# FILTRATION TEST USING TENAX TRI-PLANAR GEOCOMPOSITE WITH LEAN CLAY

by

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## Preface

The tests conducted for Tenax, Incorporated, were developed by Karen Henry, with assistance from many CRREL employees, including Rosa Affleck, who was especially helpful in setting up the tests. The experimental techniques are documented in detail in Henry (in preparation) where results of many experiments of a similar nature are reported. Ms. Affleck conducted the test reported on here.

This work was performed in accordance with the 1997 Cooperative Research and Development Agreement (CRDA) between US Army Cold Region Research and Engineering Laboratory (CRREL) and Tenax Incorporated.

## INTRODUCTION

This report presents the results of a laboratory study to determine the long-term filtration behavior of a soil-geocomposite system, consisting of soil collected at Winterport, Maine and a Tenax tri-planar geocomposite. The soil tested was collected from Route 1A during August 1997, when pavement test sections containing geocomposites (provided by Tenax) were being constructed.

The Maine Department of Transportation (MDOT) constructed several test sections containing geosynthetics along a 3 km (1.9 mile) portion of Route 1A in the towns of Frankfort and Winterport. A drainage geocomposite was installed at 0.5 m (18 in.) below the subgrade in test section D-1 (survey stations 251+00 to 261+50) in order to study potential benefits of its use as a capillary barrier (Fig. 1). During soil freezing, it is hoped that the capillary barrier prevents upward migration of water to the freezing front and thereby reduces the frost heave and/or the water content of the soil above it (e.g. Henry and Affleck, 1998). The filtration test was conducted to verify that the geocomposite would neither clog with soil fines nor allows excessive amounts of soil fines to migrate through.

The method used for filtration testing in this program is based on ASTM D 5101-90, also known as the gradient ratio test. An upright cylindrical soil specimen with a geocomposite at the bottom is subjected to water flow from the top down under specified hydraulic gradients. Hydraulic head loss through the specimen is measured through manometer tubes attached at the sides. Several modifications were made to the equipment and the procedure specified by ASTM D 5101-90 for the purposes of this project. They are discussed below.

<u>Equipment used</u>

The test hardware comprises two parts--a water circulating and deairing system and the actual test equipment (Fig. 2). The water circulating and deairing system consists of a vacuum source (a Venturi device connected to a water faucet), a large water storage tank (147 liter), a 5 µm filter, a 1 µm filter, vacuum gage, a water dearator (2.4 liter capacity), a 75 liter storage tank for the de-aired water, and a variable speed pump (6-600 RPM). The gradient ratio test equipment consists of a constant-head water supply, a 100-mm-long permeameter and a constant-head water outflow device. The water supply in the large storage tank is replenished as needed by placing a drain tube from the Venturi device into it. A programmed Campbell Scientific CR10 datalogger monitors and controls the water circulation and deairing through a valve control box that is wired to three one-way and one two-way solenoid valves. For more details on the test set-up, see Henry (in preparation).

The ASTM standard permeameter requires six manometer tubes one each above and below the specimen, and two on opposite sides of the permeameter at heights above the specimen base of 25 mm and 75 mm. The CRREL permeameter includes manometers at those locations plus at heights above the base of 10, 50 and 90 mm (Fig. 3). All of the manometers were fastened with hose clamps to a manometer board, with tape marked to the nearest 1 mm behind each one. Thus, the water levels are read to an accuracy of ± 0.5 mm.

Materials used

The soil used was sampled from the soil placed on top of the geocomposite during the construction of test section D-1. Figure 4 shows the grain size distribution of the soil. This soil is most likely a mixture of the subgrade below the geocomposite and the excavated pre-existing base course materials (Henry and Affleck, 1998). The geocomposite list of specifications and properties supplied by Tenax, Inc., are listed in Appendix A.

Specimen preparation

The soil was prepared by screening air-dried test soil on a 10-mm (3/8 in.) mesh sieve, and discarding the portion retained on the sieve. The remaining soil was screened on a 2-mm (No. 10) sieve, and the portion remaining was pulverized with a rubber-covered pestle and mortar to break up all aggregated particles. The portion retained on the sieve was then recombined with the finer soil.

Specimen placement

Initially, water was added to the soil to achieve an in-situ moisture content about 20%, letting it equilibrate overnight, then carefully compacting it into the mold in layers (i.e., five layers). Each soil layer was kneaded 20 times with a metal pestle. The layers were scarified with a fork before the next layer was added. This achieved a dry density of 1.96 $Mg/m^3$. However, after 2 weeks of saturating, the specimen was so impermeable that it didn't have any water coming through the manometers. We decided to stop the saturation and the specimen was discarded.

For the second attempt at the filtration test, the dry soil was poured into the permeameter according to ASTM D 5101-90. The soil was placed carefully using a scoop to a 25-mm-thick layer. Consolidation of each layer was achieved by tapping the side of the permeameter six times using a 20-mm-diameter by 150-mm-long wooden rod. The dry density of this specimen was 1.55 $Mg/m^3$. (The dry density of the soil in the field was estimated as 1.80 $Mg/m^3$.)

Specimen saturation

Saturation was accomplished by raising the water table from the base of the specimen at a rate of approximately 25-mm per day until the water table reached the top of the specimen. The specimen was then left to stand until the manometer tubes all showed a hydraulic head within 1 cm of each other at the top of the specimen. This process took 15 days.

<u>Conducting the filtration test:</u>

The filtration test was started and conducted according to the procedure described in ASTM D 5101-90. In this test, a hydraulic gradient of one was used. Flow rate measurements were made and recorded manually approximately once per day. Because of the low hydraulic conductivity of the soil, a minimum time of about four hours was needed to make each measurement. The temperature of the water was noted at the beginning and end of each flow measurement, and the average of these two temperatures was used in correcting for temperature in the hydraulic conductivity determination. The manometer readings were conducted after the flow reading was performed. The averages of the manometer readings for each manometer pairs along the specimen were taken for hydraulic conductivity calculation.

During soil placement in the permeameter, voids were noticed along the sides of the permeameter. However, no consolidation of the specimen occurred during the test. The deaired water used in the permeameter system had dissolved oxygen measured at 4.5 ppm (part per million) and bleach was also added to the storage water tank to minimize the bacteria and mold growth. The filtration test of this specimen ran for 45 days.

<u>Results and Conclusion</u>

Appendix B shows the manometer, flow and temperature readings during the test. The system hydraulic conductivity of the specimen was 2.3E-03 cm/sec for the first 3 days, then decreased to 2.79E-04 cm/sec after 13 days and remained stable for the rest of the tests (Fig. 5). Figure 6 shows the specimen gradient ratio versus time. The hydraulic conductivity and gradient ratio of the specimen are listed in Appendix C.

Gradient ratios of 3.0 or less are acceptable for most geotextile filters (e.g., ASTM D5101; Holtz, et al, 1995). Although ASTM D 5101-90 was developed for geotextiles, the Tenax tri-planar geocomposite appears to be an acceptable filter for the test conditions under a hydraulic gradient of approximately 1.0. The geocomposite did not clog, and demonstrated stable flow behavior with time.

Acknowledgments

We appreciate the interest and assistance from the Maine Department of Transportation, especially Mr. Scott Hayden, as well as the University of Maine, including Professor Dana Humphrey and Civil Engineering student Adam Smart. In addition, we thank Dr. Barry Christopher for his advice and assistance in the field.

References

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Holtz, R.D., B.R. Christopher and R.R. Berg (1995) "Geosynthetic design and construction guidelines," Publication No. FHWA HI-95-038, Federal Highway Administration, U.S. Department of Transportation, Washington, DC, 395 p.

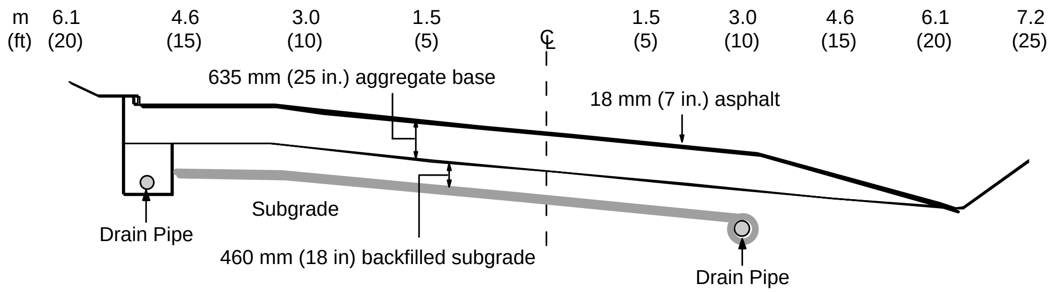


Figure 1. Cross-section showing Maine Department of Transportation test section D-1, in Winterport, Maine.

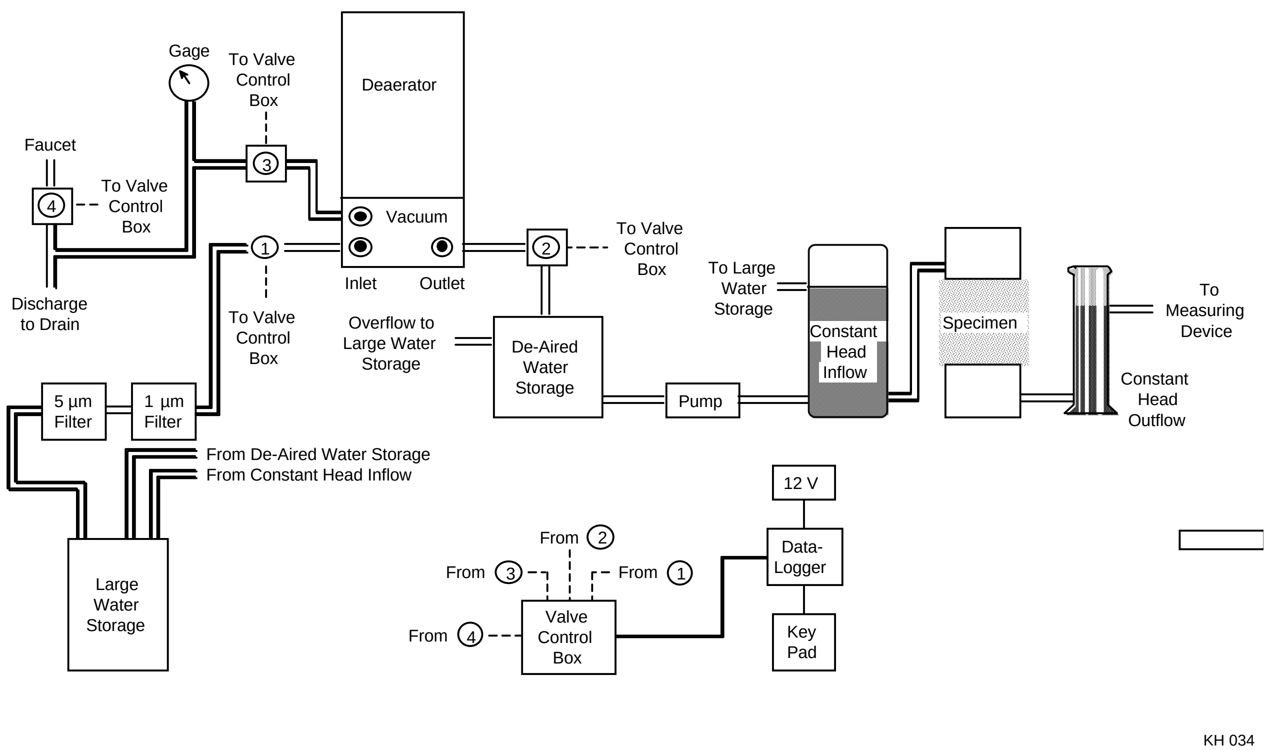


Figure 2. Schematic of the equipment set up used to run the long-term filtration tests. The solenoid valves are designated as follows: 1 - Water inlet to the deaerator, 2 - Water outlet from the dearator, 3 - Two way valve connecting the vent to either ambient air of the vacuum source, and 4 - Vacuum source.

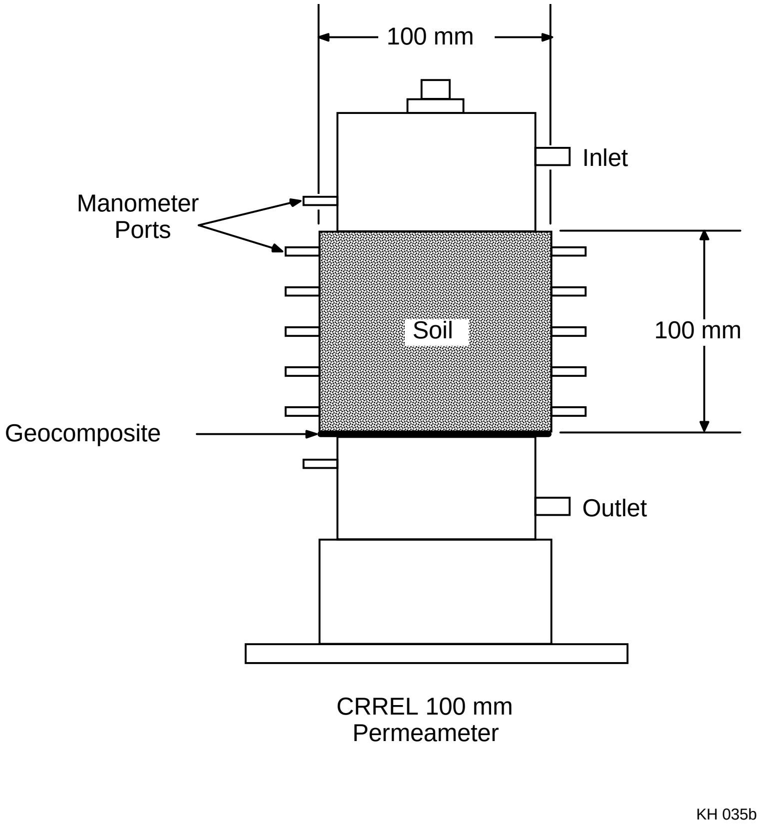


Figure 3. Schematic of the CRREL 100-mm permeameter.

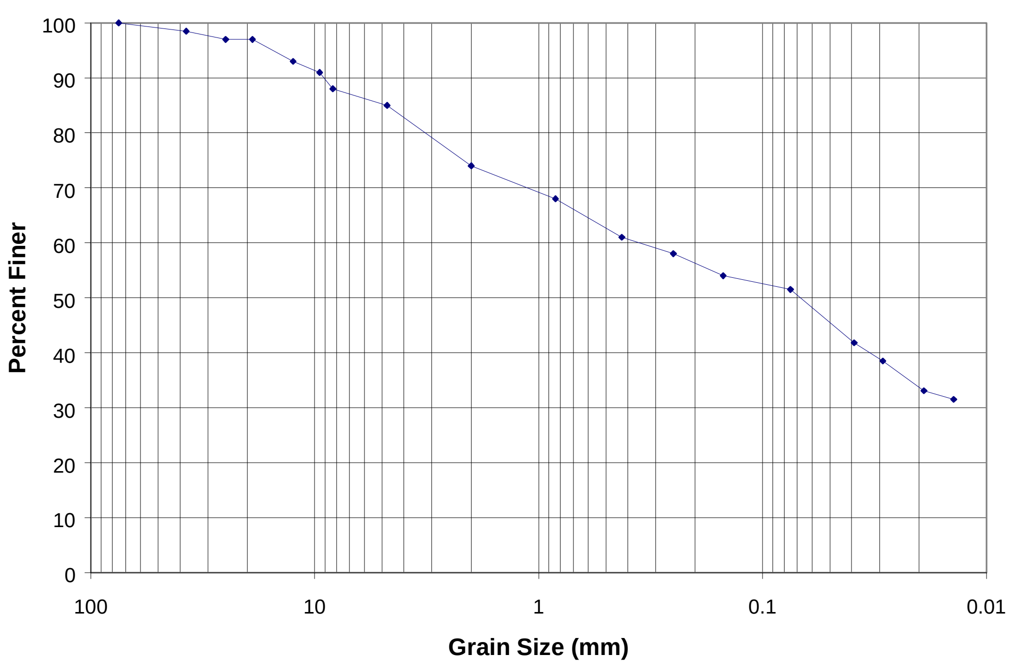


Figure 4. Grain size distribution of soil placed on top of the geocomposite

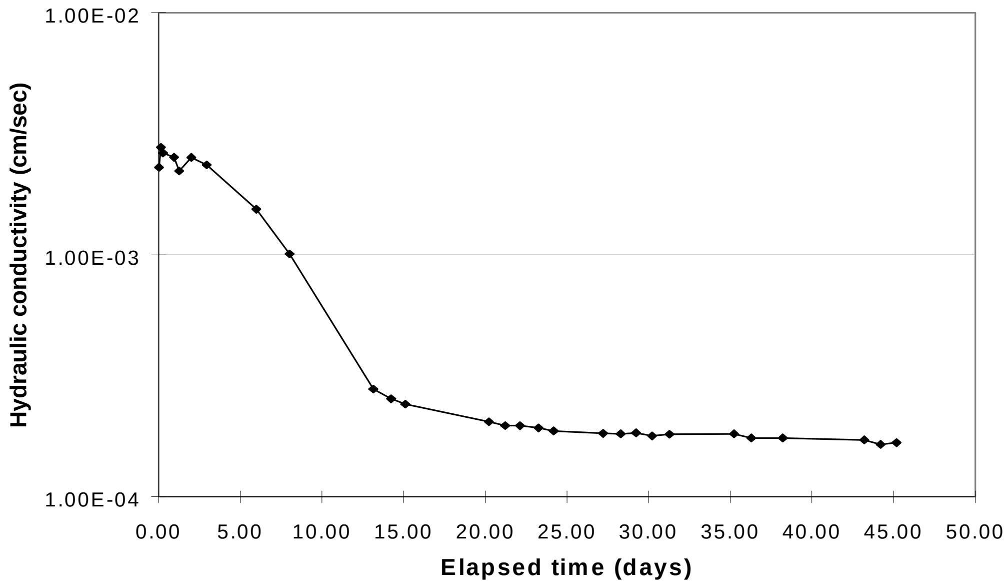


Figure 5. Hydraulic conductivity of the specimen

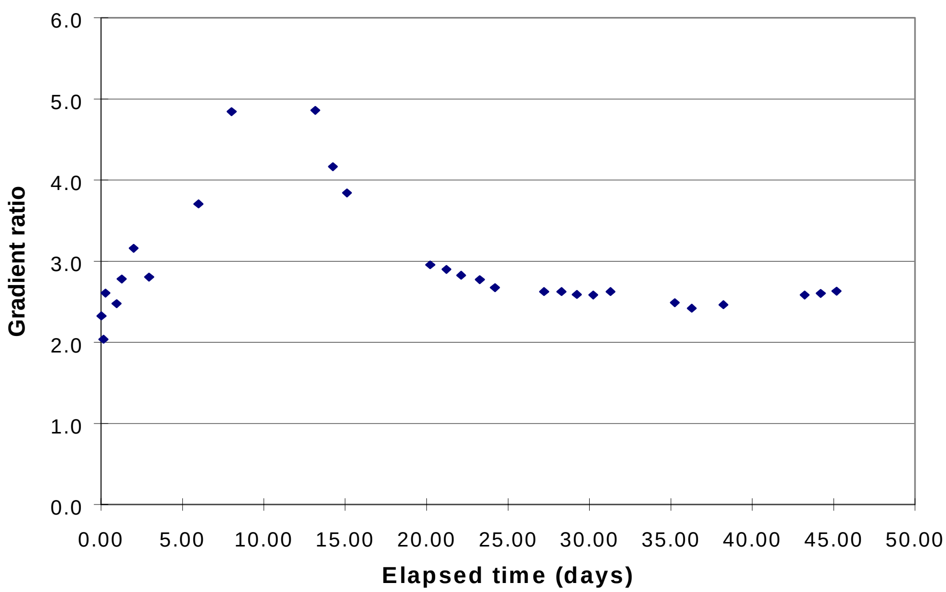


Figure 6. Specimen gradient ratio over time

Appendix A

# TENDRAIN 100-2

DOUBLE-SIDED GEOCOMPOSITE (GEOTEXTILE - TRI-PLANAR GEONET -GEOTEXTILE)

**The drainage geocomposite is comprised of a tri-planar geonet structure consisting of thick supporting ribs with diagonally placed top and bottom ribs and with a thermally bonded, non-woven geotextile on both sides. The product is capable of providing high flow rates in a soil environment under high normal loads and will have properties conforming with the values and test methods listed below :**

| PROPERTIES | TEST METHOD | UNIT | VALUE | QUALIFIER |
|---|---|---|---|---|
| ***GEONET CORE*** | | | | |
| Tensile Strength - MD | ASTM D4595 | lb/ft | 1000 | c, Note 1 |
| Compressive Behavior | | | | |
| (% Retained thickness) | | | | |
| @50,000 psf (short term) | ASTM D1621 | % | 50 | a, Note 2 |
| @25,000 psf (10,000 hours) | | % | 60 | a |
| Resin Density | ASTM D1505 | $g/cm^3$ | 0.94 | c |
| Resin Melt Index | ASTM D1238 | g/10 min. | 1.0 | d |
| Carbon Black Content | ASTM D4218 | % | 2.0 | c |
| Thickness | ASTM D5199 | mils | 300 | c, Note 3 |
| ***GEOTEXTILE*** | | | | |
| Apparent Opening Size (AOS) | ASTM D4751 | US Sieve (mm) | 100(0.15) | b,4 |
| Weight | ASTM D3776 | oz/sy | 8 | b,4 |
| Water Flow Rate | ASTM D4491 | $gal/min/ft^2$ | 100 | b,4 |
| Permeability | ASTM D4491 | cm/sec | 0.3 | b,4 |
| Puncture | ASTM D4833 | lbs | 130 | b,4 |
| Trapezoid Tear | ASTM D4533 | lbs | 80 | b,4 |
| Grab Tensile Strength | ASTM D4632 | lbs | 200 | b,4 |
| Grab Elongation | ASTM D4632 | % | 50 | b,4 |
| Mullen Burst | ASTM D3786 | psi | 450 | b,4 |
| UV Resistance @500 Hours | ASTM D4355 | % | 70 | b,4 |
| ***GEOCOMPOSITE*** | | | | |
| Roll Width | | ft | 6.7 | a, Note 5 |
| Roll Length | | ft | 200 | a, Note 5 |
| Ply Adhesion | ASTM D413 | lbs/in | 2 | c, Note 6 |

***HYDRAULIC BEHAVIOR OF GEOCOMPOSITE IN SOIL***

Transmissivity - MD ( X $10^{-4}$ $m^2$/sec) ASTM D 4716-95 — Notes 7

| ~~Gradient/Load:~~ | ~~15,000 psf~~ | ~~25,000 psf~~ |
|---|---|---|
| 0.1 | 22.5 | 10 |
| 0.5 | 12 | 5 |
| 1 | 8 | 4 |

Flow Rate Per Unit Width - MD (gpm/ft) ASTM D 4716-95 — Notes 7

| ~~Gradient/Load:~~ | ~~15,000 psf~~ | ~~25,000 psf~~ |
|---|---|---|
| 0.1 | 1.1 | 0.5 |
| 0.5 | 2.9 | 1.2 |
| 1 | 3.9 | 1.9 |

Qualifiers: a = Typical Value b = Minimum Average Roll Value (MARV)
c = Minimum Value d = Maximum Value

**NOTES:**

1. Tensile properties tested by manufacturer every 40,000 square feet of product per ASTM D4595 with a specimen width of 8.0 in. and cross-head speed of 0.04 in./min.
2. Compression behavior tested by manufacturer every 40,000 square feet of product per ASTM D1621 with a 2 in. x 2 in. specimen and a constant rate of strain of 0.04 in./min.
3. Thickness measured by manufacturer every 40,000 square feet of product per ASTM D5199 with a 2.22 in. diameter presser foot and 2.9 psi pressure.
4. Geotextile properties listed are prior to lamination.
5. Roll dimensions are measured at the time of manufacture.
6. Ply adhesion tested by manufacturer every 40,000 square feet of product per ASTM D413 with a 2 in. wide strip where the geotextile bonded to either side of the geonet is pulled apart at a speed of 2.0 in/min. The value reported for each laminated side is the average of the 5 peak values from each specimen. Both the top and bottom geotextile interfaces must be evaluated.
7. Geocomposite transmissivity measured by manufacturer every 100,000 square feet of product as per ASTM D4716-95 with testing boundary conditions as follows: steel plate / uniform sand / geocomposite / 60 mil HDPE geomembrane / steel plate

# Appendix B

Results of long-term gradient ratio test on Route 1A, Winterport/Frankfort, Maine Test Soil

| Date | Start Temp | Stop Temp | Avg. Temp (C) | Q (cc) | Start Time | Stop Time | Time (min) | Time (sec) | Elapsed time (day) | Q/time ml/sec |
|---|---|---|---|---|---|---|---|---|---|---|
| 12/16/97 10:05 | | | | | | | | | 0.00 | |
| 12/16/97 10:35 | 22.3 | 22.3 | 22.3 | 454.75 | 9:57:00 | 10:33:00 | 0:36:00 | 2160 | 0.02 | 0.210532 |
| 12/16/97 13:32 | 22.7 | | 22.7 | 292.79 | 13:10:00 | 13:29:00 | 0:19:00 | 1140 | 0.14 | 0.256833 |
| 12/16/97 16:35 | 22.5 | | 22.5 | 58.82 | 16:35:00 | 16:39:00 | 0:04:00 | 240 | 0.27 | 0.245083 |
| 12/17/97 9:00 | 20.8 | 21.1 | 21.0 | 226.65 | 8:48:00 | 9:05:00 | 0:17:00 | 1020 | 0.95 | 0.222206 |
| 12/17/97 16:25 | 21.5 | 21.5 | 21.5 | 515.29 | 15:41:00 | 16:24:00 | 0:43:00 | 2580 | 1.26 | 0.199725 |
| 12/18/97 10:05 | 20.6 | | 20.6 | 484.60 | 9:28:00 | 10:04:00 | 0:36:00 | 2160 | 2.00 | 0.224352 |
| 12/19/97 8:55 | 20.9 | 21.3 | 21.1 | 251.28 | 8:30:00 | 8:50:00 | 0:20:00 | 1200 | 2.95 | 0.209400 |
| 12/22/97 9:40 | 20.4 | 20.8 | 20.6 | 319.94 | 9:00:00 | 9:38:00 | 0:38:00 | 2280 | 5.98 | 0.140325 |
| 12/24/97 10:35 | 21.5 | 22.0 | 21.8 | 383.29 | 9:24:00 | 10:31:00 | 1:07:00 | 4020 | 8.02 | 0.095346 |
| 12/29/97 13:45 | 20.8 | 22.6 | 21.7 | 485.12 | 8:38:00 | 13:42:00 | 5:04:00 | 18240 | 13.15 | 0.026596 |
| 12/30/97 15:50 | 21.9 | 21.8 | 21.9 | 583.32 | 8:59:00 | 15:42:00 | 6:43:00 | 24180 | 14.24 | 0.024124 |
| 12/31/97 12:31 | 21.0 | 20.8 | 20.9 | 263.66 | 8:55:00 | 12:13:00 | 3:18:00 | 11880 | 15.10 | 0.022194 |
| 1/5/98 15:30 | 21.8 | 22.0 | 21.9 | 434.61 | 9:04:00 | 15:21:00 | 6:17:00 | 22620 | 20.23 | 0.019214 |
| 1/6/98 15:21 | 21.9 | 22.2 | 22.1 | 388.89 | 9:32:00 | 15:17:00 | 5:45:00 | 20700 | 21.22 | 0.018787 |
| 1/7/98 13:03 | 21.7 | 22.3 | 22.0 | 303.85 | 8:24:00 | 12:57:00 | 4:33:00 | 16380 | 22.12 | 0.018550 |
| 1/8/98 16:23 | 21.5 | 21.6 | 21.6 | 490.35 | 8:36:00 | 16:11:00 | 7:35:00 | 27300 | 23.26 | 0.017962 |
| 1/9/98 14:39 | 21.3 | 21.2 | 21.3 | 373.00 | 8:40:00 | 14:35:00 | 5:55:00 | 21300 | 24.19 | 0.017512 |
| 1/12/98 15:12 | 19.9 | 21.0 | 20.5 | 350.24 | 9:16:00 | 15:07:00 | 5:51:00 | 21060 | 27.21 | 0.016631 |
| 1/13/98 16:50 | 21.8 | 21.5 | 21.7 | 488.47 | 8:49:00 | 16:47:00 | 7:58:00 | 28680 | 28.28 | 0.017032 |
| 1/14/98 15:27 | 19.9 | 19.6 | 19.8 | 335.07 | 9:37:00 | 15:20:00 | 5:43:00 | 20580 | 29.22 | 0.016281 |
| 1/15/98 15:27 | 20.3 | 20.3 | 20.3 | 352.21 | 8:47:00 | 14:50:00 | 6:03:00 | 21780 | 30.22 | 0.016171 |
| 1/16/98 16:59 | 20.3 | 20.6 | 20.5 | 287.97 | 12:00:00 | 16:51:00 | 4:51:00 | 17460 | 31.29 | 0.016493 |
| 1/20/98 15:47 | 20.7 | 21.6 | 21.2 | 342.42 | 9:58:00 | 15:40:00 | 5:42:00 | 20520 | 35.24 | 0.016687 |
| 1/21/98 17:00 | 20.3 | 20.9 | 20.6 | 461.65 | 8:49:00 | 16:51:00 | 8:02:00 | 28920 | 36.29 | 0.015963 |
| 1/23/98 15:18 | 20.0 | 20.3 | 20.2 | 382.72 | 8:28:00 | 15:12:00 | 6:44:00 | 24240 | 38.22 | 0.015789 |
| 1/28/98 15:06 | 20.1 | 20.3 | 20.2 | 337.34 | 8:55:00 | 14:57:00 | 6:02:00 | 21720 | 43.21 | 0.015531 |
| 1/29/98 15:06 | 20.1 | 20.5 | 20.3 | 358.89 | 9:11:00 | 15:52:00 | 6:41:00 | 24060 | 44.21 | 0.014916 |
| 1/30/98 14:16 | 19.9 | 20.8 | 20.4 | 238.81 | 9:52:00 | 14:14:00 | 4:22:00 | 15720 | 45.17 | 0.015191 |

Hydraulic head readings

| Date and Time | Head Top (cm) | 1-L Head at 90 mm, L | 1-R Head at 90 mm, R | 2-L Head at 75 mm, L | 2-R Head at 75 mm, R | 3-L Head at 50 mm, L | 3-R Head at 50 mm, R | 4-L Head at 25 mm, L | 4-R Head at 25 mm, R | 5-L Head at 10 mm, L | 5-R Head at 10 mm, R | Head bottom |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 12/16/97 10:05 | 31.5 | 31.5 | 32.6 | | 31.5 | 29.6 | 30.0 | 27.3 | 24.1 | 25.0 | 23.7 | 20.8 |
| 12/16/97 10:35 | 31.5 | 31.5 | 32.1 | | 31.4 | 29.6 | 30.1 | 27.8 | 25.2 | 26.2 | 24.6 | 20.8 |
| 12/16/97 13:32 | 31.5 | 31.4 | 31.9 | | 31.4 | 29.6 | 29.8 | 27.3 | 25.0 | 24.8 | 24.7 | 20.8 |
| 12/16/97 16:35 | 31.5 | 31.4 | 31.8 | | 31.3 | 29.5 | 29.8 | 27.4 | 26.0 | 25.2 | 25.3 | 20.7 |
| 12/17/97 9:00 | 31.4 | 30.5 | 31.2 | | 30.2 | 28.6 | 28.9 | 26.8 | 25.2 | 24.4 | 24.9 | 20.8 |
| 12/17/97 16:25 | 31.5 | 31.4 | 31.8 | 31.1 | 31.3 | 29.4 | 29.8 | 27.4 | 26.3 | 25.7 | 25.6 | 20.8 |
| 12/18/97 10:05 | 31.6 | 31.4 | 31.6 | 31.2 | 31.3 | 29.5 | 29.8 | 27.9 | 26.5 | 25.9 | 26.0 | 20.8 |
| 12/19/97 8:55 | 31.5 | 31.4 | 31.7 | 31.2 | 31.3 | 29.6 | 29.8 | 27.8 | 26.0 | 25.2 | 25.9 | 20.8 |
| 12/22/97 9:40 | 31.6 | 31.4 | 31.6 | 31.3 | 31.3 | 29.7 | 30.1 | 28.3 | 26.8 | 25.7 | 26.6 | 20.6 |
| 12/24/97 10:35 | 31.7 | 31.5 | 31.6 | 31.4 | 31.5 | 30.1 | 30.5 | 28.8 | 27.7 | 26.2 | 27.5 | 20.5 |
| 12/29/97 13:45 | 31.7 | 31.6 | 31.7 | 31.6 | 31.5 | 30.8 | 30.7 | 29.4 | 27.2 | 25.3 | 27.0 | 20.4 |
| 12/30/97 15:50 | 31.6 | 31.5 | 31.6 | 31.5 | 31.5 | 30.8 | 30.5 | 29.0 | 26.8 | 24.9 | 26.5 | 20.4 |
| 12/31/97 12:31 | 31.5 | 31.5 | 31.6 | 31.5 | 31.5 | 30.7 | 30.5 | 28.8 | 26.6 | 24.5 | 26.3 | 20.4 |
| 1/5/98 15:30 | 31.5 | 31.5 | 31.6 | 31.6 | 31.5 | 30.5 | 30.2 | 28.0 | 26.1 | 24.1 | 25.9 | 20.4 |
| 1/6/98 15:21 | 31.6 | 31.5 | 31.6 | 31.6 | 31.5 | 30.4 | 30.1 | 27.9 | 26.1 | 24.0 | 25.8 | 20.4 |
| 1/7/98 13:03 | 31.5 | 31.5 | 31.6 | 31.5 | 31.5 | 30.3 | 30.0 | 27.8 | 26.0 | 24.0 | 25.7 | 20.4 |
| 1/8/98 16:23 | 31.5 | 31.5 | 31.7 | 31.5 | 31.5 | 30.2 | 30.0 | 27.7 | 26.0 | 23.8 | 25.7 | 20.4 |
| 1/9/98 14:39 | 31.6 | 31.5 | 31.7 | 31.5 | 31.5 | 30.2 | 29.9 | 27.6 | 25.9 | 23.8 | 25.6 | 20.4 |
| 1/12/98 15:12 | 31.5 | 31.5 | 31.7 | 31.5 | 31.5 | 30.1 | 29.9 | 27.5 | 25.9 | 23.8 | 25.6 | 20.4 |
| 1/13/98 16:50 | 31.5 | 31.5 | 31.7 | 31.5 | 31.5 | 30.0 | 29.8 | 27.6 | 25.8 | 23.8 | 25.6 | 20.4 |
| 1/14/98 15:27 | 31.6 | 31.5 | 31.7 | 31.5 | 31.5 | 29.9 | 29.8 | 27.6 | 25.9 | 23.8 | 25.6 | 20.6 |
| 1/15/98 15:27 | 31.6 | 31.5 | 31.7 | 31.5 | 31.5 | 29.9 | 29.8 | 27.5 | 25.9 | 23.8 | 25.6 | 20.5 |
| 1/16/98 16:59 | 31.5 | 31.5 | 31.7 | 31.5 | 31.5 | 29.8 | 29.8 | 27.6 | 25.8 | 23.7 | 25.5 | 20.4 |
| 1/20/98 15:47 | 31.5 | 31.5 | 31.7 | 31.5 | 31.5 | 29.5 | 29.7 | 27.4 | 25.8 | 23.8 | 25.5 | 20.5 |
| 1/21/98 17:00 | 31.5 | 31.5 | 31.7 | 31.5 | 31.4 | 29.3 | 29.6 | 27.3 | 25.6 | 23.7 | 25.4 | 20.4 |
| 1/23/98 15:18 | 31.5 | 31.5 | 31.7 | 31.5 | 31.4 | 29.3 | 29.6 | 27.3 | 25.7 | 23.7 | 25.4 | 20.4 |
| 1/28/98 15:06 | 31.5 | 31.5 | 31.7 | 31.4 | 31.4 | 29.3 | 29.6 | 27.4 | 25.8 | 23.8 | 25.6 | 20.4 |
| 1/29/98 15:06 | 31.5 | 31.5 | 31.7 | 31.5 | 31.4 | 29.3 | 29.6 | 27.4 | 25.9 | 23.9 | 25.7 | 20.4 |
| 1/30/98 14:16 | 31.5 | 31.5 | 31.7 | 31.5 | 31.3 | 29.3 | 29.6 | 27.4 | 25.9 | 23.9 | 25.7 | 20.4 |

Appendix C

Results of long-term gradient ratio test on Route 1A, Winterport/Frankfort, Maine Test Soil

| Time | Avg. Temp (C) | Q/time (ml/sec) | Head Top (cm) | Head Bottom (cm) | Elapsed Time (days) | Hydraulic Gradient | uncorrected k (cm/sec) | Correction | K (cm/sec) |
|---|---|---|---|---|---|---|---|---|---|
| 12/16/97 10:05 | | | 31.5 | 20.8 | 0.00 | | | | |
| 12/16/97 10:35 | 22.3 | 0.210532 | 31.5 | 20.8 | 0.02 | 1.07 | 2.43E-03 | 0.95 | 2.30E-03 |
| 12/16/97 13:32 | 22.7 | 0.256833 | 31.5 | 20.8 | 0.14 | 1.07 | 2.96E-03 | 0.94 | 2.78E-03 |
| 12/16/97 16:35 | 22.5 | 0.245083 | 31.5 | 20.7 | 0.27 | 1.08 | 2.80E-03 | 0.94 | 2.64E-03 |
| 12/17/97 9:00 | 21.0 | 0.222206 | 31.4 | 20.8 | 0.95 | 1.06 | 2.59E-03 | 0.98 | 2.53E-03 |
| 12/17/97 16:25 | 21.5 | 0.199725 | 31.5 | 20.8 | 1.26 | 1.07 | 2.30E-03 | 0.96 | 2.22E-03 |
| 12/18/97 10:05 | 20.6 | 0.224352 | 31.6 | 20.8 | 2.00 | 1.08 | 2.56E-03 | 0.99 | 2.53E-03 |
| 12/19/97 8:55 | 21.1 | 0.209400 | 31.5 | 20.8 | 2.95 | 1.07 | 2.42E-03 | 0.97 | 2.35E-03 |
| 12/22/97 9:40 | 20.8 | 0.140325 | 31.6 | 20.6 | 5.98 | 1.10 | 1.57E-03 | 0.98 | 1.54E-03 |
| 12/24/97 10:35 | 21.8 | 0.095346 | 31.7 | 20.5 | 8.02 | 1.12 | 1.05E-03 | 0.96 | 1.01E-03 |
| 12/29/97 13:45 | 21.7 | 0.026596 | 31.7 | 20.4 | 13.15 | 1.13 | 2.91E-04 | 0.96 | 2.79E-04 |
| 12/30/97 15:50 | 21.9 | 0.024124 | 31.6 | 20.4 | 14.24 | 1.12 | 2.66E-04 | 0.96 | 2.54E-04 |
| 12/31/97 12:31 | 20.9 | 0.022194 | 31.5 | 20.4 | 15.10 | 1.11 | 2.47E-04 | 0.98 | 2.42E-04 |
| 1/5/98 15:30 | 21.9 | 0.019214 | 31.5 | 20.4 | 20.23 | 1.11 | 2.14E-04 | 0.96 | 2.04E-04 |
| 1/6/98 15:21 | 22.1 | 0.018787 | 31.6 | 20.4 | 21.22 | 1.12 | 2.07E-04 | 0.95 | 1.97E-04 |
| 1/7/98 13:03 | 22.0 | 0.018550 | 31.5 | 20.4 | 22.12 | 1.11 | 2.06E-04 | 0.95 | 1.97E-04 |
| 1/8/98 16:23 | 21.6 | 0.017962 | 31.5 | 20.4 | 23.26 | 1.11 | 2.00E-04 | 0.96 | 1.92E-04 |
| 1/9/98 14:39 | 21.3 | 0.017512 | 31.6 | 20.4 | 24.19 | 1.12 | 1.93E-04 | 0.97 | 1.87E-04 |
| 1/12/98 15:12 | 20.5 | 0.016631 | 31.5 | 20.4 | 27.21 | 1.11 | 1.85E-04 | 0.99 | 1.83E-04 |
| 1/13/98 16:50 | 21.7 | 0.017032 | 31.5 | 20.4 | 28.28 | 1.11 | 1.89E-04 | 0.96 | 1.82E-04 |
| 1/14/98 15:27 | 19.8 | 0.016281 | 31.6 | 20.6 | 29.22 | 1.10 | 1.83E-04 | 1.01 | 1.84E-04 |
| 1/15/98 15:27 | 20.3 | 0.016171 | 31.6 | 20.5 | 30.22 | 1.11 | 1.80E-04 | 0.99 | 1.79E-04 |
| 1/16/98 16:59 | 20.5 | 0.016493 | 31.5 | 20.4 | 31.29 | 1.11 | 1.83E-04 | 0.99 | 1.81E-04 |
| 1/20/98 15:47 | 21.2 | 0.016687 | 31.5 | 20.5 | 35.24 | 1.10 | 1.87E-04 | 0.97 | 1.82E-04 |
| 1/21/98 17:00 | 20.6 | 0.015963 | 31.5 | 20.4 | 36.29 | 1.11 | 1.78E-04 | 0.99 | 1.75E-04 |
| 1/23/98 15:18 | 20.2 | 0.015789 | 31.5 | 20.4 | 38.22 | 1.11 | 1.76E-04 | 1.00 | 1.75E-04 |
| 1/28/98 15:06 | 20.2 | 0.015531 | 31.5 | 20.4 | 43.21 | 1.11 | 1.73E-04 | 1.00 | 1.72E-04 |
| 1/29/98 15:06 | 20.3 | 0.014916 | 31.5 | 20.4 | 44.21 | 1.11 | 1.66E-04 | 0.99 | 1.65E-04 |
| 1/30/98 14:16 | 20.4 | 0.015191 | 31.5 | 20.4 | 45.17 | 1.11 | 1.69E-04 | 0.99 | 1.68E-04 |

Results of long-term gradient ratio test on
Route 1A, Winterport/Frankfort, Maine Test Soil

| Time | Elapsed time (days) | In soil gradient 75 to 25 mm | Bottom 25 mm | Gradient Ratio |
|---|---|---|---|---|
| 12/16/97 10:05 | 0.00 | | | |
| 12/16/97 10:35 | 0.02 | 0.98 | 2.28 | 2.33 |
| 12/16/97 13:32 | 0.14 | 1.05 | 2.14 | 2.04 |
| 12/16/97 16:35 | 0.27 | 0.92 | 2.40 | 2.61 |
| 12/17/97 9:00 | 0.95 | 0.84 | 2.08 | 2.48 |
| 12/17/97 16:25 | 1.26 | 0.87 | 2.42 | 2.78 |
| 12/18/97 10:05 | 2.00 | 0.81 | 2.56 | 3.16 |
| 12/19/97 8:55 | 2.95 | 0.87 | 2.44 | 2.80 |
| 12/22/97 9:40 | 5.98 | 0.75 | 2.78 | 3.71 |
| 12/24/97 10:35 | 8.02 | 0.64 | 3.10 | 4.84 |
| 12/29/97 13:45 | 13.15 | 0.65 | 3.16 | 4.86 |
| 12/30/97 15:50 | 14.24 | 0.72 | 3.00 | 4.17 |
| 12/31/97 12:31 | 15.10 | 0.76 | 2.92 | 3.84 |
| 1/5/98 15:30 | 20.23 | 0.90 | 2.66 | 2.96 |
| 1/6/98 15:21 | 21.22 | 0.91 | 2.64 | 2.90 |
| 1/7/98 13:03 | 22.12 | 0.92 | 2.60 | 2.83 |
| 1/8/98 16:23 | 23.26 | 0.93 | 2.58 | 2.77 |
| 1/9/98 14:39 | 24.19 | 0.95 | 2.54 | 2.67 |
| 1/12/98 15:12 | 27.21 | 0.96 | 2.52 | 2.63 |
| 1/13/98 16:50 | 28.28 | 0.96 | 2.52 | 2.63 |
| 1/14/98 15:27 | 29.22 | 0.95 | 2.46 | 2.59 |
| 1/15/98 15:27 | 30.22 | 0.96 | 2.48 | 2.58 |
| 1/16/98 16:59 | 31.29 | 0.96 | 2.52 | 2.63 |
| 1/20/98 15:47 | 35.24 | 0.98 | 2.44 | 2.49 |
| 1/21/98 17:00 | 36.29 | 1.00 | 2.42 | 2.42 |
| 1/23/98 15:18 | 38.22 | 0.99 | 2.44 | 2.46 |
| 1/28/98 15:06 | 43.21 | 0.96 | 2.48 | 2.58 |
| 1/29/98 15:06 | 44.21 | 0.96 | 2.50 | 2.60 |
| 1/30/98 14:16 | 45.17 | 0.95 | 2.50 | 2.63 |