbidity	340 NTU	370 NTU	400 NTU	344 NTU
Flow Weight Effluent Turbidity	114 NTU	184 NTU	128 NTU	108 NTU

Figure 9. Percent Turbidity Reduction Provided by the Terra Tex N10 Dewatering Bag on Its Own and With the Addition of a Straw Bale Treated With H30 Polyacrylamide Flocculant

This could be attributable to the formation of an impermeable layer of semi-hydrated flocculant that formed between the bag and the top of the straw bale, as shown in Figure 10. This layer could be directing water out and around the straw bale, decreasing its capacity to collect and retain sediment.

A closer inspection of the treated straw bale indicated that in fact floc formation was occurring on the surface of the bale, as seen in the right-hand side of Figure 10. During the testing of the straw bale alone, the accumulation of sediment on the surface of the straw could not be seen. This indicates that although the granular flocculant was active and producing flocs, these flocs either were of low quality (small in size and easily broken up) or were not retained by the straw bale once formed.

In order to determine if these inferences were correct, further testing using a large-scale straw bale corral would be needed. This corral would reduce the ability of turbid water to bypass the straw bales rather than flow through them. In addition, it would be of interest to conduct additional testing of straw bales with granular flocculant "mixed" with the bales rather than applied directly to the surface of the bale. This 'mixing" could have the effect of allowing the water to penetrate into the bale before coming into contact with the flocculant.

Figure 10. Activated (Hydrated) H30 Polyacrylamide Flocculant (Left) and Semi-Hydrated H30 Polyacrylamide Flocculant Next to Sediment Flocs (Right)

CONCLUSIONS

- *Based on the results from the field testing, although limited to two sites, the filtration effectiveness of GTX dewatering bags can be highly variable between locations and in certain cases within the same project site.* This is primarily due to variations in soil characteristics across the state and the sediment load in the CDW. Results from the field and laboratory testing conducted during this study indicate that dewatering bags used at construction sites with soils categorized as "fine-grained" per the USCS definition perform poorly compared to sites with coarser soil gradations.

- *VDOT's material specifications for the physical properties of nonwoven GTX materials used for dewatering bags are appropriate for maximizing the retention of sediments when treating CDW.* These specifications are also consistent with specifications from other states. Further, no alternative GTX was identified that would provide a higher level of filtration when AOS and permittivity values alone are considered.

- *The addition of secondary sediment barriers, such as straw bales, can be used to increase the retention of sediment when used in conjunction with dewatering bags.* Although limited by the testing apparatus used for this study, flocculants show promise as a method of increasing the effectiveness of these secondary sediment barriers. These potential improvements are further supported by the literature.

- *If treating the same volume of CDW with similar sediment concentrations and characteristics, woven GTX dewatering bags are capable of maintaining a higher flow rate for a longer period of use compared to nonwoven GTX dewatering bags.* However, woven GTX dewatering bags provide a lower degree of sediment retention during the initial stages of use (i.e., prior to filter cake formation).

- *Dewatering bags constructed from nonwoven GTXs will stretch with use.* Based on the results from this study, the amount and direction of stretching are related to the orientation and reinforcement of the stitched seam of the bag.

RECOMMENDATIONS

1. *VDOT's Environmental Division should develop a special provision to direct contractors working in areas where fine-grained soils are present either to implement secondary sediment barriers or to avoid the use of GTX dewatering bags.*

2. *VDOT's Environmental Division should work with VDOT's Location and Design Division to determine what updates need to be made to the current dewatering bag specifications provided in Specification EC-8 of VDOT's Road and Bridge Standards. Any updates to this specification should include information that establishes the proper procedures related to the sizing and siting of dewatering bags and the identification of clogged or full bags.*

3. *VDOT's Environmental Division should decide whether additional investigations should be conducted to determine better the efficacy of secondary sediment barriers and to establish an empirically based method of determining when a dewatering bag has reached the end of its service life. Investigations of secondary sediment barriers should include field-scale testing at a variety of sites with different soil classifications. Investigations regarding the service*

life of dewatering bags should include an evaluation of the amount of stretching GTXs used for this application can withstand prior to rupture and a method of identifying this threshold in the field.

IMPLEMENTATION AND BENEFITS

Implementation

With regard to Recommendation 1, VDOT's Environmental Division will develop this special provision using the information provided in this report. It is anticipated that this special provision will be available for implementation by the end of the fourth quarter of FY 2021.

With regard to Recommendation 2, during the course of this study, an extensive search of the specifications of other state DOTs and environmental protection agencies identified a number of relevant specifications that could be adapted to suit VDOT's needs. This information will be evaluated and changes to Specification EC-8 of VDOT's *Road and Bridge Standards* proposed to VDOT's Construction Division, as appropriate, by the end of Calendar Year 2021 by VDOT's Environmental Division.

With regard to Recommendation 3, if VDOT's Environmental Division determines that additional research would be beneficial, the Environmental Division will develop and submit this topic as a research needs statement to the Virginia Transportation Research Council's Environmental Research Advisory Committee for scoring and prioritization before the committee's spring 2021 meeting.

Benefits

Implementing Recommendation 1 will reduce the risk of an inadvertent release of sediment into waterways by modifying or restricting the use of GTX dewatering bags in areas with soils classified as fine-grained using the USCS system. In addition, implementation of this recommendation will provide the additional benefit of increasing the awareness of contractors and VDOT personnel of the limitations associated with the filtration effectiveness of dewatering bags.

Implementing Recommendation 2 will ensure that contractors are consistently provided with the necessary information to size and site dewatering bags properly and the basic information to identify dewatering bags that have become clogged or full of sediment. This will provide a benefit to VDOT by preventing the misuse of dewatering bags, which could potentially lead to rupture and/or an inadvertent release of sediment into surface waters.

Implementing Recommendation 3 will enable VDOT to collect the necessary information to develop a procedure to identify dewatering bags that are nearing failure in the field based on a numerical attribute rather than anecdotal observations. This would remove much of the uncertainty experienced by dewatering bag users and site inspectors when determining if a bag needed to be replaced or increased in size. In addition, field-scale testing of secondary sediment barriers would provide VDOT with a better understanding of the potential improvements that use of these barriers can provide in areas with fine-grained soils. The development of these tools and techniques will reduce the chance of rupture of dewatering bags caused by over-pressurization. In addition, if confirmed to be effective, secondary sediment barriers would provide users with additional tools when using dewatering bags in areas with fine-grained soils.

ACKNOWLEDGMENTS

The author is grateful to Meg Short, Ed Wallingford, and George Young for their continued support and guidance regarding this project. Thanks are also extended to Clint Steel for his assistance with sample collection and site evaluations. The author also thanks Kaitlyn Elliot for her dedication during the laboratory testing, field sampling, and sample analysis. A great deal of thanks is also extended to Matthew Bray for his tenacity during laboratory testing and most notably sample analysis. Finally, thanks also go to G. Michael Fitch and Amy O'Leary for their support of this research and the invaluable guidance they provided throughout the course of this project and beyond.

REFERENCES

Alaska Department of Transportation and Public Facilities. Alaska Storm Water Pollution Prevention Plan Guide (BMP 07.00), 2016. http://www.dot.state.ak.us/stwddes/desenviron/assets/pdf/swppp/english/2016/swppp_guide_with_apdx.pdf. Accessed November 4, 2020.

American Machine & Tool Company. 3" & 4" Self-Priming Engine Driven Trash Pumps, 2012. http://amtpumps.com/site/wp-content/uploads/2017/01/ENG-17-18.pdf. Accessed October 5, 2019.

ASTM International. ASTM D6913/D6913M: Standard Test Methods for Particle-Size Distribution (Gradation) of Soils Using Sieve Analysis. In *Annual Book of ASTM Standards.* West Conshohocken, PA, 2009.

ASTM International. ASTM D4491/D4491M: Standard Test Methods for Water Permeability of Geotextiles by Permittivity. In *Annual Book of ASTM Standards.* West Conshohocken, PA, 2012.

ASTM International. ASTM D6767: Standard Test Method for Pore Size Characteristics of Geotextiles by Capillary Flow Test. In *Annual Book of ASTM Standards.* West Conshohocken, PA, 2016.

ASTM International. ASTM D2487-17: Standard Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System). In *Annual Book of ASTM Standards.* West Conshohocken, PA, 2017a.

ASTM International. ASTM D4751-20a: Standard Test Methods for Determining Apparent Opening Size of a Geotextile. In *Annual Book of ASTM Standards.* West Conshohocken, PA, 2017b.

ASTM International. ASTM D5141: Standard Test Method for Determining Filtering Efficiency and Flow Rate of the Filtration Component of a Sediment Retention Device. In *Annual Book of ASTM Standards.* West Conshohocken, PA, 2018.

ASTM International. ASTM D7701: Standard Test Method for Determining the Flow Rate of Water and Suspended Solids from a Geotextile Bag (Withdrawn 2020). In *Annual Book of ASTM Standards.* West Conshohocken, PA, 2020.

California Department of Transportation. Standard Specifications, 2018. http://caltrans-opac.ca.gov/publicat.htm%0Ahttp://www.dot.ca.gov. Accessed July 4, 2019.

Elton, D.J., and Hayes, D.W. The Bubble Point Method for Characterizing Geotextile Pore Size. In *Geosynthetics in Reinforcement and Hydraulic Applications.* American Society of Civil Engineers, Reston, VA, 2007.

Flo-Water, LLC. Flo-Water Product Specifications, 2017. http://www.flo-water.net/specifications-jpg/. Accessed October 5, 2018.

Georgia Department of Transportation. Standard Specifications Construction of Transportation Systems Section 719—Silt Filter Bag. 2001.

Hanes Geo Components. TerraTex® N10 Specification Sheet. Leggett and Platt, 2016.

Kang, J., and McLaughlin, R.A. Simple Systems for Treating Pumped, Turbid Water With Flocculants and a Geotextile Dewatering Bag. *Journal of Environmental Management*, Vol. 182, 2016, pp. 208-213.

Kang, J., King, S.E., McLaughlin, R.A., and Wiseman, J.D. Flocculated Sediment and Runoff Quality Improvement by Polyacrylamide. *Transactions of the ASABE*, Vol. 57, No. 3, 2014, pp. 861-867.

Koerner, R.M., and Ko, F. Laboratory Studies on Long Term Drainage Capability of Geotextiles. *Second International Conference on Geotextiles*, 1982, pp. 91-96.

Koerner, R.M., and Koerner, G.R. *On the Need for a Better Test Method Than Dry or Wet Sieving to Obtain the Characteristic Opening Size for Geotextile Filter Design Purposes*. Geosynthetic Institute, No. 31, 2014.

Kutay, M.E., and Aydilek, A.H. Retention Performance of Geotextile Containers Confining Geomaterials. *Geosynthetics International*, Vol. 11, No. 2, 2004, pp. 100-113.

Maine Department of Environmental Protection. *Maine Erosion and Sediment Control Practices Field Guide for Contractors*. 2014.

Moo-Young, H.K., Gaffney, D.A., and Mo, X. Testing Procedures to Assess the Viability of Dewatering With Geotextile Tubes. *Geotextiles and Geomembranes*, Vol. 20, No. 5, 2002, pp. 289-303.

Muthukumaran, A.E., and Ilamparuthi, K. Laboratory Studies on Geotextile Filters as Used in Geotextile Tube Dewatering. *Geotextiles and Geomembranes*, Vol. 24, No. 4, 2006, pp. 210-219.

New York State Department of Environmental Conservation. *New York Standards and Specifications for Erosion and Sediment Control* (Issue November, p. 69). Empire State Chapter Soil and Water Conservation Society, New York, 2016.

Pennsylvania Department of Transportation. *Publication 408 / 2020 SPECIFICATIONS*. Harrisburg, 2020.

Przepiora, A., Hesterberg, D., Parsons, J.E., Gilliam, J.W., Cassel, D.K., and Faircloth, W. Field Evaluation of Calcium Sulfate as a Chemical Flocculant for Sedimentation Basins. *Journal of Environmental Quality*, Vol. 27, No. 3, 1998, pp. 669-678.

South Carolina Department of Transportation. Supplemental Technical Specification for Dewatering Bags SC-M-815-15(11/11), 2011. https://www.scdot.org/business/technicalPDFs/supTechSpecs/Dewatering_Bags_08_08_2011.pdf. Accessed October 10, 2020.

South Carolina Department of Transportation. Supplemental Technical Specification for Seeding, 2016. https://www.scdot.org/business/technicalPDFs/supTechSpecs/SC-M-810-4-Seeding-010121-Approved.pdf. Accessed September 7, 2019.

South Carolina Geological Survey. Fall line 500K, 2005. https://www.dnr.sc.gov/GIS/descfall500k.html. Accessed August 8, 2020.

Stoltz, G., Delmas, P., and Barral, C. Comparison of the Behavior of Various Geotextiles Used in the Filtration of Clayey Sludge: An Experimental Study. *Geotextiles and Geomembranes*, Vol. 47, No. 2, 2019, pp. 230–242.

Thrace-LINQ Inc. Product Data Sheet Thrace-LINQ 245EX, 2012. https://www.thracelinq.com/datasheets/Thrace-LINQ_DataSheet-245EX.pdf. Accessed August 8, 2019.

U.S. Environmental Protection Agency. *Residue, Non-Filterable (Gravimetric, Dried at 103-105˚C)*. Cincinnati, OH, 1971.

U.S. Environmental Protection Agency. *Determination of Turbidity by Nephelometry*. Cincinnati, OH, 1996.

U.S. Environmental Protection Agency. Polymer Flocculation. In *Stormwater Best Management Practices: Polymer Flocculation* (Issue October), 2013. www.epa.gov/npdes/pubs/polymerfloc.pdf. Accessed September 15, 2020.

US Fabrics, Inc. Crown Resources / TNS R100 Specifications. Cincinnati, OH, 2016.

Virginia Department of Transportation. *Road and Bridge Specifications*. Richmond, 2020a.

Virginia Department of Transportation. Approved Products List No. 63. Richmond, 2020b.

Wisconsin Department of Transportation. S*ection 645 Geosynthetics* (Issue December 2019). Madison, 2020a.

Wisconsin Department of Transportation. Standard Specifications for Highway and Structure Construction. Madison, 2020b.

Yee, T.W., and Lawson, C.R. Modelling the Geotextile Tube Dewatering Process. *Geosynthetics International*, Vol. 19, No. 6, 2012, pp. 498-498.

APPENDIX

DEWATERING BAG SPECIFICATIONS

Table A1. Dewatering Bag Specifications From Other States

State	Organization	Specification Document	Section
Alaska	Department of Transportation and Public Works	Stormwater Pollution Prevention Plan	BMP-07.00 Contained Silt Control System
California	Department of Transportation	Standard Specifications	Section 96-1.02G
Georgia	Department of Transportation	Standard Specifications	Section 719—Silt Filter bag
Maine	Department of Environmental Protection	Maine Erosion and Sediment Control Best Management Practices (BMPs), Manual for Designers and Engineers	Section C. Sediment Containment
New York	Department of Environmental Conservation	New York State Standards and Specifications for Erosion and Sediment Control	Section 5, p. 5.16
Pennsylvania	Department of Transportation	Publication 408/2020 Specifications	Section 855—Pumped Water Filter Bag
South Carolina	Department of Transportation	Supplemental Technical Specifications	Designation SC-M-815-15 (11/11)
Wisconsin	Department of Natural Resources	Stormwater Construction Technical Standards	Dewatering Practices for Sediment Control, Number1061

Sources: Alaska Department of Transportation and Public Facilities, 2016; California Department of Transportation, 2018; Georgia Department of Transportation, 2001; Maine Department of Environmental Protection, 2014; New York State Department of Environmental Conservation, 2016; Pennsylvania Department of Transportation, 2020; South Carolina Department of Transportation, 2011; Wisconsin Department of Transportation, 2020b.

Table A2. Geotextile Material Specifications for Each Dewatering Bag Tested

Physical Property	ASTM Test Method	Geotextile		
		Crown Resources TNS R100	**TerraTex N10**	**Pump-It Tube**
Grab Tensile Strength	D4632	250 lb	250 lb	297 lb
Grab Elongation	D4632	50%	50%	58%
CBR Puncture	D6241	650 lb	700 lb	NA
Trapezoidal Tear	D4533	100 lb	100 lb	81 lb
UV Resistance at 500 hr	D4355	70%	70%	NA
Apparent Opening Size (AOS)	D4751	100 sieve	100 sieve	60 sieve
Permittivity	D4491	1.2 sec^{-1}	1.2 sec^{-1}	2.360 sec^{-1}
Water Flow Rate	D4491	80 gpm/ft^2	80 gpm/ft^2	192 gpm/ft^2

Flo-Water, LLC, 2017; Hanes Geo Components, 2016; US Fabrics, Inc., 2016.