EXHIBIT 4

AFFIDAVIT OF DENIS ST. PETER

226

STATE OF MAINE
BOARD OF ENVIRONMENTAL PROTECTION

MUNICIPAL REVIEW COMMITTEE AND PENOBSCOT ENERGY RECOVERY COMPANY APPEAL OF DEP SOLID WASTE ORDER FOR MINOR REVISION FOR JUNIPER RIDGE LANDFILL #S-020700-WD-W-M	)))))))	AFFIDAVIT OF DENIS ST. PETER

1. My name is Denis St. Peter, and I make this affidavit based on my personal knowledge, experience, and belief.

2. I have over 20 years of civil and environmental experience, including substantial experience involving the design, operation and closure of landfills within the State of Maine.

3. Currently, I am President of CES, Inc., a 60-person environmental, engineering and consulting firm founded in 1978. We offer a wide range of services and routinely provide services to municipal, State, industrial, commercial, and institutional clients throughout the State. CES personnel includes Licensed Professional Engineers, Professional Land Surveyors, a Certified Geologist, soils and wetlands scientists, planners, environmental scientists, GIS specialists, and designers.

4. I received my undergraduate degree from the University of Maine with a Bachelor of Science in Civil Engineering.

5. I performed an evaluation of the Solid Waste Order Minor Revision *#S-020700-WD-W-M* ("Order") issued by the Department of Environmental Protection.

6. In reviewing the Order, I attempted to evaluate the technical justification for increasing the amount of municipal solid waste (MSW) bypass to be used as the "soft layer" in Cell 6 at Juniper Ridge Landfill (JRL) and all future cells.

7. JRL is owned by the State of Maine. In 2003, the Legislature directed the State Planning Office to acquire the landfill. The private operator of JRL is New England Waste Services of Maine, LLC, a subsidiary of Casella Waste Systems, Inc. JRL is sited on a 780 acre parcel, 68-acres of which are permitted for a secure landfill. According to its 2009 Annual Report, JRL accepted 528,622 tons of waste last year.

8. The 2009 Annual Report also estimated that JRL's remaining capacity is 7,114,614 cubic yards. Potential impacts to JRL's current and future cell liners are therefore significant, and make technical review of soft layer materials very important.

9. According to the Order, a four to five foot layer of "MSW bypass" will be used as the initial protective layer (referred as "soft layer" in the Order) on top of the liner/leachate collection system (LCS) in Cell 6 to satisfy the Solid Waste Management Regulations (i.e., 06-096 CMR 401.2.D(4)(a)(vii)).

10. This section of the regulations specifically states that: "A protective system must be provided for the primary liner and the leachate collection system. Protective systems must consider freeze/thaw effects from liner and leachate collection system exposure to climatic effects, erosion, and puncture during repairs or waste placement. Protective systems during operations may consist of select waste such as paper mill sludge and tire chips, provided the select waste is permitted for acceptance at the landfill."

11. Based on my understanding of secure MSW landfills in the State of Maine, an initial 10 to 12-inch thick layer of tire chips or wood/bark chips has commonly been used for this layer. These materials provide a consistent, predicable material with known frost protection, erosion control, and puncture resistance properties. As stated above, 06-096 CMR 401.2.D(4)(a)(vii) specifically mentions the use of tire chips as an appropriate material for the select layer.

12. Based on discussions with Amanda Wade of the DEP, tire chips or wood/bark chips will not be used at Juniper Ridge Landfill (JRL) for Cell 6 and other future cells, and instead, straight "MSW bypass" will be used.

13. I have concerns about the potential for puncture or other damage to the underlying liner and LCS depending upon their configuration unless there is a provision for significant construction quality assurance (CQA) to ensure that the waste items that are within the considerable amounts of MSW are consistent with its use as a select layer. I am also concerned that used alone, MSW as select layer may not provide the necessary frost protection characteristics unless there is a provision for significant CQA to make sure the varying waste materials provide the required insulation values.

14. I know of no other landfill in the state where *only* MSW is used as the select layer material.

15. CES, Inc. is the Engineer of Record for the design and operation of the Presque Isle Secure Landfill (PSL). The design at PSL utilized tire chips *and* typical household MSW as the select layer directly above the LCS. The tire chips are placed first, in a 10-inch layer, directly on top of the LCS, followed by the MSW. The tire chip

layer functions primarily as a frost protection layer, but also provides other benefits such as vertical leachate drainage and puncture/damage resistance.

16. Typically, the MSW component of the Select Layer is placed in a five foot lift. Select waste is considered "typical residential" MSW if the waste is from MSW packer trucks and has less likelihood of containing bulky, elongated, or sharp objects. No construction debris, inert fill, or bulky wastes are used within the select layer.

17. In addition to the type of waste, placement methodology is an important function of the select layer. Compaction equipment must take care to maintain appropriate thickness to reduce loads transferred by equipment. Visual inspection is ongoing at PSL to verify no unacceptable waste are placed within the select layer and risks associated with puncturing the liner system or damaging the LCS are minimized.

18. I am aware of at least three other secure landfills that CES staff have worked on, including Town of Hartland Landfill, Tri-Community Landfill (TCL) and Norridgewock Landfill and that use other materials besides MSW only for the select layer. For example, tire chips *and* MSW are used as select layer for TCL and Norridgewock Landfill. Wood chips and sludge are used as the select layer at the Town of Hartland Landfill.

19. Although MSW is used as a select layer material, it is typically used in combination with other materials. Tire chips are commonly placed as a first protective layer, usually 10-12 inches deep, prior to the placement of MSW on top of the tire chips.

20. In my professional opinion, I believe the applicant and the DEP should conduct a review of (1) JRL's liner and LCS design to evaluate its ability to provide puncture/damage protection; (2) the CQA Plan to evaluate its effectiveness to identify

objects during placement that may damage the liner and/or LCS; and (3) the frost protection ("R value"), erosion control, and puncture resistance properties of MSW as select layer.

21. The Order contains insufficient technical support to find that as a technical matter MSW is the most appropriate material, or an appropriate substitute for, tire chips and/or other materials that are traditionally used for the select layer.

22. The Order at Page 6, Section 3, states that the "applicant has used other licensed wastes including front-end process residual from the incinerators, ash, contaminated soil, and bark for the soft layer." The Order also states, "that it is possible these waste will cause problems with the leachate collection system" by hindering leachate movement into the LCS.

23. The Order does not reference any technical support or justification for this finding. Therefore, I asked DEP what material, if any, they have to support such a conclusion. Amanda Wade with the DEP informed me that report(s) summarizing previous investigations were not prepared by the DEP and only visual observations (with photographic documentation) were used to make these conclusions.

24. Based on her description, the evidence clearly showed "cementing" or other physical barriers to leachate migration. However, without physical testing of the layers in question, the reason(s) for the potential leachate migration barrier(s) cannot be determined. The photos provided to CES from Amanda Wade show a brown layer of material (which Amanda identified as "straight FEPR") and a geosynthetic material resembling a geotextile. Observations cannot determine which material (the FEPR or the geosynthetic) may be contributing to the barrier. An investigation that includes field

observations and testing (e.g., hydraulic conductivity, permittivity, grain size analysis, etc.) are necessary to determine which material or processes are causing the clogging.

25. In addition, it is not clear which waste materials (*i.e.*, FEPR, ash, contaminated soil, bark, or geotextile) or which blend(s) were causing the leachate blockage.

26. Material directly above the LCS should be at least as permeable as the waste within the landfill and not act as a physical or chemical barrier to vertical leachate migration; however, we recommend the applicant or DEP explore which waste material(s) -- or blend(s) of waste materials -- were providing the leachate migration barrier so that we are not precluding the use of potentially effective waste materials that may be more consistent with the State's Solid Waste Management Hierarchy (Title 38, M.R.S.A. §2101).

27. For example, if DEP believes that FEPR or ash should not be used as select layer because of perceived leachate clogging, it is worth studying whether such perceived clogging is eliminated by mixing them with other waste materials. It is necessary to conduct technical analysis prior to ruling out particular waste materials.

28. Moreover, the DEP photographs appear to show a landfill's leachate collection sump mechanism. Sumps are locations in landfills where leachate is collected, and are typically less than five percent of the footprint of a landfill cell. It is not surprising that ash or FEPR could become cemented in this particular location due to the collected moisture. However, before concluding that FEPR is inappropriate for select layer purposes entirely, it is important to determine whether FEPR and ash has affected

downward movement of liquids elsewhere in landfills (and not simply near sump locations).

29. After October 13, 2010, I received a report by Sevee and Maher Engineers, Inc. entitled Clogging Investigation Report Sump Area, Phase 1 Landfill Expansion Leachate Collection System, ecoMaine Landfill, September 2010. (Attachment A). This investigation involved both field observations and testing in order to evaluate the clogging issues. The testing was conducted on various landfill materials (ash, tire chips, sand) and the geotextiles separating the select waste (e.g., tire chips) and LCS and within the LCS. The tests involved hydraulic conductivity, grain size, permittivity, and other tests to determine which layer(s) and/or processes (i.e., physical, chemical, or biological) may be contributing to the clogging issues. Based on this investigation, the report concludes that the physical clogging of the geotextile was the primary reason for the clogging problems. The permittivity of the geotextile decreased from 0.9 sec^{-1} to 0.0073 sec^{-1}.

30. I then reviewed a Project Summary by the United States Environmental Protection Agency entitled "Leachate Clogging Assessment of Geotextile and Soil Landfill Filters" by Robert M. Koerner and George R. Koerner (September 1995), (Attachment B). The Summary provides performance, design, testing, and recommendations for filters used for leachate collection drainage systems at the base of landfills and other solid waste facilities. Three out of the four landfills that were studied had geotextile filters that were "excessively clogged."

31. Based upon my review of the statements in the Order and the record, I have concluded that there is insufficient data and information to support a technical

finding that "MSW bypass" by itself is the best material, or even an appropriate material, for the select layer at the JRL landfill.

32. I have further concluded that available technical evidence conflicts with DEP's conclusion that FEPR is unsuitable for use in the select layer.

IN WITNESS WHEREOF, this is my true and correct statement made in the matter of the Appeal of the Department of Environmental Protection's Solid Waste Order for Minor Revision for Juniper Ridge Landfill #S-020700-WD-W-M, based upon my personal knowledge and professional experience.

DATED: 2/21/11

Denis St. Peter

STATE OF MAINE
CUMBERLAND, ss.

Personally appeared before me the above-named **Denis St. Peter**, known to me, and gave oath that the foregoing is true and based upon his personal knowledge, information and belief.

Kay A. Allcroft
Notary Public/~~Attorney at Law~~

Print Name and Title
My Commission Expires:

Kay A. Allcroft
NOTARY PUBLIC
State of Maine
My Commission Expires
April 7, 2016

ATTACHMENT A

a36

CLOGGING INVESTIGATION REPORT
SUMP AREA

PHASE I LANDFILL EXPANSION
LEACHATE COLLECTION SYSTEM

ecomaine Landfill
South Portland and Scarborough, Maine

September 2010

SME
Sevee & Maher Engineers, Inc.

ENVIRONMENTAL • CIVIL • GEOTECHNICAL • WATER • COMPLIANCE

4 Blanchard Road, PO Box 85A, Cumberland Center, ME 04021 • Phone 207.829.5016 • Fax 207.829.5692 • www.smemaine.com

STATE OF MAINE
JOHN E. SEVEE
LICENSED
PROFESSIONAL ENGINEER

TABLE OF CONTENTS

LIST OF APPENDICES

238

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

An investigation of the clogged sump area at ecomaine's Phase I Landfill Expansion was completed. The Phase I sump was constructed using tire chips as the porous media to store stormwater runoff within the south east corner of the landfill cell until it could infiltrate into the leachate collection system for removal via pumping. Excavation of the tire chips in the sump area showed the underlying geotextile components of the leachate collection system to be clogged. In particular, the outer most layer of geotextile for the leachate collection system was observed to be severely clogged. The principle cause of clogging was determined to be the soil component of the tire chip layer. Apparently, the tire chips used for the sump construction contained a considerable amount of fine grained material (silt and clay). The somewhat open void space within the tire chip layer allowed the fine materials to sift downward during periods of infiltration and rising/falling leachate levels within the sump area. The fine grained materials were retained on the geotextile layers (especially the outer most layer) thereby limiting the drainage capacity of the overall leachate collection system in the sump area. Minimal physical clogging of the sand and stone components of the leachate was detected as part of investigation, further supporting that the soil fraction of the tire chips was the principle cause of clogging.

Chemical clogging of the leachate collection system geotextile components from the sump area was investigated by way of analyzing the leachate chemistry (i.e. ionic balancing of chemical constituents for potential precipitate formation), and scanning electron microscope with x-ray spectrographic examination for soil particles and crystal precipitates within samples of the various geotextile components recovered from the sump area. The evaluation showed limited chemical clogging as compared to the physical clogging.

Limited evaluation of piezometric conditions within the landfilled waste showed that little or no hydraulic mounding above the leachate collection system is occurring in spite of potential clogging of the leachate collection system's geotextile components. The principle reason for the lack of mounding appears to be that the in-place ash is acting to absorb infiltration rather than transmit it to the leachate drainage layer. ecomaine has also observed that considerable runoff occurs from the landfill operating surface during precipitation events regardless of the relatively

240

high hydraulic conductivity of the ash. Apparently, the vehicle traffic on the ash surface (and possibly some weak cementation) is sufficient to partially seal the ash surface to infiltration. Implications of the clogging as related to Phase I relates mainly to the sump area and management of stormwater runoff in that area. At this time, ecomaine has removed a portion of the tire chips from the sump area and installed a temporary manhole and collection piping to manage the collected runoff. The leachate collection piping, the sump volume and the associated leachate pump sizes have not been evaluated in terms of their combined capability to handle the appropriate design storms and intermediate covering scenarios/runoff for Phase I. It is recommended that such a hydraulic evaluation be undertaken prior to Spring freshet conditions. To that end, consideration for long-term sump and pump performance also needs to be given in terms maintaining effective leachate levels in the sump. Finally, it is recommended that future landfill expansion designs consider use of graded soil filters, woven geotextiles for filtering and ample line cleaning opportunities for the leachate collection system.

1.0 INTRODUCTION

This report summarizes the findings of an investigation into the observed hydraulic clogging of the portion of the leachate collection system located in the eastern corner of the Phase I Landfill expansion at the ecomaine Landfill in South Portland and Scarborough, Maine. The investigation was prompted by past observed flooding of runoff/leachate in the eastern corner of the landfill where the leachate sump and associated pumps/piping are located. The investigation included both physical and chemical testing of the various drainage layer components collected from the sump area. This report summarizes Sevee & Maher Engineers, Inc.'s (SME) approach, methods, and conclusions relative to investigating the cause of the hydraulic clogging. Based on the findings, recommendations are provided for corrective actions, as well as, future considerations of leachate collection system design.

2.0 FIELD INVESTIGATIONS

June 24, 2010

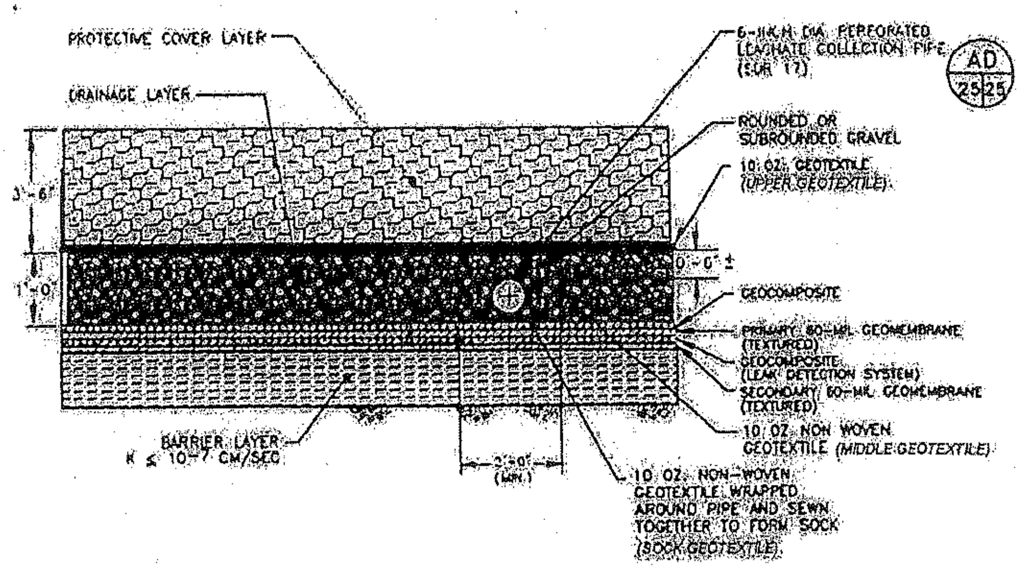
On June 24, Matt Muzzy, P.E., and John Sevee, P.E. met with ecomaine representatives to excavate into the leachate collection layer in the sump area located in the eastern corner of Phase I of the landfill expansion. At the time of SME's arrival, the excavation had been completed to the top of the upper geotextile layer. Figure 1 shows the leachate collection system build-up for Phase I based on Detail AE from the landfill expansion construction drawings. For purposes of clarity, the detail has been edited to show the location of the upper geotextile layer relative to other geotextile layers used in the leachate collection system. Observation of the excavation showed the upper geotextile to be overlain by approximately four to five feet of tire chips (i.e., the protective cover layer on Detail AE). The tire chips contained a significant amount of sand, silt, and clay. There were also plentiful void spaces observed in the exposed tire chip layer. Upon visual inspection, the topside, or upstream side of the upper geotextile layer was found to be encrusted with up to a ¼ inch of sand, silt, and clay. In some areas, a crust of reddish cementation was observed atop the soil crust. In other areas, the upper geotextile and soil were black with what appeared to be bacterial stains. There was a distinct putrescible odor to the upper geotextile and it effervesced when subjected to a solution of 10 percent hydrochloric acid. Visual inspection of the bottom side of the geotextile indicated that it was not encrusted with soil, but was covered with rusty- and black-colored staining, 24a

similar to the top surface. Hand-excavation below the upper geotextile showed that directly beneath the geotextile was a layer of 1-inch-minus stone which had very little silt or sand fraction. The stone was stained rusty in some areas and black in others. However, the pore spaces were open and no cementation of the stones was observed. The stone layer was approximately 1-foot thick and surrounded a drainage pipe. The stone was enveloped by another (i.e., second) layer of the same type of geotextile. Approximately one foot lateral of the pipe, the stone was replaced by drainage sand; the second layer of geotextile separated the stone and sand. This second or middle layer of geotextile was covered with rusty and black-colored staining in most areas, but only had a small amount of soil on its top side; the bottom side appeared free of sediment. There was no obvious encrustation, chemical precipitate, or bio-film on the second layer of fabric, other than the stained areas which coated most of the geotextile surface.

During the excavation of the drainage layers, leachate was continually running out of the tire chips and onto the upper geotextile. The upper geotextile had lost enough infiltration capacity such that the several gallons per minute of leachate flowing out of the tire chips could not drain through the upper geotextile layer but, instead, ran across the geotextile's crusted surface to the temporary sump manhole placed earlier by **eco**maine. Once the upper layer of geotextile was removed, the leachate flowing from the tire chips entered the stone. The stone readily accepted the several gallons minute of flow and did not appear to exhibit a loss in hydraulic capacity. It should be noted that the stone daylighted approximately 10 feet downstream at the temporary sump manhole. On exposure of the second geotextile layer at the base of the stone, the leachate running out of the tire chips ran across that surface as well, showing little sign of drainage through the geotextile. The stone was in contact with a geotextile "sock" wrapped, 6-inch diameter, perforated leachate drainage pipe. The sock was constructed of the same geotextile as the upper two fabric layers. The sock layer did not appear to have any soil encrusted into its top or bottom surfaces, but some soil particles could be observed on the upper surface. The sock geotextile effervesced when subjected to a few drops of 10 percent hydrochloric acid solution. .

FIGURE 1

LEACHATE COLLECTION SYSTEM BUILD-UP



LEACHATE HEADER AND LATERAL DETAIL

N.T.S.

AE 6 25

At locations where the stone layer was not present, a medium to coarse sand was found to underlie the second layer of geotextile. This sand layer was approximately 12 inches thick and had a blackish color. When subjected to a 10 percent hydrochloric acid solution, the second layer of geotextile as well as the sand, both effervesced. The blackish color was easily washed from the sand with the acid solution, leaving a brownish sand with some blackish staining. On exposure to the atmosphere, the sand layer began to develop a reddish brown color. The sand particles were not cemented together and the sand appeared to readily accept water and drain when piled outside of the excavation.

The geotextile comprising the upper, middle, and sock layers, according to construction documentation provided by **ecomaine**, consisted of a 10-ounce non-woven polyethylene fabric that was manufactured by Skaps Industries. The various drainage layers exposed by the excavation appeared to be in general agreement with the landfill design drawing (Figure 1) as provided by **ecomaine**. It should be noted that all excavation done within the limits of the leachate collection system was carefully performed using hand methods.

July 1, 2010

On July 1, Matt Muzzy revisited the sump area to observe vacuum removal of the sand and stone around a portion of the leachate collection line in the sump area. The purpose of the removal was to give a clearer view of the leachate collection system build-up, without risking damage of the underlying liner and expose a sufficient length of pipe such that an opening could be cut into the pipe to allow insertion of a closed-circuit television camera. Ted Berry Co. provided the vacuum and cameraing services. The Appendix 1 DVD presents the images recorded for the inside leachate collection pipe that parallels the eastern boundary of Phase I. The DVD contains two files. Film 2010-07-01-0660 shows approximately the first 100 feet of leachate pipe starting at the west end of Phase I and moving east. This section of line appears to have a near-new condition in that the eastern portion of Phase I has a temporary cover over it and is not yet currently receiving waste. Note that the perforations in the pipe are easily discernible. Film 2010-07-01-0662 shows approximately 100 feet of leachate pipe starting at the east side of Phase I (i.e., at the sump), and moving west. This portion of the pipe is active and contains leachate. Note that the first part of the film shows water entering through a perforation in the pipe; however, as the camera advances into the pipe, little or no water is observed entering through the pipe perforations. In general, the portion of pipe viewed appeared free of sediment with no obstructions. Some clumps of floating bacteria-like substances were observed in the pipeline possibly suggesting that flow velocity in the pipe is low.

September 1, 2010

On September 1, Matt Muzzy observed excavation of a test pit and installation of a standpipe piezometer in that test pit in the Phase I Landfill expansion. The test pit was excavated to a depth of approximately 18 feet and was located approximately due south of existing slope inclinometer. The purpose of the test pit was to observe landfilled ash with respect to depth, collect representative samples for water content testing and install a piezometer with its bottom at the top of the leachate collection sand. The following vertical distribution of waste and leachate collection sand was observed in the test pit.

TEST PIT DATA

Depth (ft)	Waste Description	Water Content
0	Gray ash and metal fragments.	
2	Slightly damp.	3' = 33.7
4		
6	Slightly cemented at 6 feet?	6' = 29.0
8		
10	Becoming slightly more damp at 9 feet.	9' = 41.7
12	More metal at 11 feet.	
14	Trash layer 12 to 16 feet.	
16	Screened ash at 16 to 17-1/2 feet.	17' = 36.4
15	Top of sand at 17-1/2 feet.	18' = 16.4

Notes:
Bottom of test pit at 18 feet in sand.
No seepage observed.

The test pit excavation was terminated at the top of the leachate collection sand. Water contents of the materials encountered were measured as follows:

No water was observed in the piezometer 10 days after installation.

3.0 PHYSICAL TESTING

Samples of the three encountered geotextile layers, that is, the top layer, the second or middle layer, and the pipe sock, were collected and returned to SME's soils laboratory for testing. A clean sample of the same geotextile that was found along the outer edge of the landfill cell was also collected; based on the appearance and odor of that sample, it was considered that the sample had not been previously submerged in leachate. The clean geotextile, however, did contain some windblown ash dust from the landfill and effervesced when subjected to a 10 percent hydrochloric acid solution. A sample of the drainage sand was also returned to SME's soils laboratory for grain size and permeability testing. The drainage stone (beside the leachate collection pipe) was not sampled because its permeability appeared to be intact and there was no apparent hydraulic clogging. Leachate that was flowing in the leachate collection pipe was sampled for chemical analysis. A sample of the tire chips was collected for grain size and permeability testing. A sample of landfilled ash was collected for permeability and grain size testing, and chemical assay.

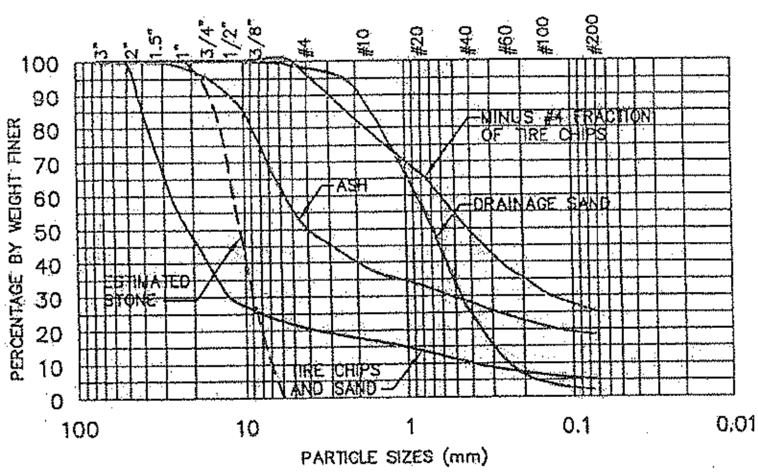
Grain size distribution curves for the sand, tire chips, and the ash are shown in Figure 2. The grain size distribution for the ash shows that it tends to be a relatively coarse gravelly sand to

246

sandy gravel that contains approximately 50 percent (by weight) gravel size particles based on the Unified Soil Classification System. Because of the somewhat gap-graded nature of the ash, the gravel-sized particles "float" in the silty sand matrix; that is to say, the finer material will control the ash's physical behavior. Literature and experience with the ash suggests it may have some pozzolanic characteristic and, as such, the ash grain size distribution may be more granular due to some previous cementing. The drainage sand is a relatively silt- and clay-free, medium to coarse sand that appears to be consistent with the desired design requirements. The tire chips show an approximately 5 percent combined sand, silt, and clay content when analyzed as a single sample. Figure 2 also shows the grain size distribution for the minus-No. 4 sieve fraction of the tire chip sample. That grain size distribution shows the soil portion of the tire chips to be considerably more fine-grained with approximately 25 percent of the particles being smaller than the No. 200 sieve size.

FIGURE 2

GRAIN SIZE DISTRIBUTIONS



Hydraulic conductivity testing of these various leachate collection system components showed the sand to exhibit a hydraulic conductivity of 1.7×10^{-2} cm/sec, which is generally consistent with its grain size and the project requirements. Other than a slight blackish to brown discoloration, there did not appear to be any cementation of the sand, and the sand appeared to be free-flowing when being sampled and tested. The tire chips had a hydraulic conductivity of at least 28 cm/sec. Due to the tire chip coarseness, void spaces, and scale effects, it was difficult to get an accurate hydraulic conductivity of tire chips, but it was significantly more permeable than the sand layer. Even observations of the tire chips in the field and laboratory showed that even though there is a sand, silt, and clay component to the tire chips, there is not enough soil to fill all the void space, and consequently there are significant void throughout the tire chips around the tire chips in situ. The void spaces allow the sand, silt, and clay to be mobile when submerged and sift through the tire chip layer to accumulate at the base of that layer.

Laboratory testing of the ash using medium compaction resulted in a measured hydraulic conductivity of approximately 3 x 10^{-2} cm/sec. The end of test water content of the ash was measured to be 46 percent, suggesting the in-place ash has considerable moisture holding capacity as compared to the ash water contents measured in the test pit installed in Phase I on September 1, 2010. No hydraulic conductivity of the stone layer was conducted, but based on the field observations and it is likely at least on the same order of magnitude as the tire chips.

The various retrieved geotextile samples were also analyzed for relative water permittivity between samples and physical clogging by soil particles. Relative permittivity was calculated from a constant-head permeability test of the geotextile specimen and assuming a unit geotextile thickness. No appreciable normal load was applied to the geotextile during testing so as to allow as much through-flow as possible. Table 1 summarizes the results of the physical testing of the geotextile materials. The relatively clean fabric taken from the outer edge of the sump showed a permittivity very close to that indicated by the manufacturer's literature as shown in Table 1. Each of the geotextile specimens were tested as if oriented in situ, with water flowing from the top side to bottom side of the geotextile as positioned in the leachate collection system.

In addition to testing the geotextile samples as-received, the samples were tested after scraping off the surficial sediments from the surface of the various specimens and/or disturbing the upper geotextile surface to loosen any sediment particles on it. This showed the permittivity of the various samples to noticeably increase. Photographs of the geotextile samples, tire chips, and soil drainage materials are shown in Figure 3. The underside of the uppermost geotextile layer can be seen in the lower right-hand corner of Figure 3c, and contrasts dramatically with the top of the same fabric in Figure 3b. Similarly, the bottom of the middle geotextile layer can be seen in the upper right-hand corner of Figure 3e. The top of the same geotextile is shown in Figure 3d, with its soil, rust-colored-staining and black stains. The tire chip layer in Figure 3a shows the degree of soil mixed into the chips.

248

TABLE 1

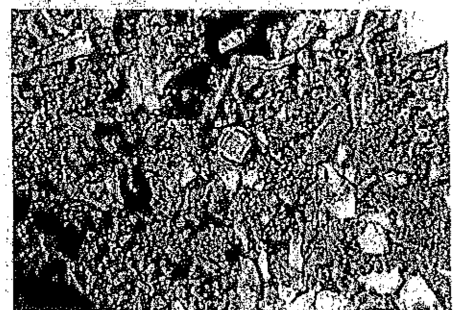
FILTER FABRIC PHYSICAL MEASUREMENTS

	Permittivity as received (sec^{-1})	Permittivity after scraping (sec^{-1})	Specimen Weight (gm/ft^2)	Soil mass removed from upper surface by scraping (gm/ft^2)	Calculated total porosity	Ash upon ignition (% by weight)
Top geotextile	0.0073	0.097	150.5	91.7	0.70	68.7
Middle geotextile	0.0095	0.065	111.9	71.6	0.75	51.9
Sock geotextile	0.025	0.067	77.1	44.0	0.80	58.1
"Clean" geotextile	0.5	-	49.5	0	0.84	4.5
Manufacturer's specs[1]	0.9	-	31.5	-	0.87[2]	-

Notes:
1. Skaps Industries letter to RTD Enterprises dated April 26, 2006.
2. Polyethylene specific gravity of 0.905 based on personal communication with Anurag Shah, Skaps Industries, Athens, Georgia.

FIGURE 3

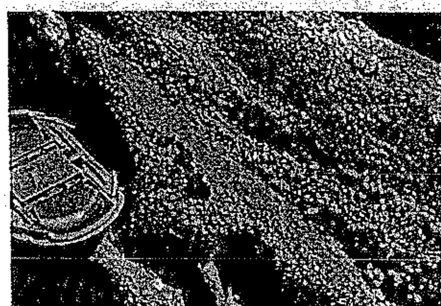
SUB-LANDFILL DRAINAGE LAYERS



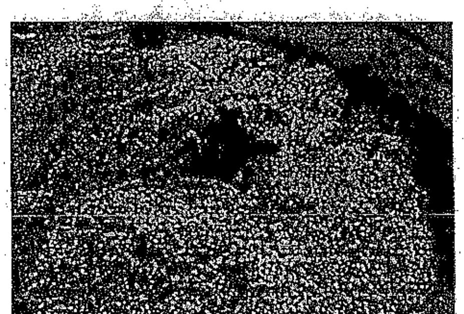
a) Shredded tires

b) Top surface of upper geotextile

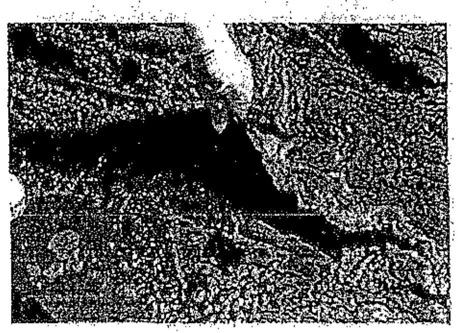
c) Stone layer



d) Top surface of middle geotextile



e) Sand layer



f) "Sock" geotextile being held away from perforated PVC drainage pipe

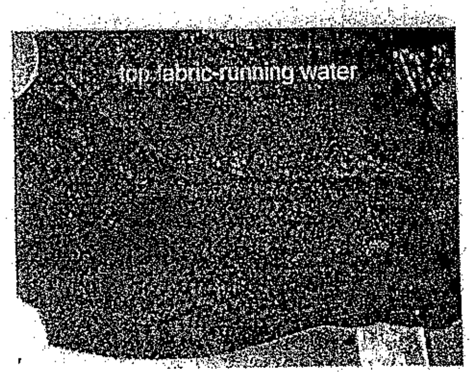
250

The weight per unit area of the geotextile specimens was measured. This was done by cutting out a circular piece of geotextile of known diameter and drying it in an oven at approximately 60° Centigrade and then weighing the sample. Samples were weighed both with any surficial sediment in-place as well as after scraping the surficial sediments away. Removal of the upper surficial sediments allowed an estimate of the amount of sediment trapped on the surface of the various geotextile layers (see Table 1). In addition, the porosities of the geotextile layers were estimated based on an initial fabric porosity calculated from manufacturer's data. It can be seen from the weight per unit area and porosity results that sediment particles are present within the geotextile at progressively smaller amounts starting with the upper geotextile and ending with the sock geotextile. Samples of the geotextile layers were also tested for ash content. For these tests, specimens of the various geotextile layers were brushed free of surface sediment and then burned free of organic components (i.e., the geotextile). The results of the ash testing are included in Table 1 and show a clear difference when compared to the clean geotextile.

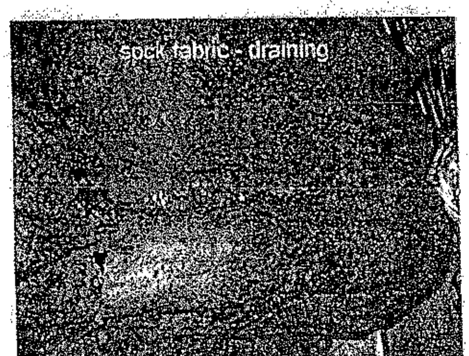
In addition to the permittivity testing, the geotextile samples were subject to water running across their surfaces. This was done by creating a sloped, concave, trough-like surface using the upper and middle geotextile samples, then pouring water into the trough and observing the results. Figure 4 shows the results for the top and middle geotextile layer sampling, as well as a sample of the clean geotextile. It is observed that water runs across the surfaces of the upper and sock geotextile layers with essentially no infiltration. On the other hand, a similar amount of water poured onto the clean geotextile, readily infiltrates the geotextile without running along the surface of the specimen. From the permittivity testing, as well as the test of flowing water across the geotextile surface, it is clear that the upper geotextile layer is hydraulically clogged by sediment accumulating on the surface. This sediment is believed to be primarily the result of washing or erosion of sand, silt, and clay particles from within the overlying tire chip layer onto the surface of the upper geotextile. The middle geotextile layer is also hydraulically clogged possibly from entrapment of sediment that washed off the stone or from sediment that migrated through the upper geotextile. Finally, the sock geotextile, though observed to exhibit little sediment on its surface as compared to the upper and middle geotextiles, also too appears to be clogged. The extent to which there may be biochemical effects, the most likely cause of the geotextile clogging appears to be as result of the downward

FIGURE 4

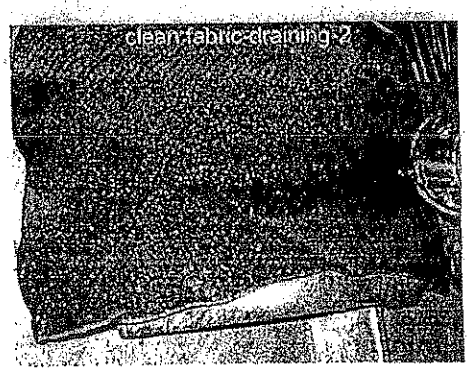
LABORATORY GEOTEXTILE INFILTRATION TEST



a) Upper geotextile



b) Sock geotextile



c) "Clean" geotextile

sifting of fines from the overlying tire chip layer. The physical clogging on the upper geotextile is enough to have created ponding of runoff in the sump area of the landfill. Even without any biochemical clogging, the amount of sediment (up to ¼-inch) on the surface of the upper geotextile, is enough to restrict water from readily entering the leachate collection layer by way of the upper geotextile layer as intended by design. CHEMICAL PROPERTIES

A sample of leachate was collected from the leachate pipeline entering the sump manhole during the recovery of the geotextile samples. Care was taken to minimize the potential for entrainment of air into the leachate sample. During sample collection, dissolved oxygen, specific conductance, temperature, and redox potential of the leachate were also measured.

The suite of parameters selected for the leachate analysis represented those parameters that are characteristic of municipal solid waste (MSW) incinerator ash and anticipated to play a role in the development of precipitates or chemical encrustation of geotextile. The parameters included silicon, calcium, magnesium, potassium, sodium, iron, manganese, chloride, alkalinity, sulfate, and sulfide. Total organic carbon (TOC) and total dissolved solids (TDS) were also measured. The results for the leachate testing are presented in Table 2. Total dissolved solids as calculated from the combined concentration weights of the test parameters checked within a percent of the measured total dissolved solids; thereby, indicating that the parameter selection included most of the dominant constituents of the ash. The chemical results were also placed into Visual MINTEQ chemical equilibrium software to examine ionic balancing as well as the equilibrium saturation indices of select inorganic compounds that may precipitate out of the leachate's chemical environment. The anions and cations balanced within 7 percent of each other. The saturation indices (SI) for some common precipitates of landfill leachate are shown in Table 2. It is noteworthy that, within the accuracy of the data, aragonite ($CaCO_3$) in the leachate is in equilibrium with respect to a solid-phase. Iron oxyhydroxides were super-saturated, which is not uncommon, and may in fact have to do with suspended iron complexes (i.e., colloids) or turbidity of the sample. The analysis also suggests that there is a potential for ferrihydrite ($Fe(OH)_3$), geothite (FeOOH) and siderite ($FeCO_3$) to precipitate as well as the aragonite. Gypsum and iron pyrite were below saturation. Quartz (SiO_2) is at saturation (within the accuracy of the data), which may be due to the ash pH where quartz is more soluble.

A sample of ash was collected and chemically assayed. The results are summarized in Table 3 along with typical ranges of chemical constituent concentrations for incinerator ashes as presented in other studies. The assay shows the presence of both organic and inorganic carbon as well as calcium, sulfur, iron, and silica and supports the leachate chemical analyses. The ash effervesces upon treatment with hydrochloric acid.

Samples of the three geotextile layers were submitted to the Geology Department at the University of Maine in Orono for scanning electron microscope (SEM) and x-ray spectography examination. The SEM provides high resolution photomicrographs so that the geotextile surfaces can be enlarged and visually examined. The SEM also provides the opportunity for energy dispersive spectrographic (EDS) examination of particles and precipitates trapped within the geotextile mesh as well as the chemical coatings on the geotextile fibers. The x-ray spectrographic analysis provides information to infer the mineralogy of the primary constituents found on the geotextile surfaces.

TABLE 2

LEACHATE CHEMICAL ANALYSIS

Parameter	Concentration
pH (SU)	6.4
Specific conductance (μS/cm)	8,980
Temperature (°C)	19.8
E_H (mV)	+63
Dissolved oxygen (mg/L)	2.0
Total dissolved solids (mg/L)	8,940
Total organic carbon (mg/L)	236
Dissolved silica (SiO_2)	6.32
Calcium (mg/L)	1,456
Manganese (mg/L)	27.1
Sodium (mg/L)	969
Potassium (mg/L)	536
Iron (mg/L)	99
Magnesium (mg/L)	1.81
Alkalinity (mgCaCo$_3$/L)	410
Chloride (mg/L)	5,150
Sulfate (mg/L)	3.1
Sulfide (mg/L)	2.7
Carbon dioxide (atm)	0.131
$SI_{calcite}$	+0.222
$SI_{aragonite}$	+0.074
SI_{gypsum}	-2.074
SI_{pyrite}	-43.884
$SI_{siderite}$	+1.058
$SI_{ferrihydrite}$	
$SI_{geothite}$	+3.175
SI_{quartz}	+0.108

254

TABLE 3

ASH CHEMICAL ASSAY

	ecomaine Sample Results (mg/kg)	ecomaine Approximate Percentage[1,2]	Typical Values[1] (%)
Silica	25,252	2.5	3 – 13
Calcium	186,000	18.6	12 – 32
Manganese	432	0.04	0.01 – 1
Sodium	9,394	0.9	2 – 3.5
Potassium	6,737	0.7	3 – 6.5
Iron	20,100	2.0	0.5 – 3.5
Magnesium	12,928	1.3	1 – 2
Chloride	59,900	6.0	1 – 22
Sulfur	10,500	1.1	2 – 3.5
Aluminum	20,000	2.0	0.5 – 6
Inorganic Carbon	9,800	1.0	-
Organic Carbon	11,300	1.1	-

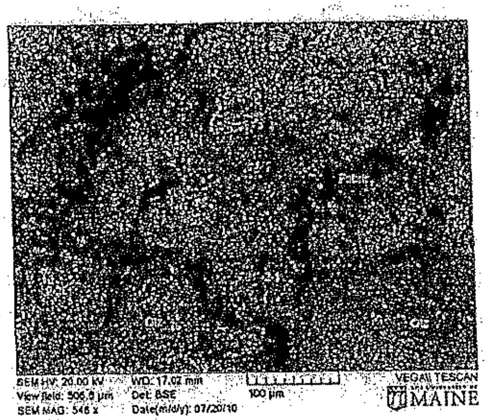
Notes:
1. After Lam, C.H.K., A.W.M. Ip, J.P. Barford, and G. McKay, 2010. Use of Incinerator MSW Ash: A Review. Sustainability Journal, vol. 2, pp.1943-1968.
2. Dry-weight basis.

SEM photomicrographs of the top surface of the upper geotextile layer is illustrated in Figure 5.[1,2] In this photomicrograph the elongated black areas represent fibers of the geotextile material (i.e., polyethylene). It can be seen that particles completely fill the void spaces between the fibers. The x-ray spectrographic analysis work shows that the larger-size particles consist of quartz grains as labeled in Figure 5a. There are some rhomboidal crystals that are smaller than the quartz that consist primarily of calcium sulfate (i.e., gypsum). This is illustrated by the crystal labeled Point 2-1 in Figure 5a. The water chemistry of the leachate suggests that gypsum is under-saturated. Therefore, the crystals of gypsum detected in the geotextile may have been transported from the ash or may have precipitated out at an earlier time when the leachate chemistry was different. The more amorphous or undifferentiated portions of the filler between the fibers consist of primarily iron oxyhydroxides as illustrated by Points 2-2 and 2-3 on Figure 5a. Visual examination of the geotextile and other drainage media in the sump area show what appears to be iron (rusty) staining of the geotextile surface, which is consistent with

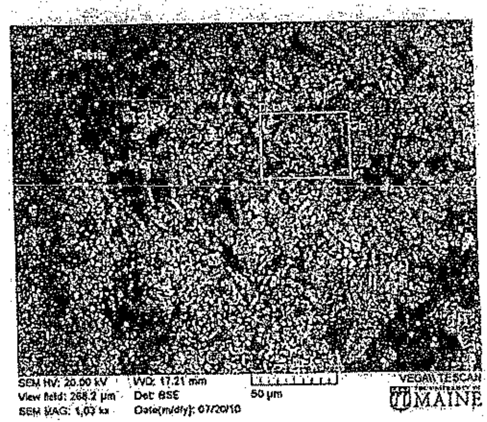
[1] For additional viewing, enlarged versions of each photomicrograph presented in this section are included as Appendix 2.
[2] SME will maintain the raw spectrographic and other supporting laboratory data on file and are available for review upon request.

FIGURE 5

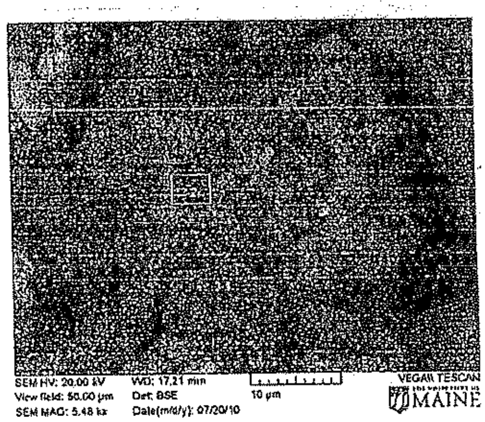
UPPER GEOTEXTILE LAYER



a) Top surface



b) Bottom surface



c) Bottom surface detail

256

the photomicrographs. The iron oxyhydroxides, based on the MINTEQ analysis, appear to be over-saturated and may suggest active precipitation. There are elements identified in the spectrographs that include calcium, sulfur, silicon, aluminum, and carbon (e.g., carbonate) through the matrix.

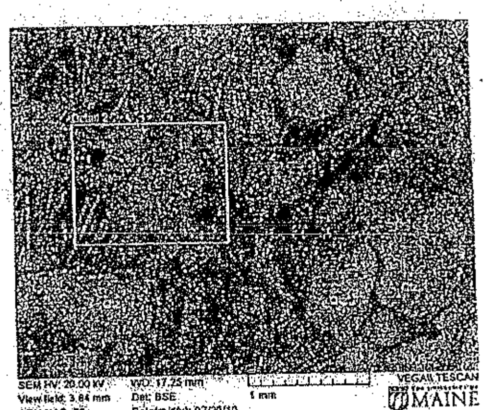
A photomicrograph of the bottom side of the upper geotextile layer is illustrated in Figure 5b. The photomicrograph shows some fibers of the geotextile, as well as quartz particles and finer silt or clay particles. The x-ray spectrographic analysis shows that some particles such as on Point 2-1 in Figure 5b consist primarily of iron oxyhydroxides; while others such as Point 2-2, are primarily calcium sulfate. A significant amount of calcium sulfate crystals are also present as shown in Figure 5b. There is also a matrix of silt and clay particles surrounding the larger crystals and soil grains, as shown in both Figures 5a and 5b. This undifferentiated mixture of other particles appears to be coated with a precipitate in some areas as shown in Figure 5c.

A detail of the amorphous background is magnified in Figure 5c (see Figure 5b for location of detail). The detail shows calcium sulfate crystals (e.g., Point 3-1). Point 3-2 in Figure 5c shows calcium sulfate, iron oxyhydroxides, and carbonates, possibly $CaCO_3$ (e.g., aragonite, calcite, or monohydrocalcite). Individual crystals can be seen, but they appear grown together or cemented. No obvious bacteria (typical size in the order of 1 µm) are readily apparent in Figure 5c.

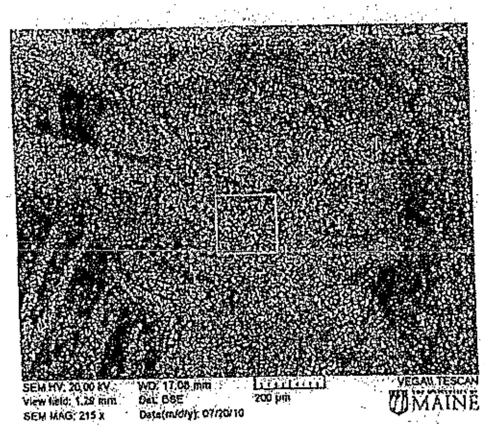
The top surface of the second geotextile layer is illustrated by photomicrographs shown in Figure 6. Figure 6a shows numerous quartz particles, but also shows rhomboidal calcium sulfate crystals. The elongated fibrous features in the background of Figure 6 represent the individual polyethylene fibers of the geotextile. There is an amorphous or undifferentiated mixture of finer-grained soil and clay particles amongst the quartz and geotextile fibers. Gypsum crystals appear to have grown atop this amorphous matrix. Figure 6b shows elongated calcium sulfate crystals that appear to have grown in-place. By comparison, the gypsum crystals found in the upper geotextile fabric appear to have been formed elsewhere and then transported into the geotextile with the soil particles (see Figure 6b). Based on the x-ray spectrographic analysis, the finer matrix around the gypsum crystals consists of a mixture of iron oxyhydroxides, carbonates (probably calcium carbonates), silica, and aluminum. Some of the finer matrix may also be ash particles and/or some particles may represent aragonite or calcite, based on the saturation indices obtained during the MINTEQ analysis. The chemistry of Point 2-1 in Figure 6b is not unlike that of Point 3-2 in Figure 6c. There appears to be a coating of the particles in Point 2-1 in Figure 6b, as with the geotextile fibers in the same figure. Figure 6a appears to suggest both a physical (soil) and chemical (crystal) clogging, although the relative importance of each in decreasing the permittivity of the geotextiles cannot be determined from this study.

FIGURE 6

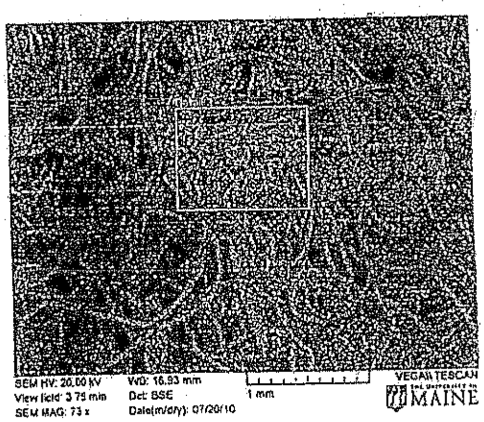
SECOND GEOTEXTILE LAYER



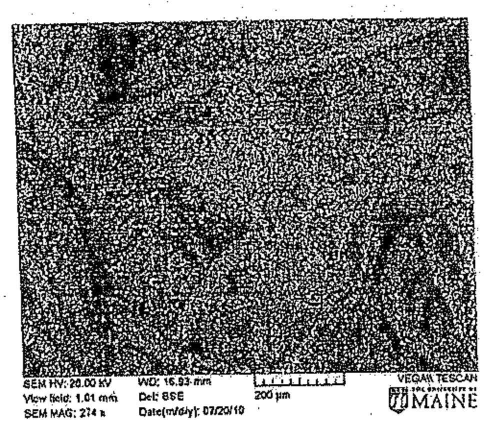
a) Top surface



b) Top surface detail



c) Bottom surface



d) Bottom surface detail

258

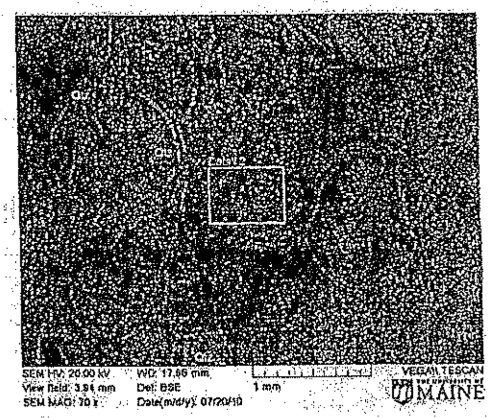
The bottom side of the middle geotextile layer, appears to contain less soil particles, but the fibers are coated (see Figure 6c). This is consistent with visual observation of this geotextile layer in the field. The detailed area of Figure 6c (see Figure 6d) shows quartz soil particles and gypsum crystal growth. The geotextile fibers in Figure 6b are coated and that coating appears to be cracked. The coating may be clay particles that separated after drying.

The top of the sock geotextile layer shows a similar collection of quartz particles with a finer soil particle mixture amongst the geotextile fibers (see Figure 7a). The x-ray spectrographs show calcium sulfate (Point 2-1) and iron oxyhydroxides (Point 2-2) on Figure 7b. More fiber presence is obvious in this material compared to the upper and middle geotextiles, indicating less physical clogging of the sock geotextile. This is consistent with the field observations and laboratory permittivity testing. The detail of the sock in Figure 7c shows many individual patches with a crystal of iron oxyhydroxides (Point 3-1). It appears that some bacteria may be present in the geotextile as represented by the circular gray "blobs" about 1 μm in diameter. Though no attempt has been made to confirm this interpretation, heavy bacterial growth appears unlikely in Figure 7c.

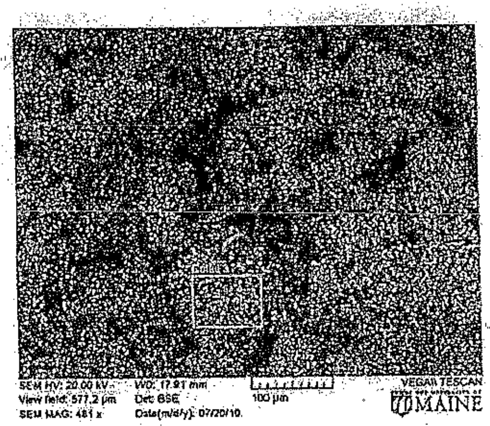
Photomicrographs of the clean geotextile sample shows a precipitate on only small portions of the geotextile fibers, with no pore clogging (see Figure 8a). X-ray spectroscopy of the geotextile fibers suggests they are predominantly carbon which would be consistent with polyethylene plastic. The lighter areas, however, as shown in Point 2-2 of detail Figure 8b, consist primarily of calcium carbonate and silica.

FIGURE 7

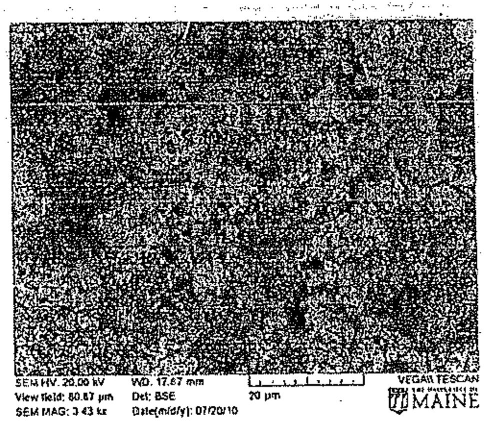
"SOCK" GEOTEXTILE



a) Top surface



b) Top surface detail

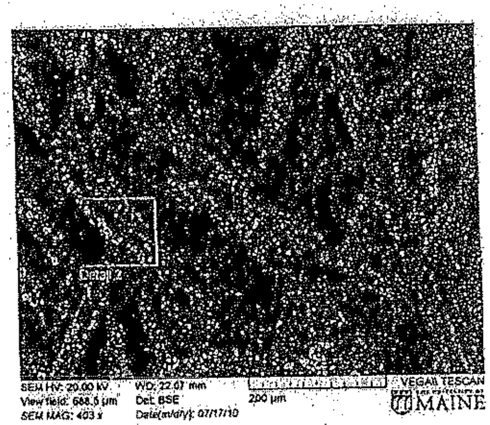


c) Top surface detail

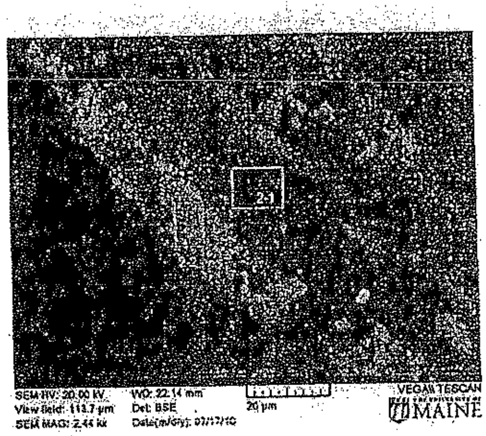
260

FIGURE 8

"CLEAN" FABRIC



a) Geotextile fiber



b) Detail of HDPE fibers with crystal growth

4.0 DISCUSSION

Based on the field investigation and the laboratory examinations, it is concluded that the upper layer of the geotextile found in the sump area of Phase I was physically clogged with soil fines that had been migrated downward from the overlying tire chip layer. The tire chips contain sand, silt, and clay particles, and the open void spaces within the tire chip layer allow for this material to erode through the tire chips as result of infiltration and rising/falling leachate levels in the sump. The upper geotextile acted to stop the bulk of this downward movement of fine-grained material, forcing the fine-grained materials to accumulate on the top surface of the upper geotextile. The permittivity testing of the geotextile samples recovered from the sump area demonstrated a progressive loss of hydraulic capacity between the geotextile layers, with the upper geotextile having the lowest hydraulic capacity. The photomicrographs as well as the physical testing show that some of the soil particles entered into the upper and middle geotextiles; thus, reducing their permittivity.

The photomicrographs and the x-ray spectroscopy indicate that some chemical precipitation of iron and calcium is occurring. The quartz particles shown on the photomicrographs are believed to represent soil grains trapped in the geotextile fibers as they migrate from the base of the tire chip layer into the geotextiles. The precipitation of gypsum in the geotextiles clearly has occurred. The crystals appear to have grown in-place, as well as possibly transported into the geotextile by way of leachate flow. Overall, the photomicrographs confirm that the geotextiles contain soils and chemical precipitates. However, it appears that the predominant impact on the permittivity of the upper geotextile layer was from physical clogging by soil particles migrating from the overlying chip tire layer. The role and importance of chemical precipitation of calcium and iron compounds could not be defined within the scope of this investigation. Bacteria growth and its impact with respect clogging was also difficult to assess.

In regards to mitigating the sump area of Phase I, it is concluded, based on the findings presented herein, that the tire chips are the cause of he clogging and that infiltration into the leachate collection system by way of clogged geotextiles in the sump area is not critical. Even if the in-place leachate collection system in the sump area were functioning properly, it would

263

likely not have sufficient capacity to handle stormwater collected in the sump area given the lack of water storage space in the tire chips. Developing a better means of transporting the stormwater runoff into the sump manhole or collecting the runoff before it is allowed to surcharge the sump area is the more appropriate solution. To that end, it is recommended that measures be investigated to enhance the drainage of runoff into the leachate collection piping and re-evaluate the sump pumping capacity/capability. This may be done by way of inlets positioned along the trunk line at the edges of the waste cell, and/or by enhancing ditches that would flow to the sump area with a more permanent collection manhole and leachate pumps designed to accept high inflows. Consideration should also be give to removing more of the tire chip layer that has not be covered with waste and replacing that material with a coarse grained material with open void space for temporary leachate storage. Whatever approach is selected, it must be properly designed for hydraulics, which may require changes to existing infrastructure (e.g., manhole and/or pump sizes). Also, any changes to the existing system should be designed to be periodically cleaned, as it is reasonable that the smaller ash sizes will migrate to the sump area as result of runoff related erosion.

It should be kept in mind that the investigation described herein and the above conclusion/recommendations relates mainly to the conditions encountered in the leachate collection system located in the sump area. It is unclear as to how the leachate collection system in the other portions of Phase I are functioning overall. However the test pit piezometer installed in Phase I, along with the ash water content testing suggests that the landfilled ash may be well below its moisture holding capacity and until that water content is met little infiltration will reach the leachate collection system. The test pit piezometer suggests that hydraulic mounding in the leachate collection is likely not occurring, thereby indicating that hydraulic gradients on the base liner system are minimal.

Based on our findings, we suggest that for future construction, design modifications be made to the leachate collection system to anticipate migration of soil and/or ash particles into the leachate collection system. Our preliminary recommendation would be to eliminate use of the non-woven geotextile in the leachate collection system, and where geotextile is necessary use a woven product. Use of sock geotextiles around piping for leachate collection should be also avoided. Alternatively, it may be more appropriate to use coarser filters constructed from sand

and gravel adjacent to leachate collection piping. Future use of tire chips containing soil should also be avoided. Had the tire chips used in Phase I been free of soil, the amount of clogging that was observed of the upper geotextile layer of the sump area, would have likely been substantially less. The ash material tends to be a gravelly silty sand type material. The finer matrix of the ash is representative of a very silty sand. This particular aspect of the ash needs to be considered also when designing future leachate collection system(s). A graded filter, if used, can be designed around the finer portion, that is, the minus-No. 4 sieve fraction of the ash. Finally, it is recommended that future systems be sized and laid out for easy periodic cleaning.

The ash and/or MSW chemistry can be further evaluated, along with the biological aspects of loss in drainage system capacity. As other studies have shown (see list of references attached), biochemical clogging along with physical clogging is an ongoing problem at many landfills. The one common conclusion is to design the leachate collection system so as to allow for the clogging and routine cleaning over the active filling life of the landfill.

5.0 IMPLICATIONS OF CLOGGED SUMP

From the testing results and discussion presented in the previous sections, it is clear that physical plugging of the upper filter fabric occurred primarily from the soil contained within the void spaces of the tire chips. A similar plugging was observed on the second filter fabric below the drainage stone layer, but to a lesser extent. In the second case, sand and silt believed to be attached to the drainage stone at the time of construction was eroded into the lower filter fabric. These findings suggest that for future cells any stone that is used within the leachate collection system, or other drainage features of the landfill, should be thoroughly washed to remove silt and sand before installation. Furthermore, materials such as the tire chips that contain a significant amount of soil that can readily be mobilized by water seepage should not be placed in contact with the leachate collection system, nor be used in conjunction with other drainage features, unless properly filtered.

264

One test pit piezometer installed in Phase I suggests that no hydraulic mounding is occurring in the ash. Water content measurements and observations with respect to depth in the test pit excavated on September 1, 2010 in Phase I, show unsaturated ash conditions. The water content and observations further support that mounding is not occurring in the waste. Provided no hydraulic mounding of leachate is occurring elsewhere in Phase I, no corrective action to the overall leachate collection system appears to be necessary. On the other hand, if the leachate levels atop the liner are excessive, then an approach for either draining the waste or eliminating infiltration might be considered to limit hydraulic gradients on the base liner system. It is our opinion, based on the information collected and the observations described, that there is a likelihood that little or no significant mounding on the liner is occurring. This likelihood is due to the relatively high moisture holding capacity of the ash and **eco**maine's observation that significant runoff that occurs from the ashes surface into the cell's perimeter ditches during rainfall events. This runoff characteristic has led to the problem of flooding in the sump area.

REFERENCES

Bennett, P.J., F.J. Longstaffe, and R.K. Rowe, 2000. The Stability of Dolomite in Landfill Leachate Collection Systems, Canadian Geotextile Journal, Vol. 37, pp.371-378.

Cooke, A.J. and R.K. Rowe, 2008. WD Modeling of Clogging in Landfill Leachate Collection systems, Canadian Geotechnical Journal, Vol. 45, pp.1393-1409.

Koerner, R.M. and G.R. Koerner, 1991. Landfill Leachate Clogging of Geotextile (and Soil) Filters, EPA/600/52-91/025, U.S.EPA Cincinnati, OH.

Hwang, H.J. and Ariel Un Ro, 2006. Simple Particle Characterization of Municipal Solid Waste (MSW) Ash Particle Using Low-Particle Electron Probe x-ray microanalysis, Atmospheric Environment, Vol. 40, No. 16, pp.2873-2881.

Kirby, C.S. and J.D. Rimstidt, 1993. Minerology and Surface Projections of Municipal Solid Waste Ash, Env. Science & Tech., Vol. 27, pp.652-660.

Levine, A.D., V.J. Harwood, A.J. Cordoso, L.R. Rhea, B.S. Nayah, B.M. Dodge, M.L. Decker, G. Dzana, L. Jones, E. Halley, and A.R.M. Salch, 2005. Assessment of Biogeochemical Deposits in Landfill Leachate Drainage Systems, Univ. of Fla, Gainesville, FL.

McIsaac, R. and R.K. Rowe, 2008. Clogging of Unsaturated Ground Permeameters with Landfill Leachate, Canadian Geotechnical Journal, Vol. 45, pp.1045-1063.

Record Drawings, November 2006. Phase 1 Landfill Expansion Construction Drawings, Ashfill/Balefill Expansion Project, South Portland/Scarborough, Maine October 2003, Revision 1A. Prepared by Arcadis Geraghty & Miller, Inc., Millersville, Maryland.

Rowe, R.K., I.R. Fleming, B.R. Rittmann, F.J. Longstaffe, D.R. Cullimore, R. McIsaac, P. Bennett, A.J. Couke, M.D. Armstrong, J. VanGulck, 2000. 6th Env. Eng. Specialty Conf. of the CSCE & Second Spring Conf. of the Geo-environmental Div. of the CGS, London, Ont., Ca.

266

ATTACHMENT B

United States
Environmental Protection
Agency

National Risk Management
Research Laboratory
Cincinnati, OH 45268

Research and Development

EPA/600/SR-95/141 September 1995

267

EPA

Project Summary

Leachate Clogging Assessment of Geotextile and Soil Landfill Filters

Robert M. Koerner and George R. Koerner

This project focused on the performance, design, testing, and recommendations for filters used for leachate collection drainage systems at the base of landfills, waste piles, and other solid waste facilities. The emphasis of the project was on geotextiles because of their manufactured uniformity, ease of placement, and savings in landfill volume; natural sand soil filters were also evaluated. Field exhuming of four sites indicated that problems existed at three of them. These three sites employed "socked pipe," where a geotextile was wrapped around perforated pipe. The testing and subsequent design showed that socked pipe designs should not be used in landfills nor should permitting agencies allow them this application. At the fourth site where the geotextile was moved away from the pipe, in a trench-wrap configuration performance was acceptable. Even further, the laboratory testing portion of the study indicated that an open geotextile over the entire base of the landfill (the footprint) is the proper design strategy and, thus, is recommended for general use. The introduction of a term called the "drainage correction factor" (DCF), in the standard design equation was recommended. This DCF was used to assess the various design options, and the results corroborated findings at the exhumed field sites. Other related investigations included the "no-filter" design strategy (which can be used only with extreme caution and when accompanied by long-term testing) and the use of biocides (which is not recommended).

This Project Summary was developed by EPA's National Risk Management Research Laboratory, Cincinnati, OH, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

The proper collection, transmission, and removal of leachate from the base of solid waste landfills is at the heart of a proper liquids management strategy. Although many design issues are involved, excessive system clogging is an often-raised concern. Since most leachate collection and removal systems consist of a filter, a drainage material, and a perforated pipe system, focusing on the material with the smallest void spaces, i.e., the filter, is logical.

Historically, leachate collection and removal system filters have been granular soils, primarily sands. These have recently been replaced in large measure by geotextiles because of the quality control of manufactured geotextiles, their ease of placement, and the subsequent savings in landfill volume. This project focused primarily on geotextile filters insofar as the potential for excessive clogging by leachate was concerned. Sand filters were also evaluated for comparative purposes. The project consisted of a number of separate tasks brought together in a recommended design methodology for determining a factor-of-safety value for a specific candidate filter and a set of site specific conditions.

Task 1 - Exhuming of Field Sites

The first task was arguably the most difficult and also the most rewarding of the entire project. Field sites-of-opportunity were solicited for the purpose of exhuming their respective leachate collection and removal systems. Obviously, the overlying solid waste had to be removed before the collection system could be investigated. Although only four sites were obtained, they were very significant. Table 1 gives some of the physical details and observations of the sites, and Table 2 gives the leachate characteristics at the time of exhuming. Note that the leachate removal system at Sites 1, 3, and 4 were not functioning because their filters were excessively clogged. Site 2 was still functioning; however, flow rates were less than the designer/operator had anticipated. Comments and conclusions about these exhumed sites include:

- All sites had relatively harsh leachates high in total solids (TS) and/or biochemical oxygen demand (BOD_5).
- The exhumed sites that were excessively clogged had geotextiles wrapped directly around perforated drainage pipes (socked pipes).
- Obviously, this practice of socked pipe should not be used for leachate collection systems.
- In the still-functioning site, a geotextile was wrapped around gravel that in turn, contained a perforated drainage pipe.
- These observations led to the suggested optimum design: using a filter over the landfills's footprint and as far away from the leachate removal pipe network as possible.
- This suggested design had to be corroborated by laboratory tests, analytic modeling, and appropriate design modeling. The remainder of the project focused on those specific tasks.

Task 2 - Laboratory Investigations

To determine the long-term allowable permeability (k_{allow}) of a particular filter (geotextile or sand), an new test method was proposed, carried through the necessary committees, and eventually adopted by the American Society of Testing and Materials. Its designation is ASTM D1987, and it is specifically intended to determine the leachate permeability of geotextile and soil landfill filters. In the course of this project, 144 permeameters (Figure 1) were constructed and used for periods of 120 to 300 days. The experimental variations consisted of:

- 12 filters (10 geotextile and 2 sands)
- 4 permeants (water and 3 leachates)
- 3 flow rates (all significantly greater than typical field flow rates)

The use of flow rates greater than field flow rates constituted accelerated testing with respect to the amount of leachate passing through the filters. A typical response curve for a single flow rate is shown in Figure 2. When the equilibrium value was determined, it was used with the same type of filter at different flow rates to establish a trend. Results of accelerated tests at all three flow rates were plotted and can be back-extrapolated to field anticipated flow rates. These trends for the 12 evaluated filters are given in Figure 3. These curves represent a set of master curves of commercially available filter materials for which k_{allow} can be taken at a particular site specific value of field anticipated flow rate.

Task 3 - Analytic Modeling

To counterpoint the allowable permeability of a given filter (as just described) to a required permeability, a suitable analytic model is needed. This model must be site specific for hydrology, waste type, geometry, material properties, etc. For this purpose, the EPA-sponsored model entitled Hydrologic Evaluation of Landfill Performance (HELP) is regularly used in the United States and its use is becoming common throughout the world. The HELP model is a liquids balance model that tracks the moisture in the waste and augments it with the site-specific rainfall and snowmelt. This total amount is then partitioned via a number of subroutines into runoff, interception, transpiration, evaporation, and infiltration. The infiltration is then tracked through the various layers until it meets the leachate collection and removal system at the base of the landfill.

The value of required permeability (k_{reqd}) was obtained by sequentially varying a series of trial permeabilities from 1.0 to 1 x 10^{-8} cm/sec while tracking the peak daily discharge output of the model. A site specific value for k_{reqd} was then defined as the point at which the peak daily discharge was negatively influenced by changes in the trial permeability of the filter. In effect, when the permeability of the trial filter began to significantly decrease the amount of leachate discharged, the value of k_{reqd} was reached. Version 3 of the HELP model was used to develop the k_{reqd} values of Table 3, which were based on the characteristics of the four sites.

Task 4 Design Method and Substantiation

Having values of "k_{allow}" for a particular filter and the HELP-generated "k_{reqd}" value for a particular landfill site allows for the formulation of a factor-of-safety (FS) against excessive filter clogging. A direct comparison was not possible, however, because of observations made at the field exhumed sites. For a filter with only a small drainage area directly beneath it, as in the case of socked pipe, the classical FS equation had to be modified. This was done by using a "drainage correction factor (DCS) in the denominator of the conventional FS equation. The DCF is defined as the ratio of the landfill area divided by the available drainage flow area immediately downstream of the filter. (In the case

Table 1. Overview of Exhumed Leachate Collection Systems

Site No	Waste Type	Age Exhuming	Liquid Management Scheme	Performance Exhuming	Critical Element in Drainage System
1.	Domestic and light industrial	10	Leachate recycling	Excessively clogged	Geotextile filter
2.	Domestic and light industrial	6	Leachate recycling	Marginally clogged	Drain location
3.	Industrial solids and sludge	0.5	Leachate withdrawal	Excessively clogged	Geotextile filter
4.	Domestic and rural	6	Leachate recycling	Excessively clogged	Geotextile filter

Table 2. Summary of the Leachate Characteristics of the Exhumed Field Sites

Site No.	Landfill Type	pH	COD (mg/l)	TS (mg/l)	BOD_5 (mg/l)
1.	Municipal	10	31,000	28,000	27,000
2.	Municipal	6	10,000	3,000	7,500
3.	Municipal	0.5	3,000	12,000	1,000
4.	Municipal	6	24,000	9,000	11,000

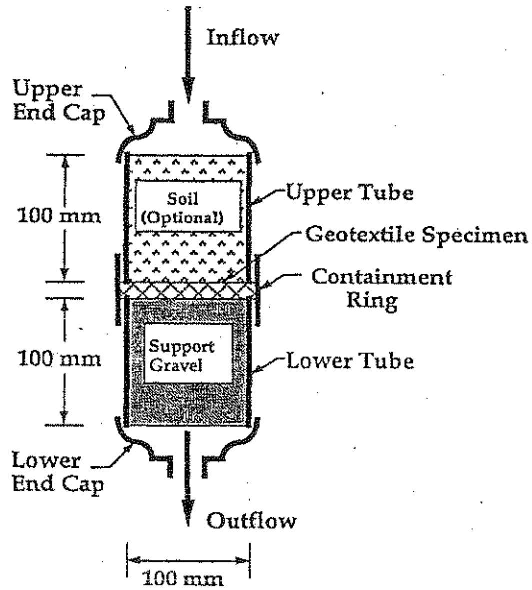


Figure 1. ASTM D1987 type permeameters.

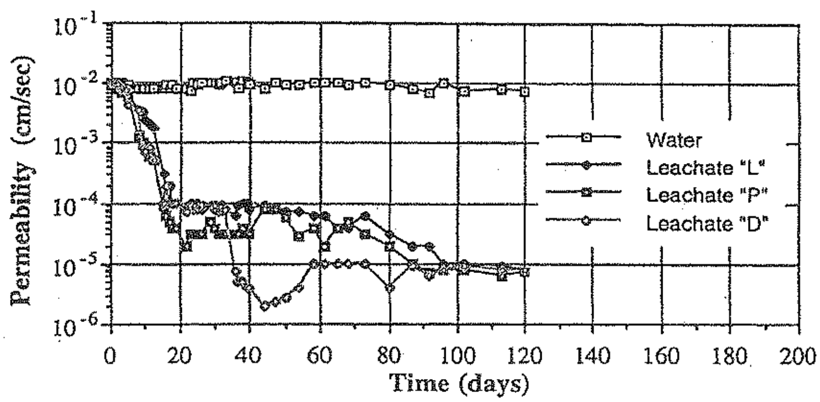


Figure 2. Typical permeability test results for a particular geotextile filter.

of socked pipe, its value is very large). The resulting formulation was as follows:

$$FS = \frac{k_{allow}}{k_{reqd} \times DCF}$$

where:

FS = *factor-of-safety (against excessive filter clogging)*
k_{allow} = *allowable filter permeability*
k_{reqd} = *required filter permeability*
DCF = *drainage correction factor*

With the use of k_{allow} value for the geotextile exhumed at each of the four field sites, the k_{reqd} value for each of the field sites from the HELP model, and the calculated site specific DCF, we obtained the data of Table 4. Here it can be seen that the three sites with excessively clogged geotextiles could easily have been predicted as failures based on their extremely low FS values.

Possible Less Expensive Alternative

Because the suggested laboratory work and design modeling are both time consuming and expensive, we explored conditions in which a "default" geotextile could be used as the filter. We concluded that if the leachate was relatively mild, i.e., TS < 2500 mg/L and BOD_5 < 2500 mg/L, geotextiles with the properties shown in Table 6 could be used with a reasonable degree of confidence. The proviso, however, is that the geotextile must cover the full footprint of the landfill or cell under consideration. In the context of this study, this type of design is defined as an aerial filter with a drainage correction factor of one, i.e., DCF = 1.0.

Additional aspects of the study investigated the use of biocides (which were not particularly encouraging) and the "no filter" design scenario (which places emphasis on potential clogging of the downstream drainage stone). Both of these design strategies can be evaluated by the laboratory test methods and design formulation developed in this study.

If the leachate has higher values than 2500 mg/L for TS and for BOD_5, the procedure and details given for Tasks 1 through 4 should be followed. The laboratory test data and the requisite design may permit less conservative filters than those described in Table 6. Properly designed they are acceptable.

270

The values of strength listed in the above table are required Class 2 and Class 1 values per the proposed AASHTO M288 specification for transportation facilities in the high and very high survivability ratings, respectively [15].

Conclusions

This project, which focused on the filters of landfill leachate collection and removal systems, resulted in a design methodology to predict the anticipated FS against excessive filter clogging. It evaluated laboratory and analytic models, along with making observations from field-exhumed sites. The use of the design model nicely substantiated the field findings. Use of the modified FS equation is recommended for design of leachate collection filters to assess the possibility of excessive clogging at the base of solid waste landfills, waste piles, and other solid waste facilities.

The full report was submitted in fulfillment of CR-819371 by Drexel University under the sponsorship of the U.S. Environmental Protection Agency.

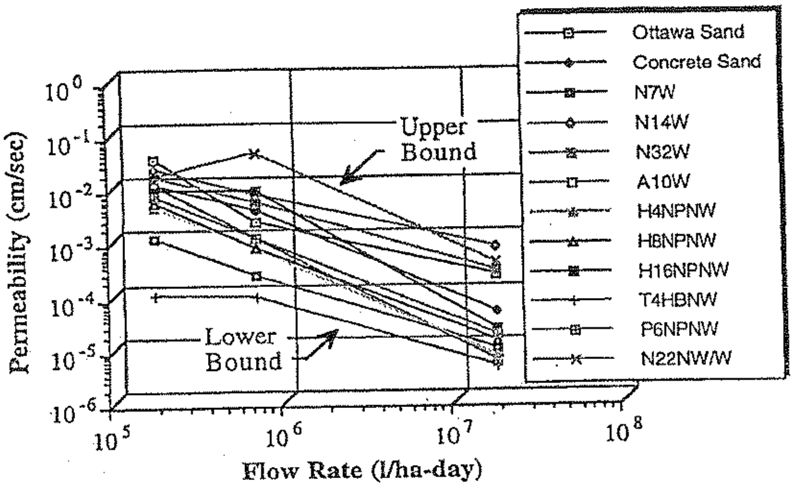


Figure 3. Master curve of 12 filters for "k_{allow}" determination at a Site specific flow rate.

Table 3. Input Data of Exhumed Sites for Use in HELP Model to Obtain Required Filter Permeability

Site No.	Cell Area (ha)	Base Slope (acre)	Pipe Spacing (0%)	$K_{drainage\ Stone}$ (m)	k_{reqd} (ft)	(cm/sec)	(cm/sec)
1.	2.8	7	1.5	61	200	0.01	1×10^{-5}
2.	2.8	7	1.5	61	200	0.3	1×10^{-5}
3.	2.9	2.9	2.0	61	200	0.3	5×10^{-5}
4.	5.6	13.8	1.5	31	100	0.3	1×10^{-5}

Table 4. Corroboration of the Modified Factor-of-Safety Equation as Applied to Four Exhumed Field Sites

Site	Observed Performance	kallow (cm/s)	kreqd (cm/s)	Value of DCF	Calculated FS Value	Predicted Performance
1.	Terrible	6×10^{-4}	1×10^{-5}	24,000	0.0003	Failure
2.	Good	1×10^{-2}	1×10^{-5}	140	7.1	Acceptable
3.	Terrible	9×10^{-3}	1×10^{-5}	990	0.18	Failure
4.	Poor	9×10^{-3}	1×10^{-5}	1,700	0.53	Failure

The variable term that greatly decreased the FS values was the DCF (Table 4). As seen in Table 5, for a number of design scenarios, the value of DCF can be enormous.

Table 5. Selected Values of Drainage Correction Factors for Use in Calculating the Factor-of-Safety of a Leachate Collection Filter*

Drain Configuration	Drain Spacing		Drain Size		Hole Size		Number of Holes		Drain Correction Factor
	(m)	(ft)	(mm)	(in.)	(mm)	(in.)	(per m)	(per ft)	
Areal coverage	n/a+	n/a	n/a	n/a	n/a	n/a	n/a	n/a	1
Geotextile wrapped around gravel (i.e., socked trench wrap)	15	50	450x300	18x12	n/a	n/a	n/a	n/a	10
	30	100	450x300	18x12	n/a	n/a	n/a	n/a	20
	45	150	450x300	18x12	n/a	n/a	n/a	n/a	30
	60	200	450x300	18x12	n/a	n/a	n/a	n/a	40
Geotextile around corrugated pipe (i.e., socked piped)	15	50	150	6.0	n/a	n/a	n/a	n/a	60
	30	100	150	6.0	n/a	n/a	n/a	n/a	130
	45	150	150	6.0	n/a	n/a	n/a	n/a	190
	60	200	150	6.0	n/a	n/a	n/a	n/a	260
Geotextile around smooth wass pipe (i.e., socked pipe)	15	50	150	6.0	12	0.5	1.8	6	7,500
	30	100	150	6.0	12	0.5	1.8	6	12,000
	45	150	150	6.0	12	0.5	1.8	6	18,000
	60	200	150	6.0	12	0.5	1.8	6	24,000

+n/a = Not applicable.
*All calculations are based on a 0.4 (1 acre) cell.

Table 6. Recommended Geotextile Filters for Use with Relatively Mild Landfill Leachates (Those Having TSS and BOD_5 Values < 2500 mg/L)

Type of Geotextile	Sand Protection Layer Over Filter		Select Waste Placed Directly on Filter	
Woven Monofilament Mass per unit area, g/sq. M (oz/sq yd)	170	(5.0	200	(6.0)
Percent open area, %	10	----	10	0000
Grab tensile strength, N (lb)*	1100	(250)	1400	(300)
Trapezoidal tear strength, N (lb)	400	(90)	490	(110)
Puncture strength, N (lb)	400	(90)	490	(110)
Burst strength, kPa (lb/sq in.)	1800	(400)	2200	(500)
Nonwoven Needle Punched Mass per unit area, g/sq. M (oz/sq yd)	270	(8.0)	400	(12.0)
Apparent opening size, mm (sieve size)	0.212	(#70)	0.212	(#70)
Grab tensile strength, N (lb)	1100	(250)	1400	(310)
Trapezoidal tear strength,N (lb)	400	(90)	490	(110)
Puncture strength, N (lb)	400	(90)	490	(110)
Burst strength, kPa (lb/sq in.)	1800	(400)	2200	(500)

*N=Newton

219

Robert N. Koerner and George R. Koerner are with Drexel University, Geosynthetic Research Institute, Philadelphia, PA 19104.
Robert E. Landreth is the EPA Project Officer (see below).
The complete report, entitled "Leachate Clogging Assessment of Geotextile and Soil Landfill Filters," (Order No. PB95-265542; Cost: $27.00, subject to change) will be available only from:
National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
Telephone: 703-487-4650
The EPA Project Officer can be contacted at:
National Risk Management Research Laboratory
U.S. Environmental Protection Agency
Cincinnati, OH 45268

United States
Environmental Protection Agency
National Risk Management Research Laboratory
Cincinnati, OH 45268

BULK RATE
POSTAGE & FEES PAID
EPA
PERMIT No. G-35

Official Business
Penalty for Private Use
$300

EPA/600/SR-95/141