

March 15, 2007

Mr. Mike O'Neal
Brown & Caldwell
One Convention Place
701 Pike Street, Suite 1200
Seattle, WA 98101

**RE: BIORETENTION SPECIFICATION DEVELOPMENT,
SEATTLE PUBLIC UTILITIES**

Dear Mr. O'Neal:

This letter represents our findings regarding developing a playfield bioretention soil specification for Seattle Public Utilities (SPU). Our study included reviewing our laboratory testing data from previous projects involving aggregate-compost mixtures and material supplier gradation data (supplied by SPU); laboratory testing of selected aggregate-compost mixtures; and developing of a draft Playfield Bioretention Soil Mix standard specification. The draft specification is intended to specify a bioretention soil that can be manufactured using readily available compost and mineral aggregate materials. The bioretention soil should have a permeability (hydraulic conductivity) of 1 to 10 inches per hour when compacted a relative compaction of between 85 and 90 percent of the modified maximum dry density (American Society for Testing and Materials [ASTM] D1557).

BIORETENTION SOIL DATA REVIEW

We reviewed the laboratory permeability performance characteristics of several compost-amended soil mixes used in past projects. Most of the data we reviewed for this specification development was generated from laboratory tests requested by SPU and from the High Point redevelopment project.

During our data review, we identified four geotechnical laboratory tests that should be performed to develop a bioretention soil dataset:

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- ▶ Grain size analysis of the mineral aggregate.
- ▶ Organic content of the soil mix. The organic content should include a visual estimate of the organic fraction by volume and a measurement of the organic fraction by weight (ASTM D 2974). For all of the projects we reviewed, the organic fraction was compost.
- ▶ Modified Proctor compaction test of the aggregate-compost mixture (ASTM D 1557).
- ▶ Permeability tests of the aggregate-compost mixture (ASTM D 2434). Tests should be performed on samples of known unit weight to relate the sample permeability to relative compaction.

We identified three previous testing programs where the above test data were available. We identified an additional project where grain size analyses were not done, but we could approximate the grain size distribution based on sample descriptions.

During the course of this project, we were retained by Washington State University (WSU) to perform bioretention testing on four sand-compost soil mixtures. Not all testing is complete at the time of this letter report, but we have incorporated available WSU data into our review.

A summary of test results we reviewed is presented in Table 1. Grain size distribution curves for previously tested bioretention soils and for the WSU samples are plotted in Figure 1.

MINERAL AGGREGATE DATA REVIEW

Based on our review of previous bioretention soil studies and a review of readily available mineral aggregate specifications, we identified City of Seattle (COS) Type 17 and Type 26 materials as potential bioretention soil mineral aggregate components. We solicited and reviewed grain size distribution data from eight construction aggregate suppliers in Snohomish and King Counties. We concluded that COS Type 17 materials have grain size distributions, which could provide the desired permeability properties when mixed with compost and compacted. Chris Robertson and Chad McMullen (Shannon & Wilson) presented our findings of this data review to Jeff Fowler (SPU) in mid-November 2007.

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GEOTECHNICAL LABORATORY TESTING

We selected Type 17 material for testing from four suppliers: Cadman, Glacier, Icon, and Miles. SPU collected samples, which we picked up from the SPU Materials Testing Laboratory.

Our laboratory testing included:

- ▶ Laboratory Compaction Characteristics of Soil Using Modified Effort (ASTM D 1557)
- ▶ Moisture, Ash, and Organic Matter of Peat and Other Organic Soils (ASTM D 2974)
- ▶ Particle Size Analysis of Soils (ASTM D 422)
- ▶ Permeability of Granular Soils (Constant Head) (ASTM D 2434)

The following paragraphs describe our testing procedures and discuss the results.

Grain Size Analyses and Bioretention Sample Preparation

We performed a grain size analysis on each of the four aggregate samples in accordance with ASTM D 422. Results of these tests are presented in Figure 2. As shown in Figure 2, the aggregate sample provided by Icon had more than 30 percent of its mass retained on a ¾-inch sieve. Standard ASTM procedures for compaction and permeability testing use only material passing the ¾-inch sieve. Because we did not have sufficient sample passing the ¾-inch sieve, we dismissed this sample from further testing. In making this decision, we considered that a soil with more than 30 percent by mass larger than ¾ inch might not be suitable for a playfield soil.

Prior to the addition of compost, we removed the ¾-inch retained fraction from the Cadman, Glacier, and Miles samples. We then loosely placed each sample into 5-gallon buckets to a measured depth. We lightly hand tamped Whitney Farms Planting compost in several layers until we reached a volumetric compost ratio of 30 percent. That is, the volume of the compost was 30 percent of the total aggregate-compost mixture volume.

Compaction Testing

We performed compaction tests on the aggregate-compost mixtures in accordance with ASTM D 1557. The compaction results do not provide smooth curves relating dry unit weight to as-compacted moisture content, which normally occurs with mineral aggregate soil. We have

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experienced similar difficulties developing compaction data previously with organic-rich specimens. We believe variations in compost content affect the amount of moisture available to the aggregate component during compaction. Figure 3 presents the compaction test results and our estimates of maximum dry density and optimum water content for the three mineral aggregate-compost mixtures.

Organic Content

We performed organic content determinations in accordance with ASTM D 2974. We measured organic contents by mass ranging from 3.7 to 5.2 percent. These tests were made using representative samples taken from compaction moisture specimens. These data are presented in Table 1.

Permeability Testing

We tested the permeability of the Cadman and Glacier aggregate-compost mixtures at 85 and 90 percent of the maximum dry densities achieved during compaction testing. Because of limited sample size, we tested the Miles aggregate-compost mixture at 90 percent only. We performed constant head permeability testing in general accordance with ASTM D 2434 using a 6-inch mold and vacuum saturation. Figures 4 through 8 present descriptions and permeability performance of the specimens. Permeability data for these tests and for our review of previous data are presented in Table 1. Plots of permeability versus relative compaction for select data from Table 1 are presented in Figure 9.

OBSERVATIONS AND RECOMMENDATIONS

Based on our data review and the aggregate-compost mixture lab testing results, we make the following observations and recommendations:

- ▶ Except for two samples tested previously, all samples had less than 5 percent fines. The two samples with 31 to 38 percent fines yielded permeabilities of approximately two orders of magnitude lower than the desired 1 to 10 inches/hour.
- ▶ The Vancouver mix tested for SPU in 2004 had a widely ranging permeability, which depended upon the relative compaction. The aggregate portion of the Vancouver mix

included a more uniformly graded sand fraction than the sand fractions of most other samples.

- ▶ Because of the difficulty in establishing the moisture-density relationships of bioretention soil, we recommend the specification include a requirement that contractor submittals include moisture-density relationships (compaction tests) using a minimum of six specimens.
- ▶ We understand that large gravel in the mineral aggregate fraction of a bioretention soil may not be desirable for plant growth or for a smooth surface for foot traffic. Therefore, we recommend that the maximum nominal particle diameter be limited to 1½ inches. In our opinion, this restriction should not substantially reduce the number of aggregate suppliers already selling Type 17 or other products that may satisfy the mineral aggregate requirements. We present our proposed gradation in Figure 10, which also includes a summary of grain size distributions included in our bioretention soil dataset.
- ▶ We recommend compacting the bioretention soil to 85 to 90 percent of the maximum dry density (ASTM D1557). This level of relative compaction of aggregate-compost mixtures should result in laboratory permeability values similar to what we have presented in Figure 9.
- ▶ We recommend that SPU maintain a bioretention soil database using contractor-performed test data provided in submittals. Submittal data should be supplemented with laboratory permeability tests on selected aggregate-compost mixes. This would expand the bioretention soil dataset and allow for meaningful revision and refinement of the bioretention soil mix specification.
- ▶ We recognize that field infiltration rates will differ from permeability rates measured in the laboratory. While laboratory permeability test results may be regarded as a relative indicator of overall drainage performance of a particular aggregate-compost mix, other factors encountered during construction may have significant influences on as-constructed and long-term infiltration rates.

We thank you for this opportunity to develop a draft bioretention soils specification. Please call us if you have questions regarding these recommendations. We look forward to scheduling a

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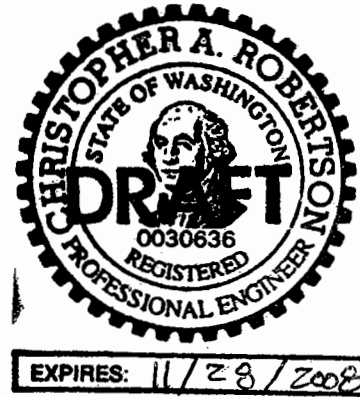
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meeting with you and other stakeholders after all parties have had an opportunity to review this report and the enclosed draft specification.

Sincerely,

SHANNON & WILSON, INC.

Chad McMullen
Staff Engineer



Christopher A. Robertson, P.E., L.E.G.
Vice President

CTM:CAR/ctm

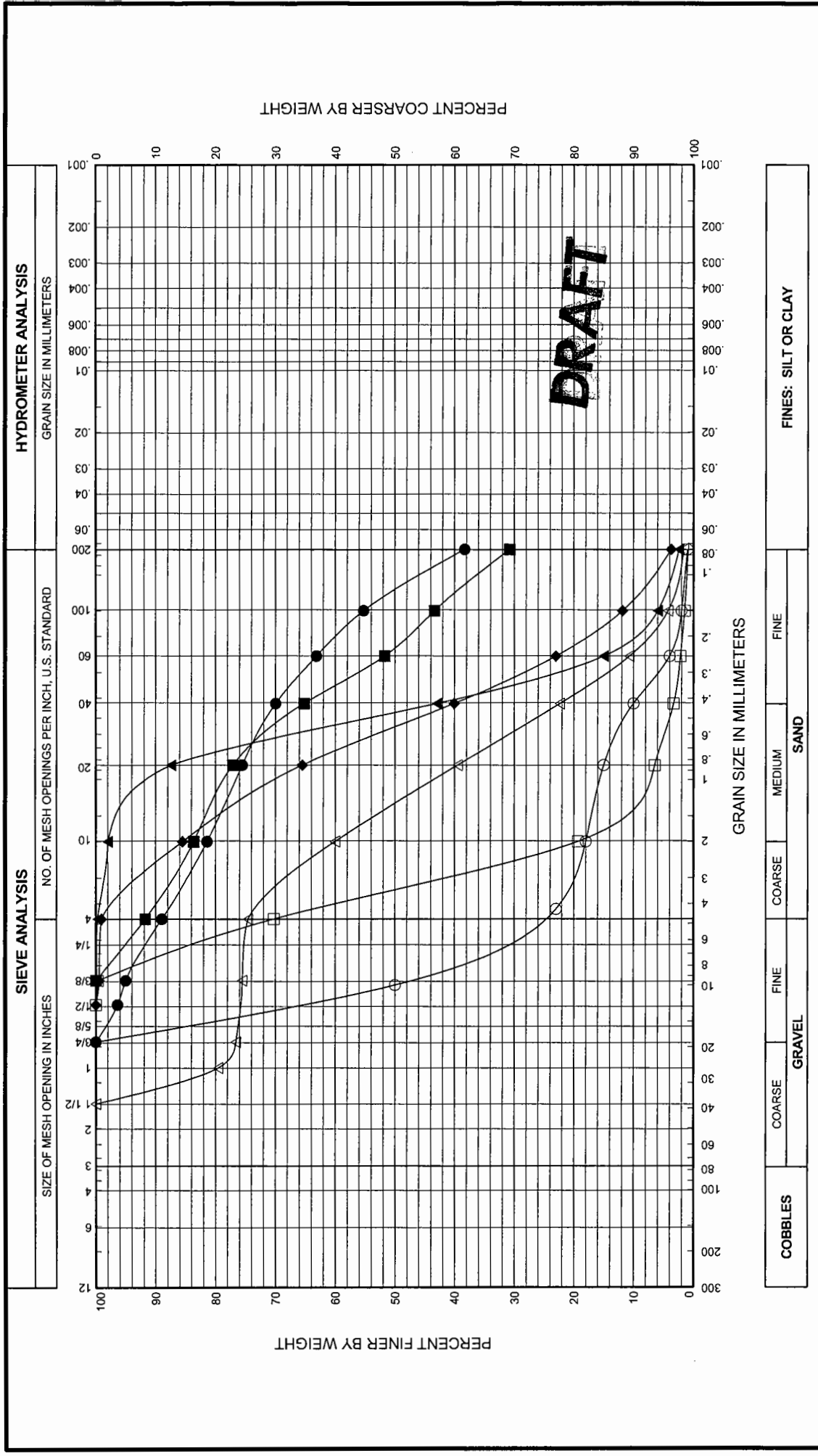
Enclosures: Table 1 – Bioretention Soil Data Summary
Figure 1 – Grain Size Distribution, Mineral Aggregates, November 2002 through February 2007
Figure 2 – Grain Size Distribution, Mineral Aggregates, March 2007
Figure 3 – Moisture-Density Tests, Cadman, Glacier Miles
Figure 4 – Permeability Summary and Plots, Cadman 85% R.C. (2 pages)
Figure 5 – Permeability Summary and Plots, Cadman 90% R.C. (2 pages)
Figure 6 – Permeability Summary and Plots, Glacier 85% R.C. (2 pages)
Figure 7 – Permeability Summary and Plots, Glacier 90% R.C. (2 pages)
Figure 8 – Permeability Summary and Plots, Miles 90% R.C. (2 pages)
Figure 9 – Permeability versus Relative Compaction
Figure 10 – Grain Size Distribution, Proposed Specification
Draft Bioretention Soil Specification

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**TABLE 1
BIORETENTION SOIL DATA SUMMARY**

Report Reference	Project Reference	Sample ID	Organic Content (%)	Percent Compost (volume)	Percent Aggregate (volume)	Figure No.	Grain Size Summary					Relative Compaction	Average Permeability (in/hour)	Results Presented in Figure 9										
							d10 (mm)	d60 (mm)	d90 (mm)	Coefficient of Uniformity Cu	% Fines													
January 06	SPU Testing	70/30		30	70	--	Dark brown, slightly silty SAND, trace of fine gravel, numerous organics (SP-SM)					80	13	Y										
January 06	SPU Testing	65/35		35	65	--						Dark brown, slightly silty SAND, trace of fine gravel, numerous organics (SP-SM)					80	9.3	Y					
January 06	SPU Testing	65/35		35	65	--											Dark brown, slightly silty SAND, trace of fine gravel, numerous organics (SP-SM)					85	4.2	Y
January 06	SPU Testing	70/30		30	70	--																Dark brown, slightly silty SAND, trace of fine gravel, numerous organics (SP-SM)		
January 04	High Point	Vancouver Mix	5.2	20	80	1	0.425	11	17	25.9	1													
January 04	High Point	Vancouver Mix	5.2	20	80	1	0.425	11	17	25.9	1	88	7	N										
January 04	High Point	Vancouver Mix	5.2	20	80	1	0.425	11	17	25.9	1	88	26	N										
January 04	High Point	Vancouver Mix	5.2	20	80	1	0.425	11	17	25.9	1	88	9	N										
January 04	High Point	Vancouver Mix	5.2	20	80	1	0.425	11	17	25.9	1	89	60	N										
January 04	High Point	Vancouver Mix	5.2	20	80	1	0.425	11	17	25.9	1	91	143	N										
January 04	High Point	Vancouver Mix	5.2	20	80	1	0.425	11	17	25.9	1	94	1.2	N										
January 04	High Point	Vancouver Mix	5.2	20	80	1	0.425	11	17	25.9	1	99	0.1	N										
August 06	SPU Testing	Test Pit 4		30	70	1	<0.075	0.35	4		30.7	84.5	0.04	N										
August 06	SPU Testing	Test Pit 2		30	70	1	<0.075	0.2	5		38.3	84.5	0.03	N										
November 02	High Point	Birdseye/granulithic		20	80	1	1.4	4	7	2.9	0.9	85	1.9	Y										
November 02	High Point	Birdseye/granulithic		40	60	1	1.4	4	7	2.9	0.9	85	6.4	Y										
November 02	High Point	Type 17 & Compost		30	70	1	0.24	2	32	8.3	1.6	79.1	4	Y										
November 02	High Point	Type 17 & Compost		30	70	1	0.24	2	32	8.3	1.6	85.6	1.5	Y										
November 02	High Point	Type 17 & Compost		30	70	1	0.24	2	32	8.3	1.6	90	0.9	Y										
February 07	WSU Testing	Green Earth Screen Sand	9.6	40	60	1	0.21	0.55	1	2.6	2.4	85	20	Y										
February 07	WSU Testing	Miles Utility Sand	8.9	40	60	1	0.14	0.7	2.3	5.0	3.7	85	5	Y										
March 07	SPU Testing	Glacier T-17	3.7	30	70	2	0.25	2.3	20	9.2	5.1	85	40	Y										
March 07	SPU Testing	Cadman T-17	4.0	30	70	2	0.17	3.2	25	18.8	3.2	85	13	Y										
March 07	SPU Testing	Glacier T-17	3.7	30	70	2	0.25	2.3	20	9.2	5.1	90	4.5	Y										
March 07	SPU Testing	Cadman T-17	4.0	30	70	2	0.17	3.2	25	18.8	3.2	90	6	Y										
March 07	SPU Testing	Miles T-17	5.2	30	70	2	0.22	4.2	29	19.1	3.5	90	3.4	Y										

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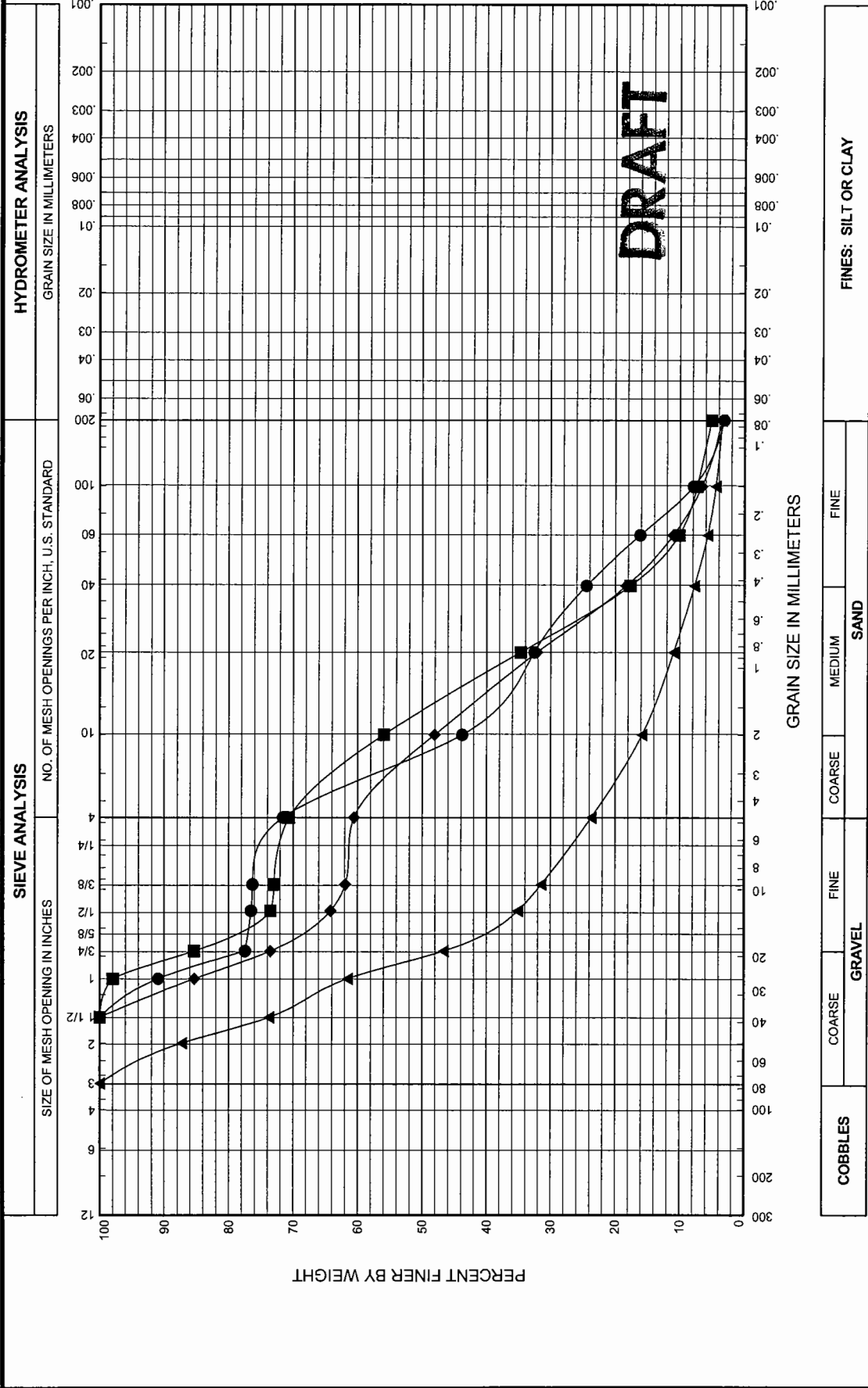


BORING AND SAMPLE NO.	U.S.S. SYMBOL	SAMPLE DESCRIPTION	FINES %	NAT. W.C. %	LL %	PL %	PI %
● August 06 Test Pit-2	SM	Light Brown, slightly fine gravelly, silty SAND, scattered fine organics	38.3				
■ August 06 Test Pit-4	SM	Light Brown, fine gravelly, silty SAND, scattered fine organics,	30.7				
▲ February 07 Green Earth	SP	Gray, fine to medium SAND, trace of silt and gravel	2.4				
◆ February 07 Miles Utility Sand	SP	Gray SAND, trace of silt and gravel	3.7				
○ January 04 Vancouver Mix	GP	Sandy GRAVEL, trace of silt	1.0				
□ November 02 Birdseye/Granulitic	SP	Brown-gray, gravelly, medium to coarse SAND, trace of silt	0.9				
△ November 02 T-17 & Compos	SP	Brown, coarse gravelly SAND, trace of silt	1.6				

Seattle Public Utilities -- Playfield Bioretention Soil Draft Specification Seattle, Washington
GRAIN SIZE DISTRIBUTION MINERAL AGGREGATES -- NOVEMBER 2002 THROUGH FEBRUARY 2007 March 2007
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FIG. 1

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FIG. 1



BORING AND SAMPLE NO.	U.S.C.S. SYMBOL	SAMPLE DESCRIPTION	GRAVEL		SAND			FINES: SILT OR CLAY		
			COARSE	FINE	COARSE	MEDIUM	FINE	LL %	PL %	PI %
● March 07 Cadman Type 17	SP	Brown, gravelly SAND, trace of silt	3.2	4.3	3.2	4.3	3.2	4.3	3.2	4.3
■ March 07 Glacier Type 17	SP-SM	Brown, slightly silty, gravelly SAND	5.1	5.9	5.1	5.9	5.1	5.9	5.1	5.9
▲ March 07 Icon Type 17	GP	Gray, sandy GRAVEL, trace of silt	3.5	3.2	3.5	3.2	3.5	3.2	3.5	3.2
◆ March 07 Miles Type 17	SP	Gray, gravelly SAND, trace of silt	3.5	5.5	3.5	5.5	3.5	5.5	3.5	5.5

Seattle Public Utilities -- Playfield Bioretention
Soil Draft Specification
Seattle, Washington

GRAIN SIZE DISTRIBUTION
MINERAL AGGREGATES -- MARCH 2007

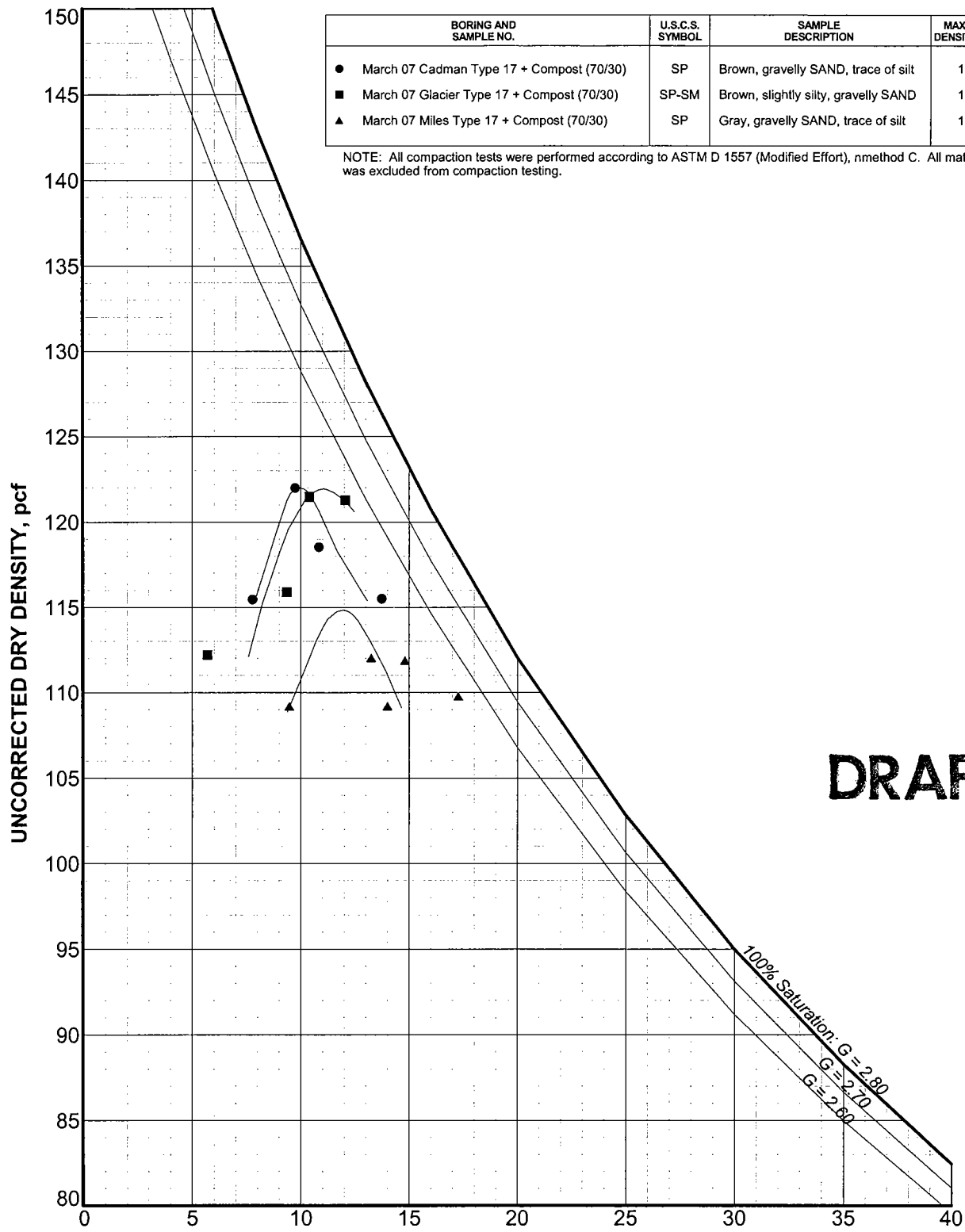
March 2007 21-1-08824-024

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FIG. 2

FIG. 2



BORING AND SAMPLE NO.	U.S.C.S. SYMBOL	SAMPLE DESCRIPTION	MAX. DRY DENSITY (pcf)	OPT. W.C. %
● March 07 Cadman Type 17 + Compost (70/30)	SP	Brown, gravelly SAND, trace of silt	122	10
■ March 07 Glacier Type 17 + Compost (70/30)	SP-SM	Brown, slightly silty, gravelly SAND	122	11
▲ March 07 Miles Type 17 + Compost (70/30)	SP	Gray, gravelly SAND, trace of silt	115	12

NOTE: All compaction tests were performed according to ASTM D 1557 (Modified Effort), method C. All material retained on a 3/4-inch sieve was excluded from compaction testing.

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Seattle Public Utilities -- Playfield Bioretention
Soil Draft Specification
Seattle, Washington

**MOISTURE-DENSITY TESTS
CADMAN, GLACIER, MILES**

March 2007

21-1-08824-024

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FIG. 3

PERMEABILITY TEST ON GRANULAR SOIL
CONSTANT HEAD
 ASTM D 2434

Specimen Data

Height (cm)	11.44
Diameter (cm)	15.16
Area (cm ²)	180.39
Volume (cm ³)	2063.58

Sample Classification

Brown, gravelly SAND, trace of silt; mixed with compost (30% by volume) after oversize particles sieved out to meet size reqs

Permeameter Dimensions

I.D. of Reservoir (cm)	15.16
O.D. of Tube (cm)	1.91
Area (cm ²)	177.54
Sample Length (cm)	11.44

Remarks

85% Compaction

Moisture Content

	Before	After
Wet + tare (g)	110.00	
Dry + tare (g)	100.00	
Tare (g)	0	
mc (%)	10.0%	

Density Determination

Initial Wet Weight (g)	3779
Final Wet Weight (g)	0
Est. Specific Gravity	2.7
Dry Unit Weight, γ_d (pcf)	103.9
Compacted Unit Weight, γ_m (pcf)	114.3
Saturated Unit Weight, γ_{sat} (pcf)	0.0
Maximum Dry Density, γ_{max} (pcf)	122 (estimated)
Relative Compaction (%)	85.2 (estimated)
Temperature (°C)	21

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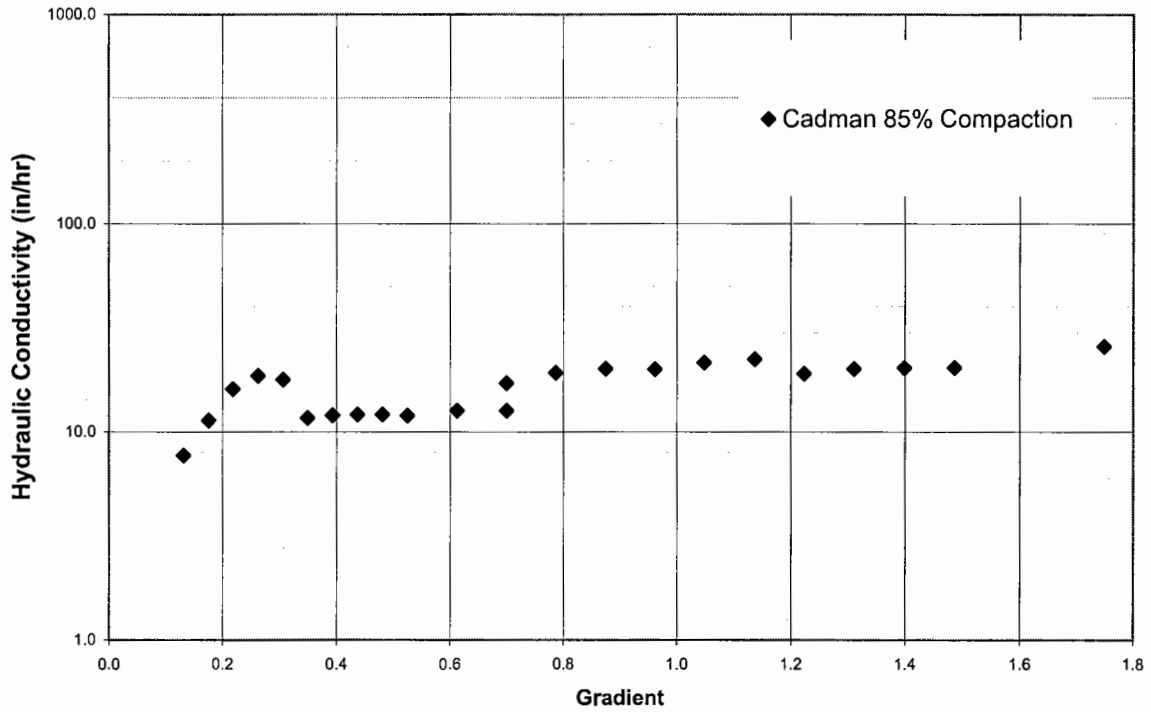
Test No.	Reservoir Level		Δh (cm)	H (cm)	t (s)	Q (cm ³)	l	Q/at	k (in/hr)
	h_1 (cm)	h_2 (cm)							
1	53.2	51.0	2.2	1.5	3090	396.9	0.13	7.1E-04	7.70E+00
2	51.0	46.8	4.2	2.0	3000	757.7	0.17	1.4E-03	1.13E+01
3	46.7	39.3	7.4	2.5	3000	1334.9	0.22	2.5E-03	1.60E+01
4	39.2	32.2	7.0	3.0	2040	1262.8	0.26	3.4E-03	1.85E+01
5	29.8	22.4	7.4	3.5	1920	1334.9	0.31	3.9E-03	1.79E+01
6	53.6	48.4	5.2	4.0	1800	938.0	0.35	2.9E-03	1.17E+01
7	48.3	44.3	4.0	4.5	1200	721.6	0.39	3.3E-03	1.20E+01
8	44.2	38.6	5.6	5.0	1500	1010.2	0.44	3.7E-03	1.21E+01
9	38.4	34.7	3.7	5.5	900	667.5	0.48	4.1E-03	1.21E+01
10	34.5	32.1	2.4	6.0	540	432.9	0.52	4.4E-03	1.20E+01
11	31.9	27.0	4.9	7.0	900	883.9	0.61	5.4E-03	1.26E+01
12	26.8	21.2	5.6	8.0	900	1010.2	0.70	6.2E-03	1.26E+01
13	54.4	45.3	9.1	8.0	1080	1641.6	0.70	8.4E-03	1.71E+01
14	44.9	38.5	6.4	9.0	600	1154.5	0.79	1.1E-02	1.92E+01
15	38.5	14.4	24.1	10.0	1950	4347.5	0.87	1.2E-02	2.00E+01
16	54.2	47.7	6.5	11.0	480	1172.6	0.96	1.4E-02	2.00E+01
17	47.1	38.5	8.6	12.0	540	1551.4	1.05	1.6E-02	2.15E+01
18	38.4	24.5	13.9	13.0	780	2507.5	1.14	1.8E-02	2.22E+01
19	52.8	41.0	11.8	14.0	720	2128.6	1.22	1.6E-02	1.90E+01
20	40.7	32.9	7.8	15.0	420	1407.1	1.31	1.9E-02	2.01E+01
21	32.0	26.0	6.0	16.0	300	1082.4	1.40	2.0E-02	2.03E+01
22	25.5	19.1	6.4	17.0	300	1154.5	1.49	2.1E-02	2.03E+01
23	25.3	19.6	5.7	20.0	180	1028.2	1.75	3.2E-02	2.57E+01
Average k									1.50E+01

Note:

h_1 is the initial reservoir water level.
 h_2 is the final reservoir water level.
 Δh is the change in reservoir water level during the test.
 H is the head difference across the specimen.
 t is the elapse time for changing water level.

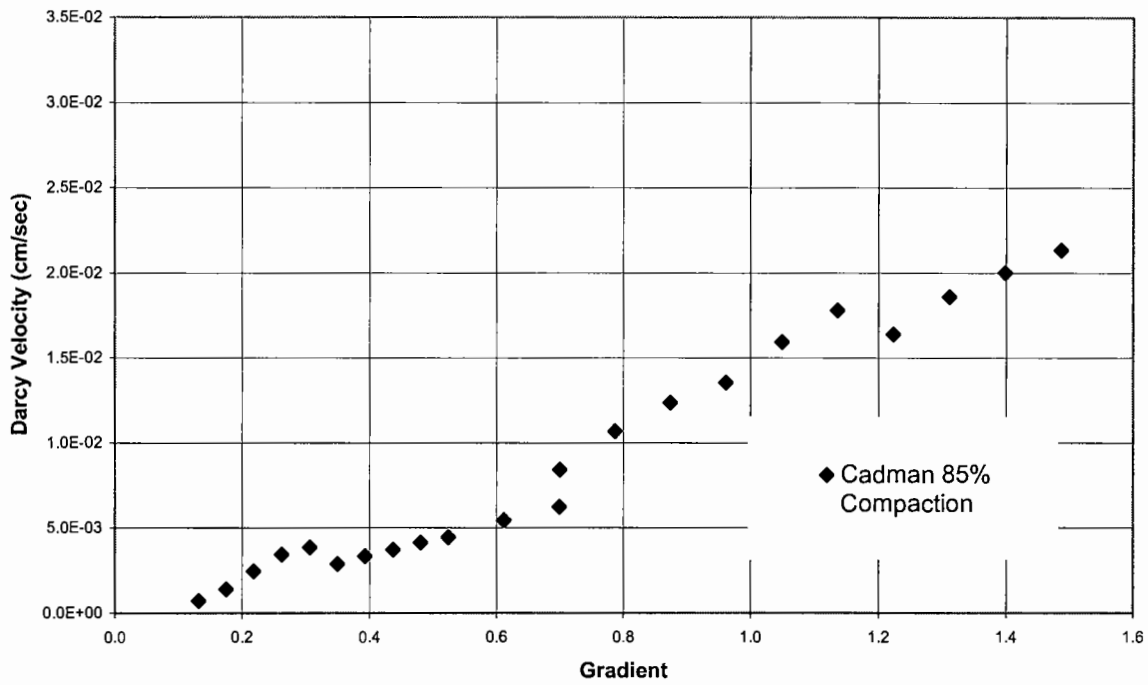
Q is the volume of water discharged.
 l is the hydraulic gradient.
 a is the cross-section area of the specimen.
 k is the hydraulic conductivity of the specimen.

Hydraulic Conductivity vs. Gradient



Darcy Velocity vs. Gradient

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PERMEABILITY TEST ON GRANULAR SOIL
CONSTANT HEAD
 ASTM D 2434

Specimen Data

Height (cm)	<u>11.44</u>
Diameter (cm)	<u>15.16</u>
Area (cm ²)	<u>180.39</u>
Volume (cm ³)	<u>2063.58</u>

Sample Classification

Brown, gravelly SAND, trace of silt; mixed with
compost (30% by volume) after oversize
particles sieved out to meet size reqs

Permeameter Dimensions

I.D. of Reservoir (cm)	<u>15.16</u>
O.D. of Tube (cm)	<u>1.91</u>
Area (cm ²)	<u>177.54</u>
Sample Length (cm)	<u>11.44</u>

Remarks

90% Compaction

Moisture Content

	Before	After
Wet + tare (g)	<u>110.00</u>	
Dry + tare (g)	<u>100.00</u>	
Tare (g)	<u>0</u>	
mc (%)	<u>10.0%</u>	

Density Determination

Initial Wet Weight (g)	<u>4000</u>
Final Wet Weight (g)	<u>0</u>
Est. Specific Gravity	<u>2.7</u>
Dry Unit Weight, γ_d (pcf)	<u>110.0</u>
Compacted Unit Weight, γ_m (pcf)	<u>121.0</u>
Saturated Unit Weight, γ_{sat} (pcf)	<u>0.0</u>
Maximum Dry Density, γ_{max} (pcf)	<u>122</u> (estimated)
Relative Compaction (%)	<u>90.2</u> (estimated)
Temperature (°C)	<u>21</u>

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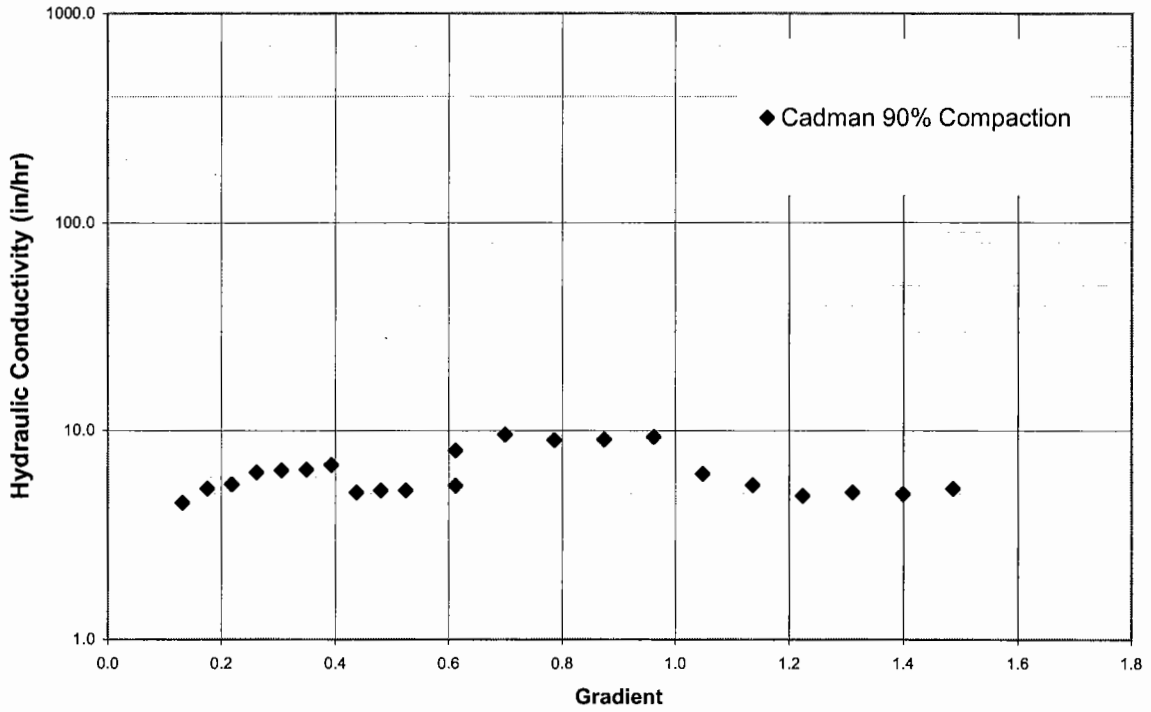
Test No.	Reservoir Level		Δh (cm)	H (cm)	t (s)	Q (cm ³)	l	Q/at	k (in/hr)
	h_1 (cm)	h_2 (cm)							
1	54.8	51.2	3.6	1.5	8640	649.4	0.13	4.2E-04	4.50E+00
2	51.2	48.4	2.8	2.0	4320	505.1	0.17	6.5E-04	5.25E+00
3	48.3	43.4	4.9	2.5	5760	883.9	0.22	8.5E-04	5.52E+00
4	43.4	39.4	4.0	3.0	3420	721.6	0.26	1.2E-03	6.32E+00
5	39.3	34.8	4.5	3.5	3240	811.8	0.31	1.4E-03	6.43E+00
6	34.8	29.5	5.3	4.0	3300	956.1	0.35	1.6E-03	6.51E+00
7	29.4	20.3	9.1	4.5	4800	1641.6	0.39	1.9E-03	6.83E+00
8	53.7	46.2	7.5	5.0	4800	1353.0	0.44	1.6E-03	5.07E+00
9	46.2	42.0	4.2	5.5	2400	757.7	0.48	1.8E-03	5.16E+00
10	41.9	35.0	6.9	6.0	3600	1244.7	0.52	1.9E-03	5.18E+00
11	34.5	29.0	5.5	7.0	2340	992.2	0.61	2.4E-03	5.44E+00
12	27.2	22.2	5.0	7.0	1440	902.0	0.61	3.5E-03	8.04E+00
13	55.2	53.5	1.7	8.0	360	306.7	0.70	4.7E-03	9.57E+00
14	49.6	46.6	3.0	9.0	600	541.2	0.79	5.0E-03	9.01E+00
15	46.2	41.5	4.7	10.0	840	847.8	0.87	5.6E-03	9.07E+00
16	41.2	37.4	3.8	11.0	600	685.5	0.96	6.3E-03	9.33E+00
17	53.8	48.3	5.5	12.0	1200	992.2	1.05	4.6E-03	6.19E+00
18	48.1	46.0	2.1	13.0	480	378.8	1.14	4.4E-03	5.46E+00
19	44.6	38.8	5.8	14.0	1380	1046.3	1.22	4.2E-03	4.87E+00
20	38.5	34.0	4.5	15.0	960	811.8	1.31	4.7E-03	5.07E+00
21	33.6	28.6	5.0	16.0	1020	902.0	1.40	4.9E-03	4.97E+00
22	28.7	13.4	15.3	17.0	2760	2760.0	1.49	5.5E-03	5.29E+00
23									
Average k									6.67E+00

Note:

h_1 is the initial reservoir water level.
 h_2 is the final reservoir water level.
 Δh is the change in reservoir water level during the test.
 H is the head difference across the specimen.
 t is the elapse time for changing water level.

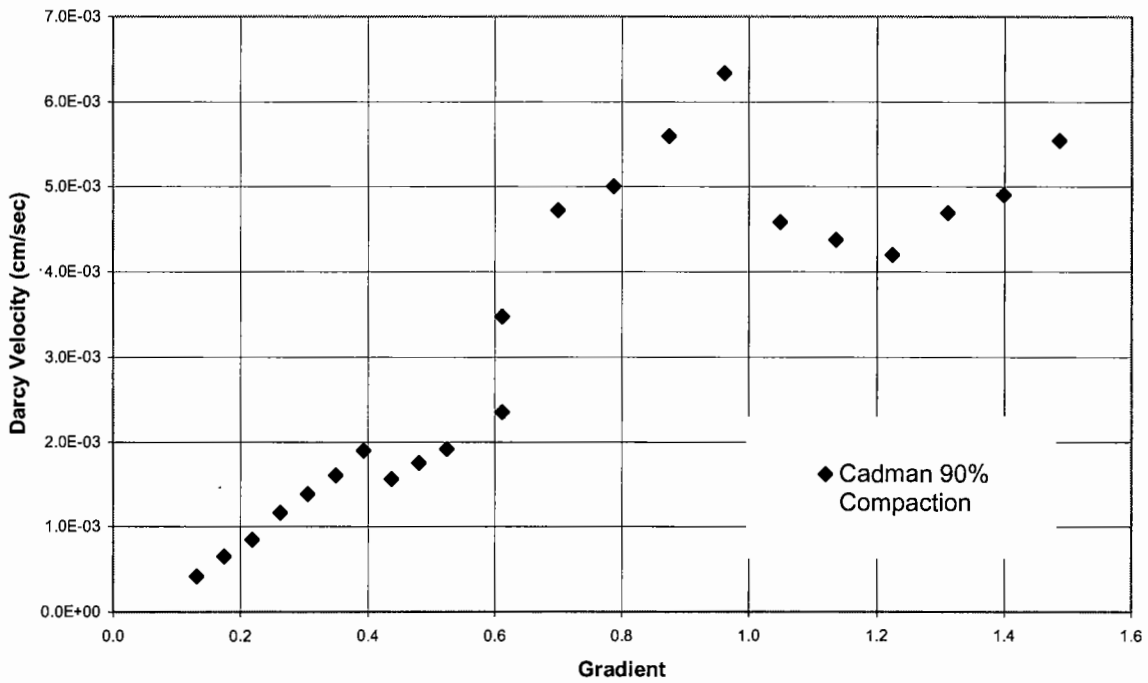
Q is the volume of water discharged.
 l is the hydraulic gradient.
 a is the cross-section area of the specimen.
 k is the hydraulic conductivity of the specimen.

Hydraulic Conductivity vs. Gradient



Darcy Velocity vs. Gradient

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**PERMEABILITY TEST ON GRANULAR SOIL
 CONSTANT HEAD
 ASTM D 2434**

Specimen Data

Height (cm)	11.44
Diameter (cm)	15.16
Area (cm ²)	180.39
Volume (cm ³)	2063.58

Sample Classification

Brown, slightly silty, gravelly SAND; mixed with
 compost (30% by volume) after oversize
 particles sieved out to meet size reqs

Permeameter Dimensions

I.D. of Reservoir (cm)	15.16
O.D. of Tube (cm)	1.91
Area (cm ²)	177.54
Sample Length (cm)	11.44

Remarks

85% Compaction

Moisture Content

	Before	After
Wet + tare (g)	600.00	
Dry + tare (g)	546.00	
Tare (g)	102.32	
mc (%)	12.2%	

Density Determination

Initial Wet Weight (g)	3860
Final Wet Weight (g)	0
Est. Specific Gravity	2.7
Dry Unit Weight, γ_d (pcf)	104.1
Compacted Unit Weight, γ_m (pcf)	116.8
Saturated Unit Weight, γ_{sat} (pcf)	0.0
Maximum Dry Density, γ_{max} (pcf)	123 (estimated)
Relative Compaction (%)	85.0 (estimated)
Temperature (°C)	20.9

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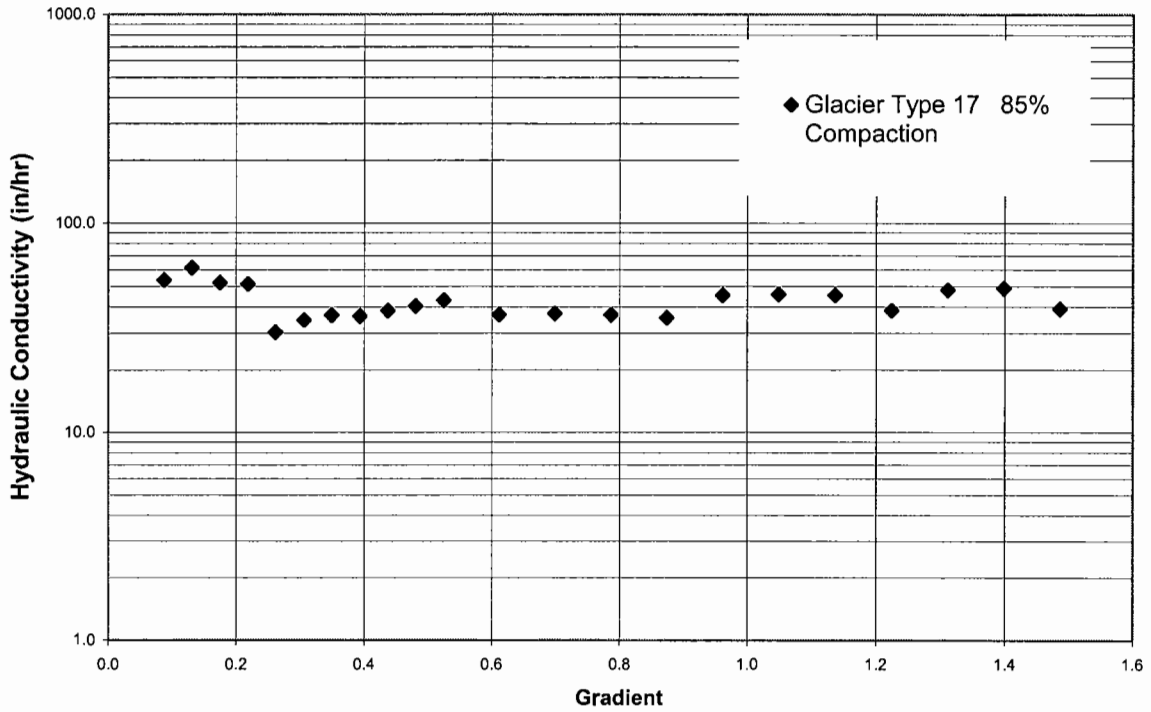
Test No.	Reservoir Level		Δh (cm)	H (cm)	t (s)	Q (cm ³)	l	Q/at	k (in/hr)
	h_1 (cm)	h_2 (cm)							
1	54.5	41.8	12.7	1.0	3840	2291.0	0.09	3.3E-03	5.4E+01
2	53.7	46.2	7.5	1.5	1320	1353.0	0.13	5.7E-03	6.1E+01
3	53.1	36.9	16.2	2.0	2520	2922.4	0.17	6.4E-03	5.2E+01
4	54.0	46.4	7.6	2.5	960	1371.0	0.22	7.9E-03	5.1E+01
5	54.6	39.8	14.8	3.0	2640	2669.8	0.26	5.6E-03	3.0E+01
6	54.3	46.2	8.1	3.5	1080	1461.2	0.31	7.5E-03	3.5E+01
7	54.5	44.8	9.7	4.0	1080	1749.8	0.35	9.0E-03	3.6E+01
8	54.2	47.0	7.2	4.5	720	1298.8	0.39	1.0E-02	3.6E+01
9	55.1	47.3	7.8	5.0	660	1407.1	0.44	1.2E-02	3.8E+01
10	47.2	35.3	11.9	5.5	870	2146.7	0.48	1.4E-02	4.0E+01
11	54.7	42.3	12.4	6.0	780	2236.9	0.52	1.6E-02	4.3E+01
12	54.8	43.4	11.4	7.0	720	2056.5	0.61	1.6E-02	3.7E+01
13	54.1	47.5	6.6	8.0	360	1190.6	0.70	1.8E-02	3.7E+01
14	46.9	39.6	7.3	9.0	360	1316.9	0.79	2.0E-02	3.7E+01
15	39.5	29.0	10.5	10.0	480	1894.1	0.87	2.2E-02	3.5E+01
16	54.6	41.7	12.9	11.0	420	2327.1	0.96	3.1E-02	4.5E+01
17	54.7	42.5	12.2	12.0	360	2200.8	1.05	3.4E-02	4.6E+01
18	54.6	43.7	10.9	13.0	300	1966.3	1.14	3.6E-02	4.5E+01
19	53.8	38.9	14.9	14.0	450	2687.9	1.22	3.3E-02	3.8E+01
20	54.9	41.6	13.3	15.0	300	2399.2	1.31	4.4E-02	4.8E+01
21	54.7	33.0	21.7	16.0	450	3914.5	1.40	4.8E-02	4.9E+01
22	54.7	37.5	17.2	17.0	420	3102.8	1.49	4.1E-02	3.9E+01
23			0.0						
Average k									4.2E+01

Note:

h_1 is the initial reservoir water level.
 h_2 is the final reservoir water level.
 Δh is the change in reservoir water level during the test.
 H is the head difference across the specimen.
 t is the elapse time for changing water level.

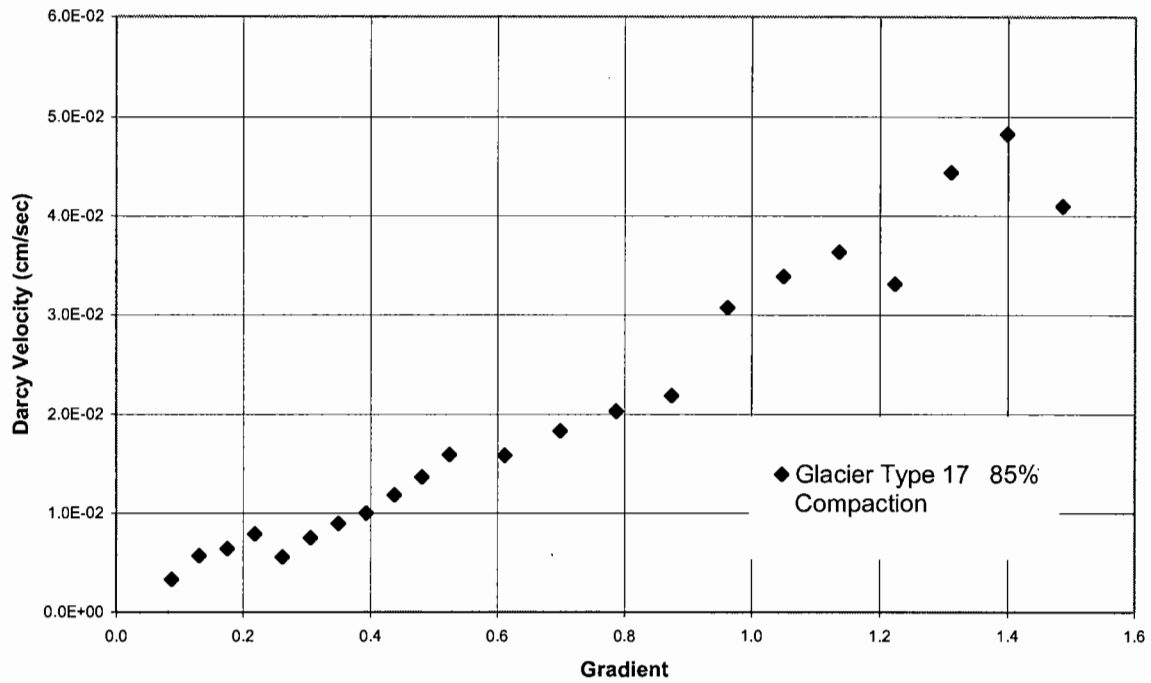
Q is the volume of water discharged.
 l is the hydraulic gradient.
 a is the cross-section area of the specimen.
 k is the hydraulic conductivity of the specimen.

Hydraulic Conductivity vs. Gradient



Darcy Velocity vs. Gradient

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**PERMEABILITY TEST ON GRANULAR SOIL
 CONSTANT HEAD
 ASTM D 2434**

Specimen Data

Height (cm)	11.44
Diameter (cm)	15.16
Area (cm ²)	180.39
Volume (cm ³)	2063.58

Sample Classification

Brown, slightly silty, gravelly SAND; mixed with
 compost (30% by volume) after oversize
 particles sieved out to meet size reqs

Permeameter Dimensions

I.D. of Reservoir (cm)	15.16
O.D. of Tube (cm)	1.91
Area (cm ²)	177.54
Sample Length (cm)	11.44

Remarks

90% Compaction

Moisture Content

	Before	After
Wet + tare (g)	600.00	
Dry + tare (g)	546.50	
Tare (g)	102.32	
mc (%)	12.0%	#DIV/0!

Density Determination

Initial Wet Weight (g)	4091
Final Wet Weight (g)	0
Est. Specific Gravity	2.7
Dry Unit Weight, γ_d (pcf)	110.5
Compacted Unit Weight, γ_m (pcf)	123.8
Saturated Unit Weight, γ_{sat} (pcf)	0.0
Maximum Dry Density, γ_{max} (pcf)	123 (estimated)
Relative Compaction (%)	90.2 (estimated)
Temperature (°C)	21

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Test No.	Reservoir Level		Δh (cm)	H (cm)	t (s)	Q (cm ³)	l	Q/at	k (in/hr)
	h_1 (cm)	h_2 (cm)							
1	54.5	50.5	4.0	1.5	10800	721.6	0.13	3.7E-04	4.00E+00
2	50.5	44.7	5.8	2.0	9180	1046.3	0.17	6.3E-04	5.12E+00
3	44.6	38.1	6.5	2.5	9360	1172.6	0.22	6.9E-04	4.50E+00
4	38.1	31.3	6.8	3.0	6600	1226.7	0.26	1.0E-03	5.57E+00
5	31.2	27.0	4.2	3.5	3300	757.7	0.31	1.3E-03	5.90E+00
6	26.8	22.7	4.1	4.0	2700	739.6	0.35	1.5E-03	6.16E+00
7	22.5	14.9	7.6	4.5	4440	1371.0	0.39	1.7E-03	6.17E+00
8	55.0	52.4	2.6	5.0	5400	469.0	0.44	4.8E-04	1.56E+00
9	52.2	48.5	3.7	5.5	6480	667.5	0.48	5.7E-04	1.68E+00
10	48.4	43.1	5.3	6.0	6840	956.1	0.52	7.7E-04	2.09E+00
11	38.7	27.9	10.8	6.0	17460	1948.2	0.52	6.2E-04	1.67E+00
12	54.6	48.4	6.2	7.0	10140	1118.4	0.61	6.1E-04	1.42E+00
13	48.3	41.5	6.8	2.0	68280	1226.7	0.17	1.0E-04	8.07E-01
14	41.3	35.7	5.6	3.0	28740	1010.2	0.26	1.9E-04	1.05E+00
15	53.8	42.7	11.1	4.0	11520	2002.4	0.35	9.6E-04	3.91E+00
16	42.8	32.6	10.2	5.0	8460	1840.0	0.44	1.2E-03	3.91E+00
17	32.1	26.3	5.8	6.0	2940	1046.3	0.52	2.0E-03	5.33E+00
18	54.6	48.8	5.8	7.0	1920	1046.3	0.61	3.0E-03	7.00E+00
19	48.7	43.2	5.5	8.0	1320	992.2	0.70	4.2E-03	8.44E+00
20	43.0	39.0	4.0	9.0	900	721.6	0.79	4.4E-03	8.01E+00
21	20.0	12.4	7.6	10.0	1680	1371.0	0.87	4.5E-03	7.33E+00
22	55.2	51.6	3.6	11.0	720	649.4	0.96	5.0E-03	7.37E+00
23	51.2	47.0	4.2	12.0	720	757.7	1.05	5.8E-03	7.88E+00
24	46.5	42.8	3.7	17.0	480	667.5	1.49	7.7E-03	7.35E+00
Average k									4.6E+00

Note:

h_1 is the initial reservoir water level.

h_2 is the final reservoir water level.

Δh is the change in reservoir water level during the test.

H is the head difference across the specimen.

t is the elapse time for changing water level.

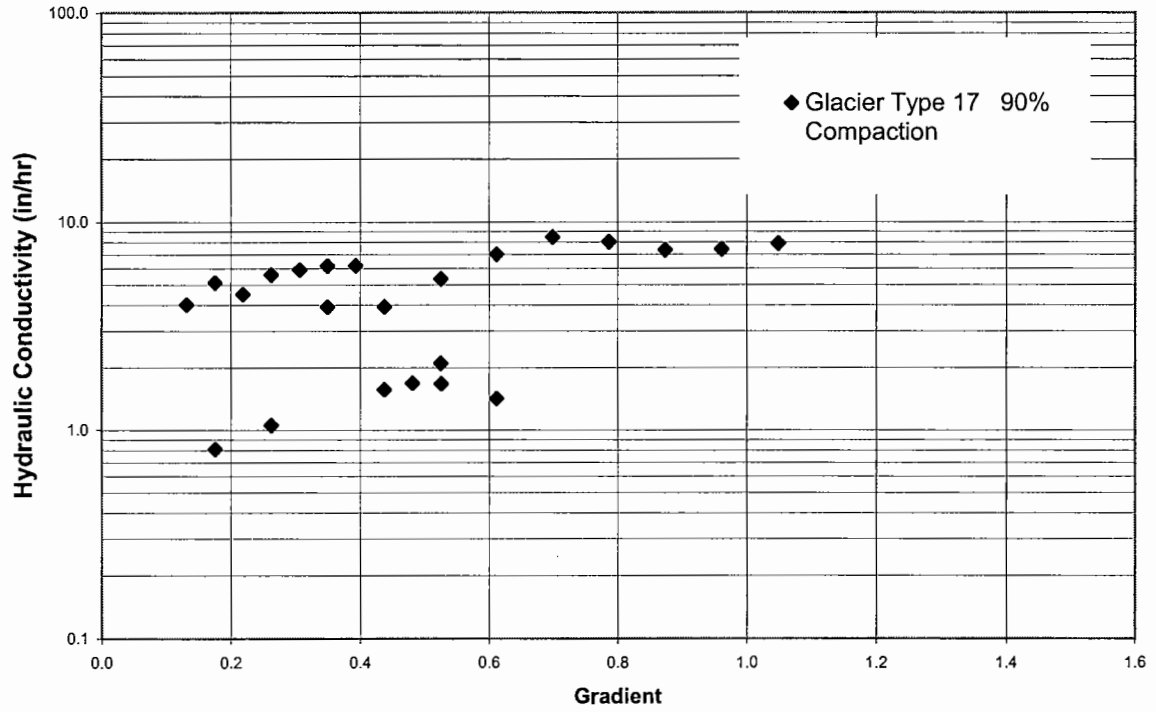
Q is the volume of water discharged.

l is the hydraulic gradient.

a is the cross-section area of the specimen.

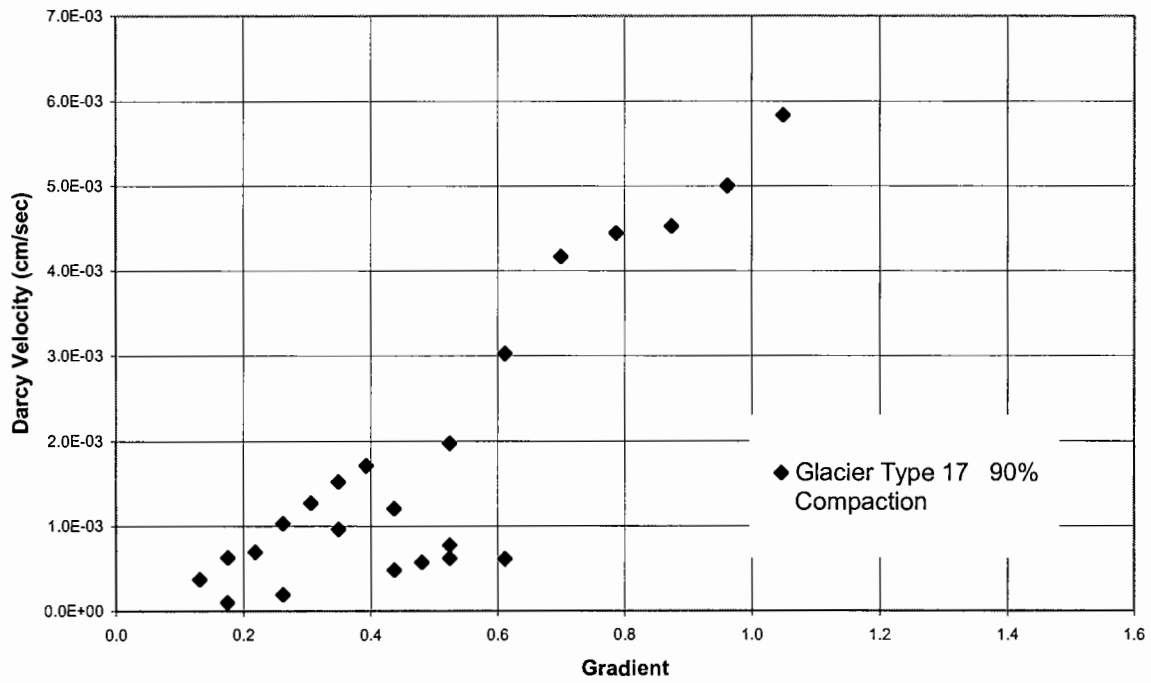
k is the hydraulic conductivity of the specimen.

Hydraulic Conductivity vs. Gradient



Darcy Velocity vs. Gradient

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**PERMEABILITY TEST ON GRANULAR SOIL
 CONSTANT HEAD
 ASTM D 2434**

Specimen Data

Height (cm)	11.44
Diameter (cm)	15.16
Area (cm ²)	180.39
Volume (cm ³)	2063.58

Sample Classification

Brown, gravelly SAND, trace of silt; mixed with
 compost (30% by volume) after oversize
 particles sieved out to meet size reqs

Permeameter Dimensions

I.D. of Reservoir (cm)	15.16
O.D. of Tube (cm)	1.91
Area (cm ²)	177.54
Sample Length (cm)	11.44

Remarks

90% Compaction

Moisture Content

	Before	After
Wet + tare (g)	413.73	
Dry + tare (g)	393.60	
Tare (g)	67.74	
mc (%)	6.2%	

Density Determination

Initial Wet Weight (g)	3640
Final Wet Weight (g)	0
Est. Specific Gravity	2.7
Dry Unit Weight, γ_d (pcf)	103.7
Compacted Unit Weight, γ_m (pcf)	110.1
Saturated Unit Weight, γ_{sat} (pcf)	0.0
Maximum Dry Density, γ_{max} (pcf)	115 (estimated)
Relative Compaction (%)	90.2 (estimated)
Temperature (°C)	21

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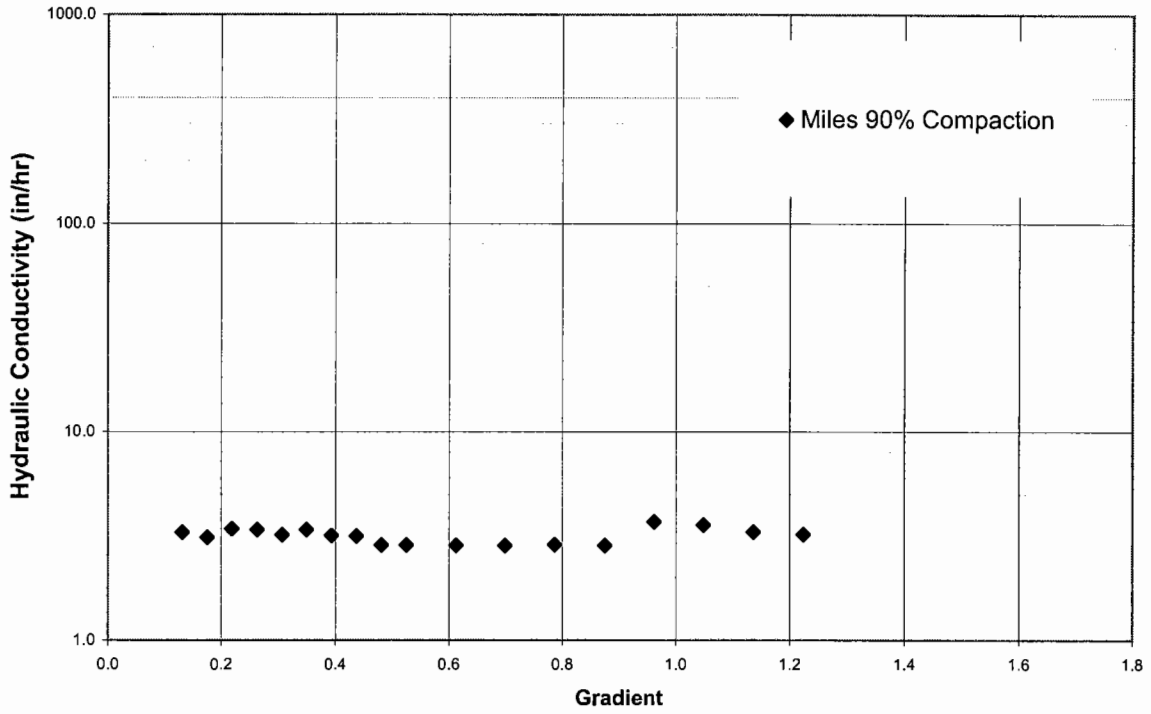
Test No.	Reservoir Level		Δh (cm)	H (cm)	t (s)	Q (cm ³)	l	Q/at	k (in/hr)
	h_1 (cm)	h_2 (cm)							
1	54.1	52.6	1.5	1.5	4920	270.6	0.13	3.0E-04	3.30E+00
2	52.7	51.5	1.2	2.0	3120	216.5	0.17	3.8E-04	3.12E+00
3	51.5	49.0	2.5	2.5	4740	451.0	0.22	5.3E-04	3.42E+00
4	48.7	45.8	2.9	3.0	4620	523.1	0.26	6.3E-04	3.39E+00
5	45.7	42.1	3.6	3.5	5220	649.4	0.31	6.9E-04	3.19E+00
6	42.0	40.7	1.3	4.0	1560	234.5	0.35	8.3E-04	3.38E+00
7	40.6	38.7	1.9	4.5	2160	342.7	0.39	8.8E-04	3.17E+00
8	38.5	37.1	1.4	5.0	1440	252.6	0.44	9.7E-04	3.15E+00
9	21.7	20.6	1.1	5.5	1140	198.4	0.48	9.6E-04	2.84E+00
10	20.5	19.1	1.4	6.0	1320	252.6	0.52	1.1E-03	2.87E+00
11	19.0	17.3	1.7	7.0	1380	306.7	0.61	1.2E-03	2.85E+00
12	17.0	15.4	1.6	8.0	1140	288.6	0.70	1.4E-03	2.84E+00
13	15.2	13.1	2.1	9.0	1320	378.8	0.79	1.6E-03	2.87E+00
14	13.0	6.7	6.3	10.0	3600	1136.5	0.87	1.8E-03	2.84E+00
15	54.5	47.7	6.8	11.0	2700	1226.7	0.96	2.5E-03	3.71E+00
16	47.5	37.5	10.0	12.0	3780	1803.9	1.05	2.6E-03	3.57E+00
17	54.3	52.4	1.9	13.0	720	342.7	1.14	2.6E-03	3.29E+00
18	52.0	34.7	17.3	14.0	6240	3120.8	1.22	2.8E-03	3.21E+00
19									
20									
21									
22									
23									
Average k									3.17E+00

Note:

h_1 is the initial reservoir water level.
 h_2 is the final reservoir water level.
 Δh is the change in reservoir water level during the test.
 H is the head difference across the specimen.
 t is the elapse time for changing water level.

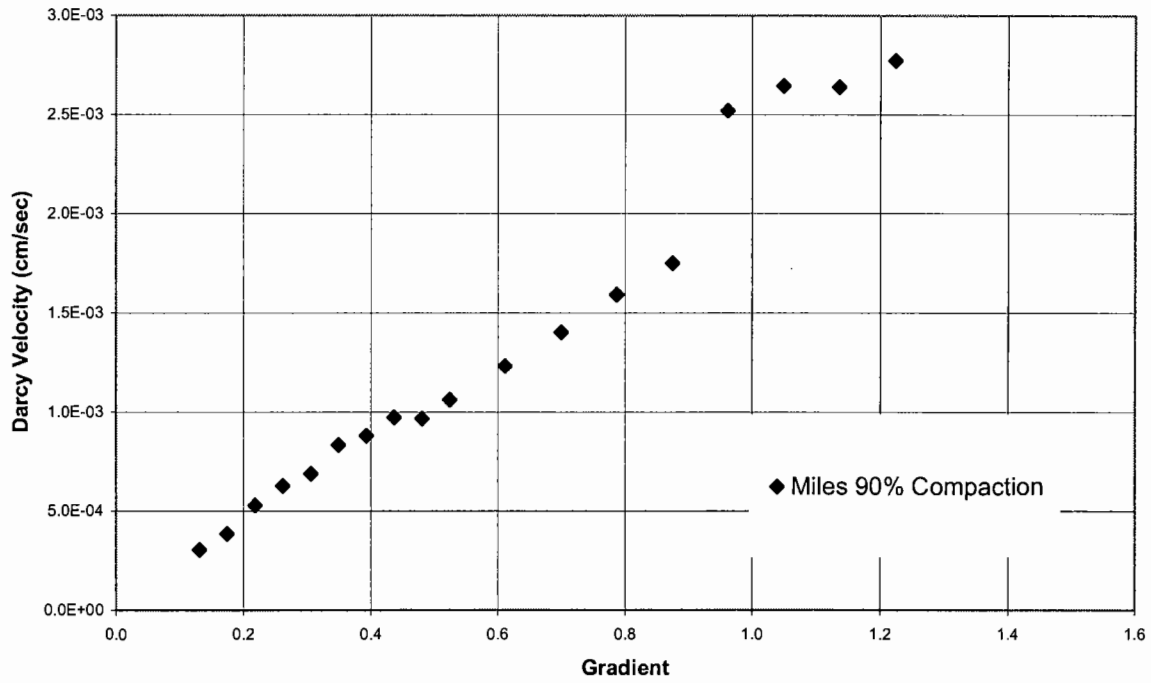
Q is the volume of water discharged.
 l is the hydraulic gradient.
 a is the cross-section area of the specimen.
 k is the hydraulic conductivity of the specimen.

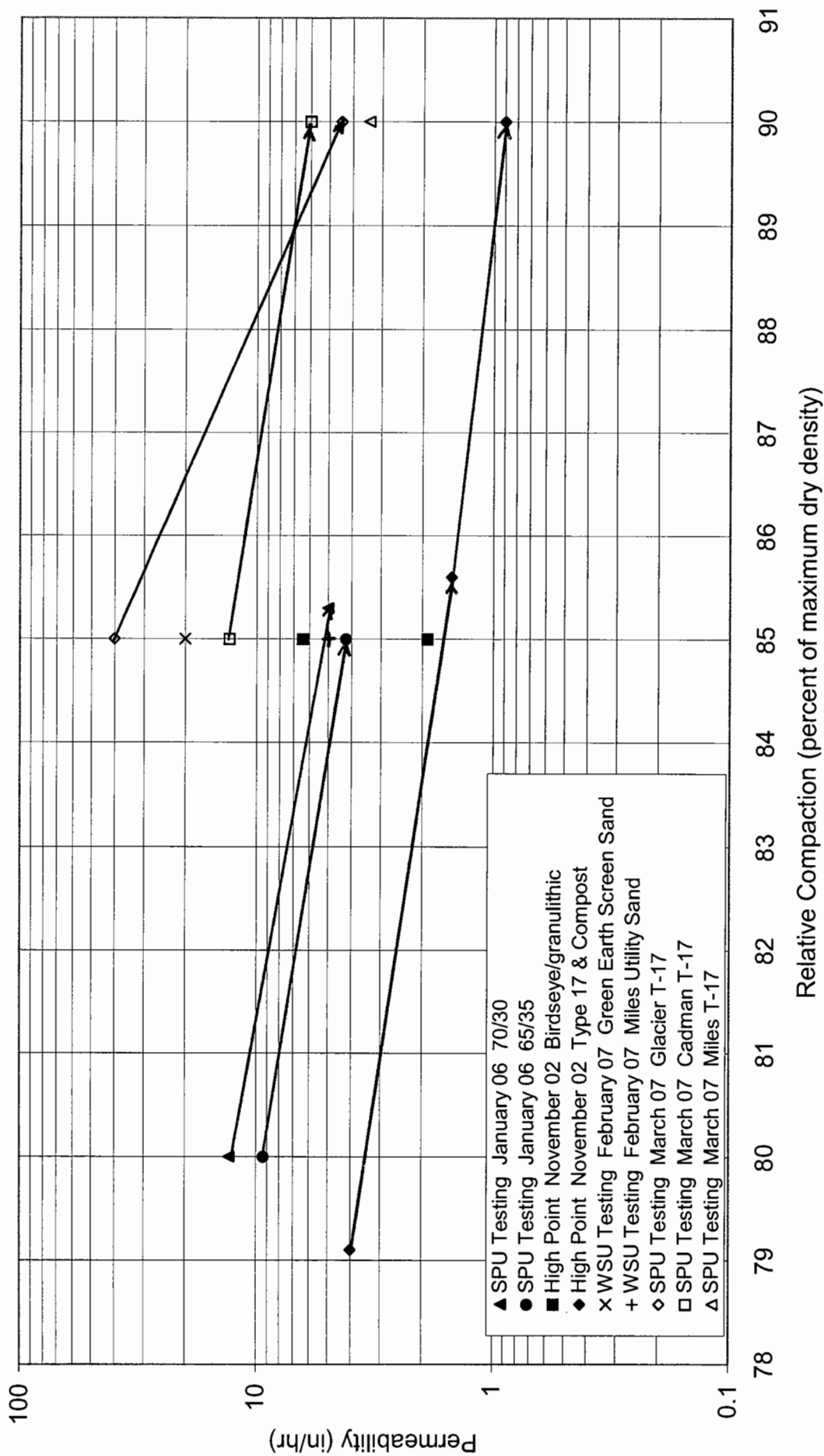
Hydraulic Conductivity vs. Gradient



Darcy Velocity vs. Gradient

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Notes:

Refer to text of letter report for discussion.

Seattle Public Utilities -- Playfield Bioretention
Soil Draft Specification
Seattle, Washington

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**PERMEABILITY VERSUS
COMPACTION** **RELATIVE
COMPACTION**

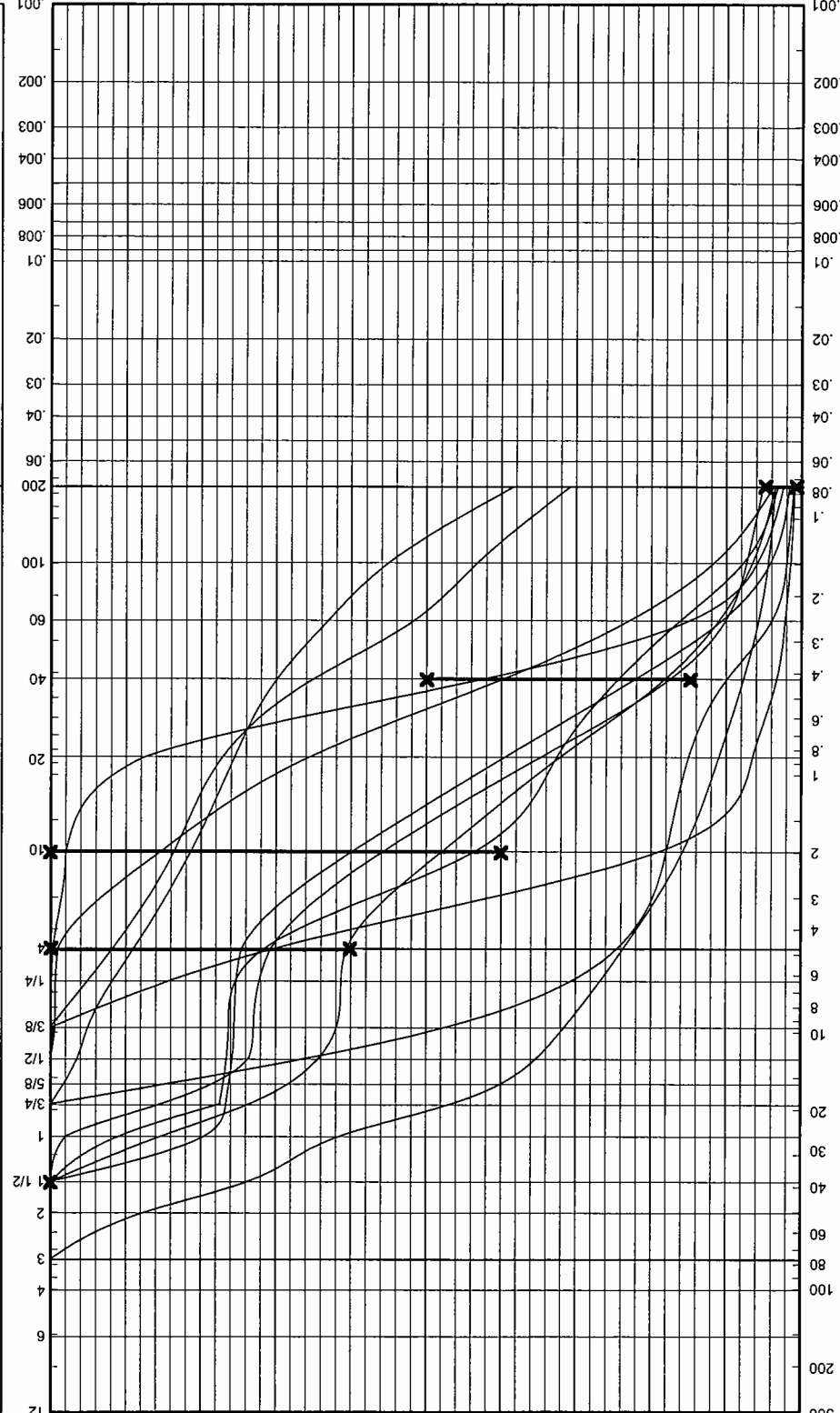
March 2007 21-1-08824-024

SHANNON & WILSON, INC.
Geotechnical and Environmental Consultants

FIG. 9

FIG. 9

HYDROMETER ANALYSIS
GRAIN SIZE IN MILLIMETERS



SIEVE ANALYSIS
NO. OF MESH OPENINGS PER INCH, U.S. STANDARD

GRAIN SIZE IN MILLIMETERS

COBBLES COARSE FINE GRAVEL COARSE FINE SAND MEDIUM SAND FINE SAND FINES: SILT OR CLAY

Seattle Public Utilities -- Playfield Bioretention
Soil Draft Specification
Seattle, Washington

**GRAIN SIZE DISTRIBUTION
PROPOSED SPECIFICATION**

March 2007 21-1-08824-024

SHANNON & WILSON, INC.
Geotechnical and Environmental Consultants

FIG. 10

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FIG. 10

7-21 BIORETENTION SOIL

7-21.1 DESCRIPTION

Section 7-21 describes work consisting of the construction of Bioretention Soil in playfield and landscape areas to receive surface runoff for infiltration.

7-21.2 MATERIALS

Materials for Bioretention Soil will be specified in the Contract and consist of one or more of the following:

Landscape Bioretention Soil 9-14.1(3)B

Playfield Bioretention Soil 9-14.1(3)C

7-21.3 CONSTRUCTION REQUIREMENTS

7-21.3(1) GENERAL

Bioretention soil shall be protected from all sources of additional moisture at the Supplier, in covered conveyance, and at the Project Site until incorporated into the Work. Soil placement will not be allowed when the ground is frozen or excessively wet, or when the weather is too wet as determined by the Engineer.

When the Contract specifies testing by a Contractor provided testing laboratory, the laboratory must be an AASHTO or ASTM or other designated recognized standards organization accredited laboratory with certification maintained current. The laboratory must be capable of performing all tests to the designated recognized standards specified, and will provide test results with an accompanying Manufacturer's Certificate of Compliance.

7-21.3(1)A SUBMITTALS

At least, 10 Working Days in advance of construction, the Contractor must submit to the Engineer for approval:

- 1) A 10-pound minimum sample of mineral aggregate (Sections 9-03.2(2) and 9-03.2(3), as applicable);
- 2) A 100 pound sample of mixed Bioretention Soil (Sections 9-14.1(3)B and 9-14.1(3)C, as applicable);
- 3) Grain size analysis results of mineral aggregate performed in accordance with ASTM D 422, Standard Test Method for Particle Size Analysis of Soils;
- 4) **(S&W - SPU to add list of tests to be done on compost);**
- 5) Organic content test results of mixed Bioretention Soil. Organic content test shall be performed in accordance with ASTM D 2974, Standard Test Methods for Moisture, Ash, and organic Matter of Peat and Other Organic Soils;

- 6) Modified Proctor compaction testing of mixed Bioretention Soil, performed in accordance with ASTM D 1557, Test Method for Laboratory Compaction Characteristics of Soil Using Modified Effort;
- 7) A description of the equipment and methods proposed to mix the mineral aggregate and compost to produce Bioretention Soil;
- 8) Provide the following information about the testing laboratory:
 1. name of laboratory including contact person,
 2. address,
 3. phone contact,
 4. e-mail address;
 5. qualifications of laboratory and personnel including date of current certification by ASTM, AASHTO, or approved equal.

7-21.3(2) BIORETENTION SOIL CONSTRUCTION

At the locations shown on the Drawings, excavate, grade, and shape to the contours indicated to accommodate placing of Bioretention Soil to the thicknesses required. Dispose of excavated soil or reuse elsewhere as the Contract or Engineer will allow. Scarify the subgrade soil prior to placing Bioretention Soil.

Mixing or placing Bioretention Soil will not be allowed if the area receiving bioretention soil is wet or saturated or has been subjected to more than ½-inch of precipitation within 48-hours prior to mixing or placement. Engineer shall have final authority to determine if wet or saturated conditions exist.

Place Landscape Bioretention Soil in loose lifts not exceeding **XX** inches. Compact Landscape Bioretention Soil to a relative compaction of between **YY** to **ZZ** percent of Modified maximum dry density (ASTM D 1557). (**S&W - we have made no compaction recommendations for Landscape Bioretention Soil.**)

Place Playfield Bioretention Soil in loose lifts not exceeding 8 inches. Compact Playfield Bioretention Soil to a relative compaction of between 85 to 90 percent of Modified maximum dry density (ASTM D 1557). (**S&W - To us, proof rolling would imply a relative compaction in excess of 85 to 90% R.C. No proof rolling language should be included.**)

7-21.4 MEASUREMENT (**S&W - Not sure if SPU wants to split out MEASUREMENT and PAYMENT into Landscape and Playfield sub-categories**)

Bid items of Work completed pursuant to the Contract will be measured as provided in Section 1-09.1, Measurement of Quantities, unless otherwise provided for by individual measurement paragraphs here in this Section.

Measurement for Bioretention Soil Construction will be by the cubic yard.

7-21.5 PAYMENT

Compensation for the cost necessary to complete the work described in Section 7-21 will be made at the Bid item prices Bid only for the Bid items listed or referenced as follows:

1. "Bioretention Soil Construction" per cubic yard.

The Bid item price for "Bioretention Soil Construction" shall include all costs for the work necessary to furnish, place, compact, excavate, grade, shape, mix, dispose of, and as necessary.

9-03.2 MINERAL AGGREGATES FOR BIORETENTION SOIL

9-03.2(1) GENERAL

Mineral aggregate shall be free of wood; waste, coating, or any other deleterious material. All aggregate passing the No. 200 sieve size shall be non-plastic.

9-03.2(2) MINERAL AGGREGATE FOR LANDSCAPE BIORETENTION SOIL

(S&W - we have made no gradation recommendations for Landscape Bioretention Soil)

9-03.2(3) MINERAL AGGREGATE FOR PLAYFIELD BIORETENTION SOIL

Mineral aggregate for Playfield Bioretention Soil shall meet the following gradation: (S&W - the following percent passings are from our laboratory work and data review)

Sieve Size	Percent Passing
1½ inch	100
No. 4	60 - 100
No.10	40 - 100
No. 40	15 - 50
No. 200	0 - 5

(S&W - we prefer no S.E. language, as it may conflict with an otherwise satisfactory grain size distribution)

9-14.1(3) BIORETENTION SOIL

9-14.1(3)A GENERAL

Bioretention Soil shall be a mixture of mineral aggregate and compost measured on a volume basis.

9-14.1(3)B LANDSCAPE BIORETENTION SOIL

(S&W - we have made no mixture recommendations for Landscape Bioretention Soil)

DRAFT

9-14.1(3)C PLAYFIELD BIORETENTION SOIL

Playfield Bioretention Soil shall consist of 30% compost meeting the requirements of Section 9-14.4(9) and 70% mineral aggregate meeting the requirements of Section 9-03.2(3). The mixture shall be well blended to produce a homogeneous mix.

9-14.4(9) COMPOSTED MATERIAL (S&W - is this in the correct materials section? Does some of this language belong in the submittals section?)

Composted material shall be derived from a Type 1 feedstock and produced by a facility in compliance with WAC 173-350-220. The compost shall meet Grade AA Compost as defined by the Washington State Department of Ecology's Interim Guidelines for Compost Quality (Publication #94-38, Revised November 1994). Compost material shall have 100% passing a 1/2-inch screen. The carbon to nitrogen ratio (C:N) of the compost shall be in the range of 20:1 to 35:1. Organic matter of the composted Material shall be in the range 4% and 10%, and the moisture content shall be in the range of 35% to 50% as determined by ASTM D 2974. The pH of the compost shall be within the range of 5.5 to 7.0 as determined by ASTM D 2976. The maximum electrical conductivity of composted Material shall be 6 ohms/cm. Decomposed Organic Compost shall be mature as determined by US Composting Council stability test ratings referred to in the Ch 173-350 WAC.

The product shall be tested within 6 months of proposed use, and the test results shall ensure compliance with Section 9-14.4(9) requirements. The Contractor shall submit a Manufacturer's certificate of Compliance indicating the test results, a one-gallon sample, the Supplier's name and contact information, to the Engineer a minimum of 5 Working Days in advance of use.

The compost shall have a Solvita Compost Maturity Test performed at the Project Site, and shall score a number 6 or above to be accepted. Solvita Compost Maturity Test is available from Woods End Research Laboratory, phone (207) 293- 2457, or 1(800)451-0337, or www.woodsends.org.

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