SUB-ATTACHMENT D

HYDRAULIC CONDUCTIVITY FIELD TESTING

Field Hydraulic Conductivity Testing:

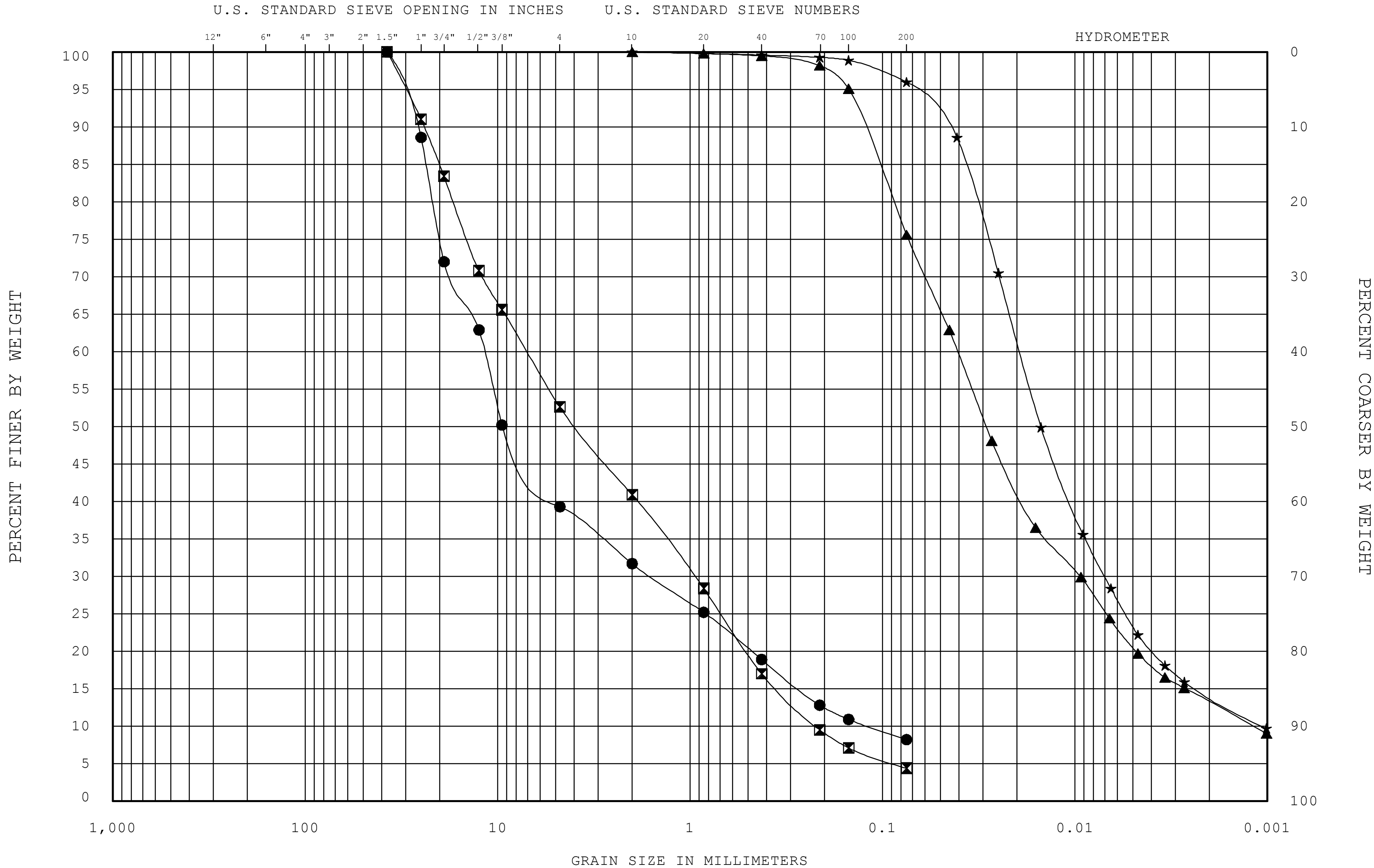
Field hydraulic conductivity (permeability) tests were performed in 2 wells at drill holes DH-3 and DH-6. The wells consisted of 4-inch diameter PVC pipe with a 5-foot length screen. The screens were placed below the groundwater level and located in the most pervious stratum encountered in the hole. A uniform sand filter pack was placed around the screen and approximately 2 feet above the top of screen. Details of the well installations and test data for each well are shown on the following pages.

The groundwater level varies along the proposed alignment. Groundwater was general encountered approximately 4 to 12 below the ground surface, with the average depth of groundwater at about 5 feet. In general the top of the previous stratum (aquifer) is approximately 5 to 16 feet below top of ground with an average thickness of about 10 feet. The well screens were installed in the previous zones, which consisted of sands and gravels, such as SP, SP-SM, and GP-GM, classified in accordance with the Unified Soil Classification System. Gradation test results for these materials are provided herein.

The field permeability testing was performed by filling the well with water and recording the various times and water levels in the well. Constant head tests were performed in both wells, where the water level and pumping rate were kept constant during the test. For DH-3, a falling head test was performed after the constant head test. The formulas for determining the hydraulic conductivity (permeability) from the field permeability tests are shown on the next page. The formulas were originally presented in the report *Time Lag and Soil Permeability in Groundwater Observation*, Bulletin No. 36 Waterways Experiment Station, by Juul Hvorslev, 1951. On the following page is a copy of the two formulas used in this analysis which is presented in the TM 5-818-5, *Dewatering and Groundwater Control for Deep Excavation*, April 1971. The first formula assumes an impervious boundary above the screen; and the second formula assumes a uniform soil at and above the screen. In addition, the analysis varied the horizontal to vertical permeability ratio to determine its impact on the calculated permeabilities. Also, for the falling head tests, various time intervals were selected to help in determining permeability values. An excel spread sheet was developed to perform the computations, and these sheets are provided in this section. In general, the testing showed that the following:

Well	Material/Zone	Hydraulic conductivity, k
DH-3	Poorly graded Sand w/ gravel (SP)	2×10^{-2} cm/sec (falling)
DH-3	Poorly graded Sand w/ gravel (SP)	4.0×10^{-3} cm/sec (constant)
DH-6	Poorly graded Sand w/ gravel & silt (SP-SM)	3.0×10^{-3} cm/sec (constant)

It is considered reasonable to assume a hydraulic conductivity value ranging from 1.0×10^{-3}cm/sec to 2.0×10^{-2}cm/sec for the sand and gravel aquifer stratum.



COBBLES	GRAVEL		SAND			SILT or CLAY
	COARSE	FINE	COARSE	MEDIUM	FINE	

Legend	Sample No.	Depth (ft)	Classification (ASTM D 2487)		Nat wc%	LL	PL	PI
—●—	Jar-4	5.0-6.5	WELL-GRADED GRAVEL with SILT and SAND	GW-GM	6.9			
—⊠—	Jars 6-8	10.0-16.5	POORLY GRADED SAND with GRAVEL	SP	11.2	27	23	4
—▲—	Jar-10	20.0-21.5	LEAN CLAY with SAND	CL	24.3	44	22	22
—★—	Jar-16	35.0-36.5	FAT CLAY	CH	26.3	54	26	28

REMARKS :

ENG FORM ENG2087HUNTINGTON VA FPP.GPJ

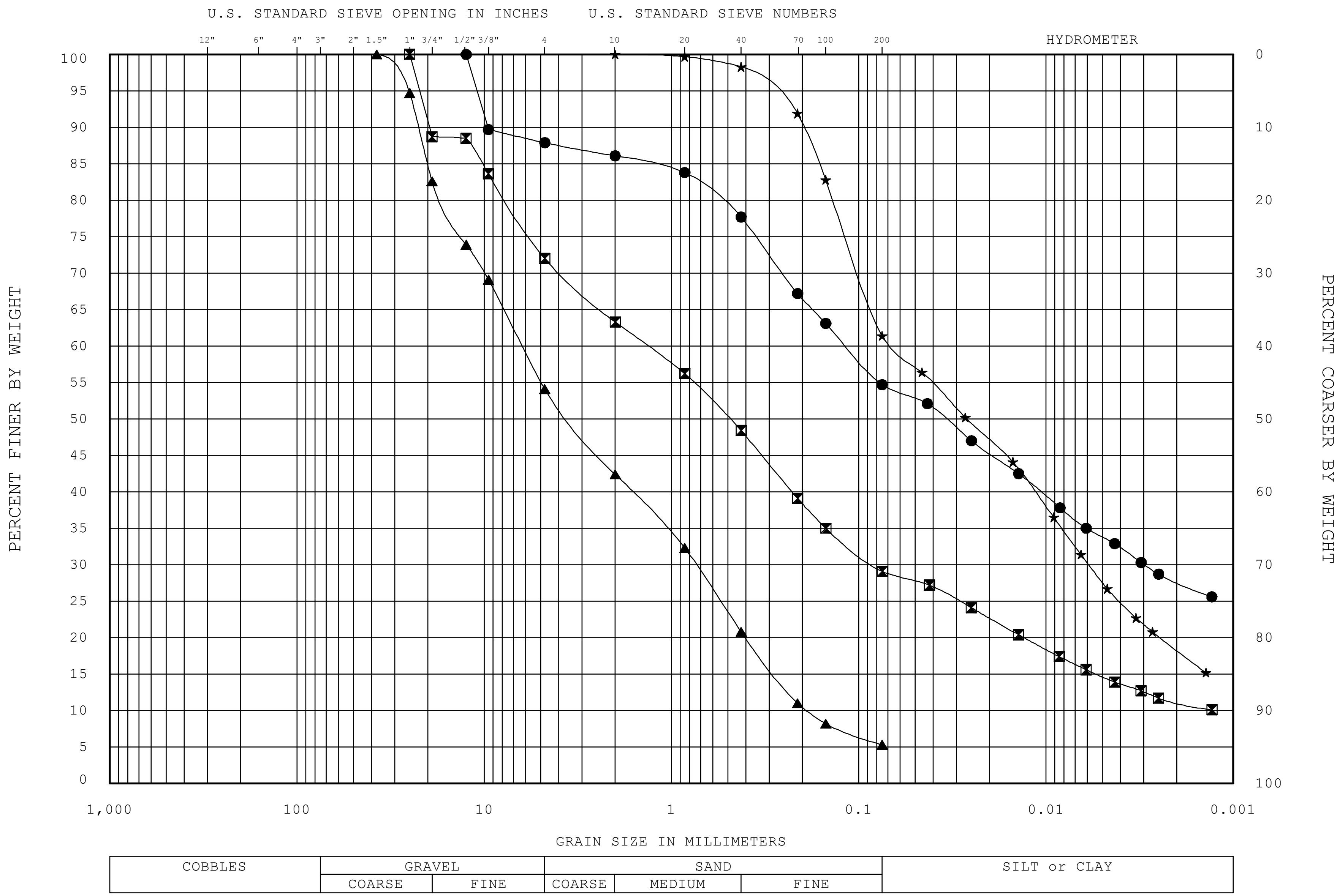
GRADATION CURVES TEST METHODS: ASTM D 422, D4318, D2216

PROJECT: *Huntington, VA*

AREA: *Flood Protection Project*

BORING NO.: *DH-3*

DATE: *May 2008*



Legend	Sample No.	Depth (ft)	Classification (ASTM D 2487)		Nat wc%	LL	PL	PI
—●—	Jar-3	1.5-3.0	SANDY FAT CLAY	CH	21.5	61	25	36
—⊠—	Jar-6	6.0-7.5	CLAYEY SAND with GRAVEL	SC	23.3	53	25	28
—▲—	Jars 7-11	7.5-16.5	POORLY GRADED SAND with SILT and GRAVEL	SP-SM				
—★—	Jar-18	32.5-34.0	SANDY FAT CLAY	CH	26.5	50	23	27

REMARKS :

PROJECT: *Huntington, VA*

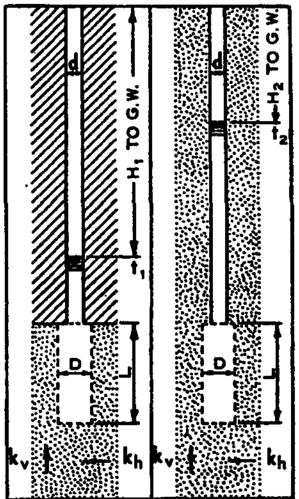
AREA: *Flood Protection Project*

BORING NO.: *DH-6*

DATE: *May 2008*

ENG FORM ENG2087HUNTINGTON VA FPP.GPJ

GRADATION CURVES TEST METHODS: ASTM D 422, D4318, D2216



WELLPOINT FILTER AT IMPERVIOUS BOUNDARY	WELLPOINT FILTER IN UNIFORM SOIL
A	B

NOTATION

D = DIAM, INTAKE, SAMPLE, CM
d = DIAM, STANDPIPE, CM
L = LENGTH, INTAKE, SAMPLE, CM
H_c = CONSTANT PIEZ HEAD, CM
H_1 = PIEZ HEAD FOR $t = t_1$, CM
H_2 = PIEZ HEAD FOR $t = t_2$, CM
q = FLOW OF WATER, CM^3/SEC
t = TIME, SEC
k'_v = VERT PERM CASING, CM/SEC
k_v = VERT PERM GROUND, CM/SEC
k_h = HORIZ PERM GROUND, CM/SEC
k_m = MEAN COEFF PERM, CM/SEC
m = TRANSFORMATION RATIO

$k_m = \sqrt{k_h k_v}$ $\qquad m = \sqrt{k_h/k_v}$

$\ln = \log_e = 2.3 \log_{10}$

CASE	CONSTANT HEAD	VARIABLE HEAD
A	$k_h = \dfrac{q \ln\left[\dfrac{2mL}{D} + \sqrt{1 + \left(\dfrac{2mL}{D}\right)^2}\right]}{2\pi L H_c}$	$k_h = \dfrac{d^2 \ln\left[\dfrac{2mL}{D} + \sqrt{1 + \left(\dfrac{2mL}{D}\right)^2}\right]}{8L(t_2 - t_1)} \ln \dfrac{H_1}{H_2}$ $k_h = \dfrac{d^2 \ln\left(\dfrac{4mL}{D}\right)}{8L(t_2 - t_1)} \ln \dfrac{H_1}{H_2}$ FOR $\dfrac{2mL}{D} > 4$
B	$k_h = \dfrac{q \ln\left[\dfrac{mL}{D} + \sqrt{1 + \left(\dfrac{mL}{D}\right)^2}\right]}{2\pi L H_c}$	$k_h = \dfrac{d^2 \ln\left[\dfrac{mL}{D} + \sqrt{1 + \left(\dfrac{mL}{D}\right)^2}\right]}{8L(t_2 - t_1)} \ln \dfrac{H_1}{H_2}$ $k_h = \dfrac{d^2 \ln\left(\dfrac{2mL}{D}\right)}{8L(t_2 - t_1)} \ln \dfrac{H_1}{H_2}$ FOR $\dfrac{mL}{D} > 4$

ASSUMPTIONS

SOIL AT INTAKE, INFINITE DEPTH AND DIRECTIONAL ISOTROPY (k_v AND k_h CONSTANT) - NO DISTURBANCE, SEGREGATION, SWELLING, OR CONSOLIDATION OF SOIL - NO SEDIMENTATION OR LEAKAGE - NO AIR OR GAS IN SOIL, WELLPOINT, OR PIPE - HYDRAULIC LOSSES IN PIPES, WELLPOINT, OR FILTER NEGLIGIBLE.

(U. S. Army Engineer Waterways Experiment Station)

Figure 20. Formulas for determining permeability from field falling head tests [modified from ref 5]

CONSTANT HEAD AND FALLING HEAD Test DATA FORM

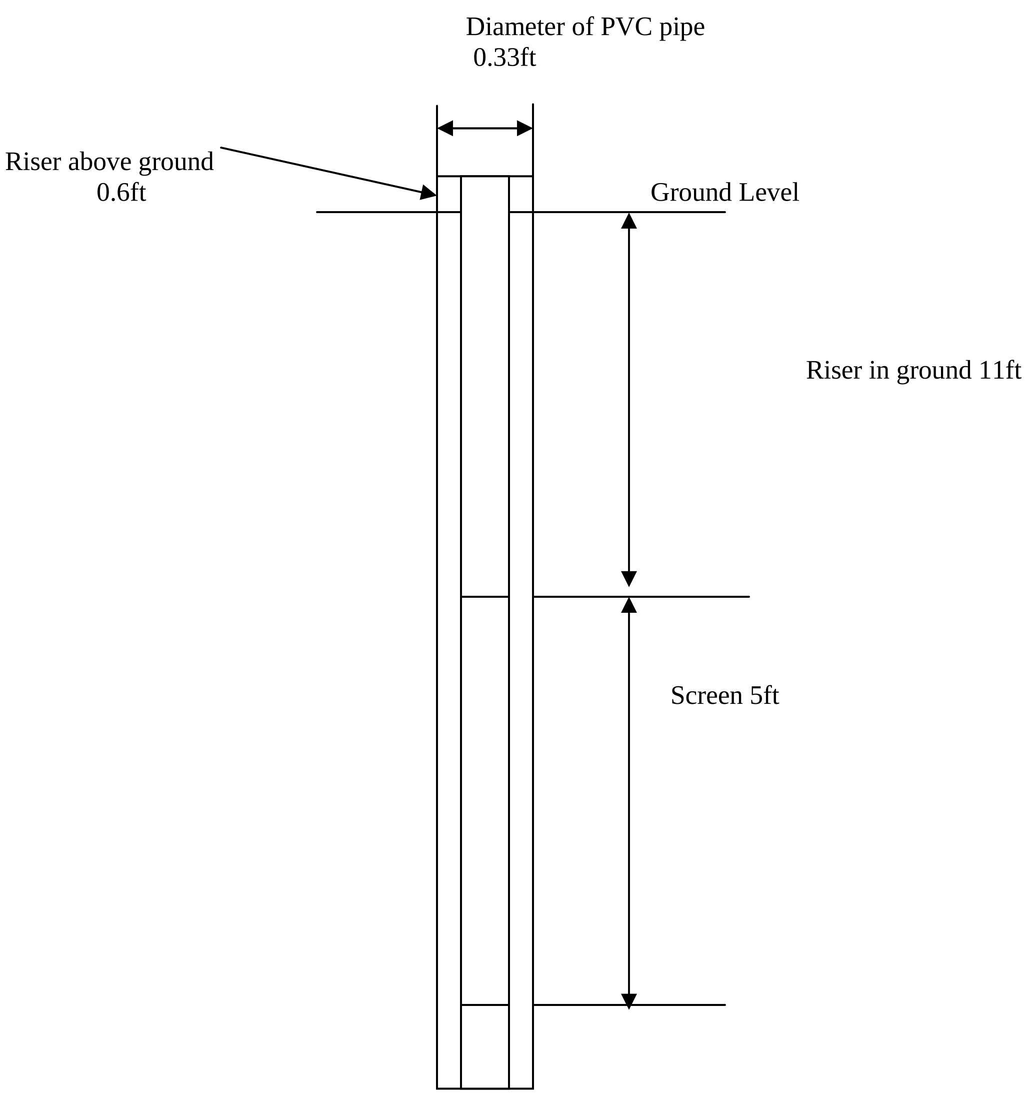
PROJECT Huntington Flood Control Project   DATE   28 March 2008   LOCATION: Huntington, VA

WELL ______DH-3A_______ LENGHT OF SCREEN__5 Ft_RISER IN GROUND 11 ft
RISER ABOVE GROUND 0.6 ft   INITIAL WATER LEVEL 6.5Ft

REMARKS____

Constant Head Test

Time (mins)	Water added (gallons)	Water Level (feet)	Pumping Rate (gallons/min)
0	0	1.0	0
5	15	1.0	3.0
10	12	1.0	2.4
15	11	1.0	2.2
20	11	1.0	2.2



CONSTANT HEAD AND FALLING HEAD Test DATA FORM

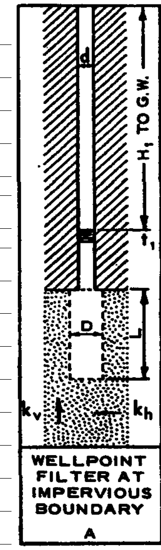
Falling Head Test for DH-3A

Time (mins)	Depth to Water (ft)	Draw Down (ft)	Draw Down Rate (ft/min)
0	1.0	0.0	0.0
0.5	5.3	4.3	9.0
1.0	5.8	0.5	1.0
1.5	6.0	0.2	0.4
2.0	6.0	0.0	0.0
2.5	6.0	0.0	0.0
3.0	6.0	0.0	0.0
4.0	6.0	0.0	0.0
5.0	6.0	0.0	0.0
6.0	6.0	0.0	0.0
7.0	6.0	0.0	0.0
8.0	6.0	0.0	0.0
9.0	6.0	0.0	0.0
10.0	6.0	0.0	0.0
11.0	6.0	0.0	0.0
12.0	6.0	0.0	0.0
17.0	6.0	0.0	0.0
22.0	6.0	0.0	0.0
27.0	6.0	0.0	0.0
32.0	6.0	0.0	0.0
37.0	6.0	0.0	0.0
42.0	6.0	0.0	0.0
47.0	6.0	0.0	0.0
52.0	6.0	0.0	0.0
57.0	6.0	0.0	0.0
62.0	6.0	0.0	0.0
67.0	6.0	0.0	0.0
72.0	6.0	0.0	0.0

DRILL HOLE: DH-3

k equation for well with Impervious boundary above aquifer

$$k_h = \frac{q \ln\left[\frac{2mL}{D} + \sqrt{1 + \left(\frac{2mL}{D}\right)^2}\right]}{2\pi L H_c}$$

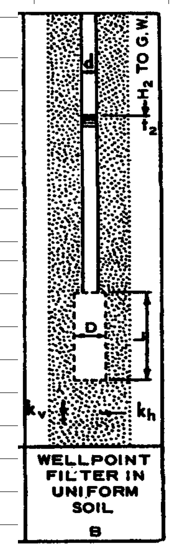


		inches	*Feet*		
Screen Diameter	D =	4.00	0.33		
Screen Length	L =		5.00		
Diam:Length Ratio	L/D	15.00			
		gpm	*cfm*		
Flow rate	q	2.45	0.33		
Head (ft)	h	5.50			
	Kh/Kv	**m**	**(2*mL/D)**	**Kh (ft/min)**	**Kh (cm/sec)**
	1.00	1.00	30.00	7.74E-03	3.95E-03
	5.00	2.24	67.08	9.26E-03	4.72E-03
	10.00	3.16	94.87	9.92E-03	5.06E-03

DRILL HOLE: DH-3

k equation for well in uniform soil:

$$k_h = \frac{q \ln\left[\frac{mL}{D} + \sqrt{1 + \left(\frac{mL}{D}\right)^2}\right]}{2\pi L H_c}$$



		inches	*Feet*		
Screen Diameter	D =	4.00	0.33		
Screen Length	L =		5.00		
Diam:Length Ratio	L/D	15.00			
		gpm	*cfm*		
Flow rate	q	2.45	0.33		
Head (ft)	h	5.50			
	Kh/Kv	**m**	**(mL/D)**	**Kh (ft/min)**	**Kh (cm/sec)**
	1.00	1.00	15.00	6.43E-03	3.28E-03
	5.00	2.24	33.54	7.95E-03	4.06E-03
	10.00	3.16	47.43	8.61E-03	4.39E-03

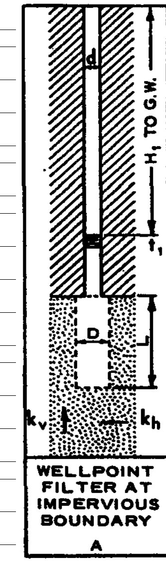
DRILL HOLE: DH-3

k equation for well with Impervious boundary above aquifer

$$k_h = \frac{d^2 \ln\left(\frac{4mL}{D}\right)}{8L\,(t_2 - t_1)} \ln \frac{H_1}{H_2} \quad \text{FOR} \quad \frac{2mL}{D} > 4$$

		inches	*Feet*
Screen Diameter	D =	4.00	0.33
Screen Length	L =		5.00
Diam:Length Ratio	L/D	15.00	

Kh/Kv	m	t1(min)	H1 (ft)	t2(min)	H2 (ft)	ln (h1/H2)	(t2-t1)	ln (4mL/D)	Kh (ft/min)	Kh (cm/sec)
1.00	1.00	0.00	5.50	0.50	1.20	1.52	0.50	4.09	3.46E-02	1.77E-02
5.00	2.24	0.00	5.50	0.50	1.20	1.52	0.50	4.90	4.14E-02	2.11E-02
10.00	3.16	0.00	5.50	0.50	1.20	1.52	0.50	5.25	4.44E-02	2.26E-02
1.00	1.00	0.50	1.20	1.00	0.70	0.54	0.50	4.09	1.23E-02	6.25E-03
5.00	2.24	0.50	1.20	1.00	0.70	0.54	0.50	4.90	1.47E-02	7.48E-03
10.00	3.16	0.50	1.20	1.00	0.70	0.54	0.50	5.25	1.57E-02	8.01E-03
1.00	1.00	0.00	5.50	1.00	0.70	2.06	1.00	4.09	2.34E-02	1.20E-02
5.00	2.24	0.00	5.50	1.00	0.70	2.06	1.00	4.90	2.81E-02	1.43E-02
10.00	3.16	0.00	5.50	1.00	0.70	2.06	1.00	5.25	3.00E-02	1.53E-02



WELLPOINT FILTER AT IMPERVIOUS BOUNDARY

A

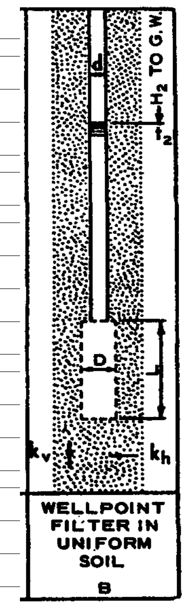
DRILL HOLE: DH-3

k equation for well in uniform soil:

$$k_h = \frac{d^2 \ln\left(\frac{2mL}{D}\right)}{8L\,(t_2 - t_1)} \ln \frac{H_1}{H_2} \quad \text{FOR} \quad \frac{mL}{D} > 4$$

		inches	*Feet*
Screen Diameter	D =	4.00	0.33
Screen Length	L =		5.00
Diam:Length Ratio	L/D	15.00	

Kh/Kv	m	t1(min)	H1 (ft)	t2(min)	H2 (ft)	ln (h1/H2)	(t2-t1)	ln (2mL/D)	Kh (ft/min)	Kh (cm/sec)
1.00	1.00	0.00	5.50	0.50	1.20	1.52	0.50	3.40	2.88E-02	1.47E-02
5.00	2.24	0.00	5.50	0.50	1.20	1.52	0.50	4.21	3.56E-02	1.81E-02
10.00	3.16	0.00	5.50	0.50	1.20	1.52	0.50	4.55	3.85E-02	1.96E-02
1.00	1.00	0.50	1.20	1.00	0.70	0.54	0.50	3.40	1.02E-02	5.19E-03
5.00	2.24	0.50	1.20	1.00	0.70	0.54	0.50	4.21	1.26E-02	6.42E-03
10.00	3.16	0.50	1.20	1.00	0.70	0.54	0.50	4.55	1.36E-02	6.95E-03
1.00	1.00	0.00	5.50	1.00	0.70	2.06	1.00	3.40	1.95E-02	9.93E-03
5.00	2.24	0.00	5.50	1.00	0.70	2.06	1.00	4.21	2.41E-02	1.23E-02
10.00	3.16	0.00	5.50	1.00	0.70	2.06	1.00	4.55	2.61E-02	1.33E-02



WELLPOINT FILTER IN UNIFORM SOIL

B

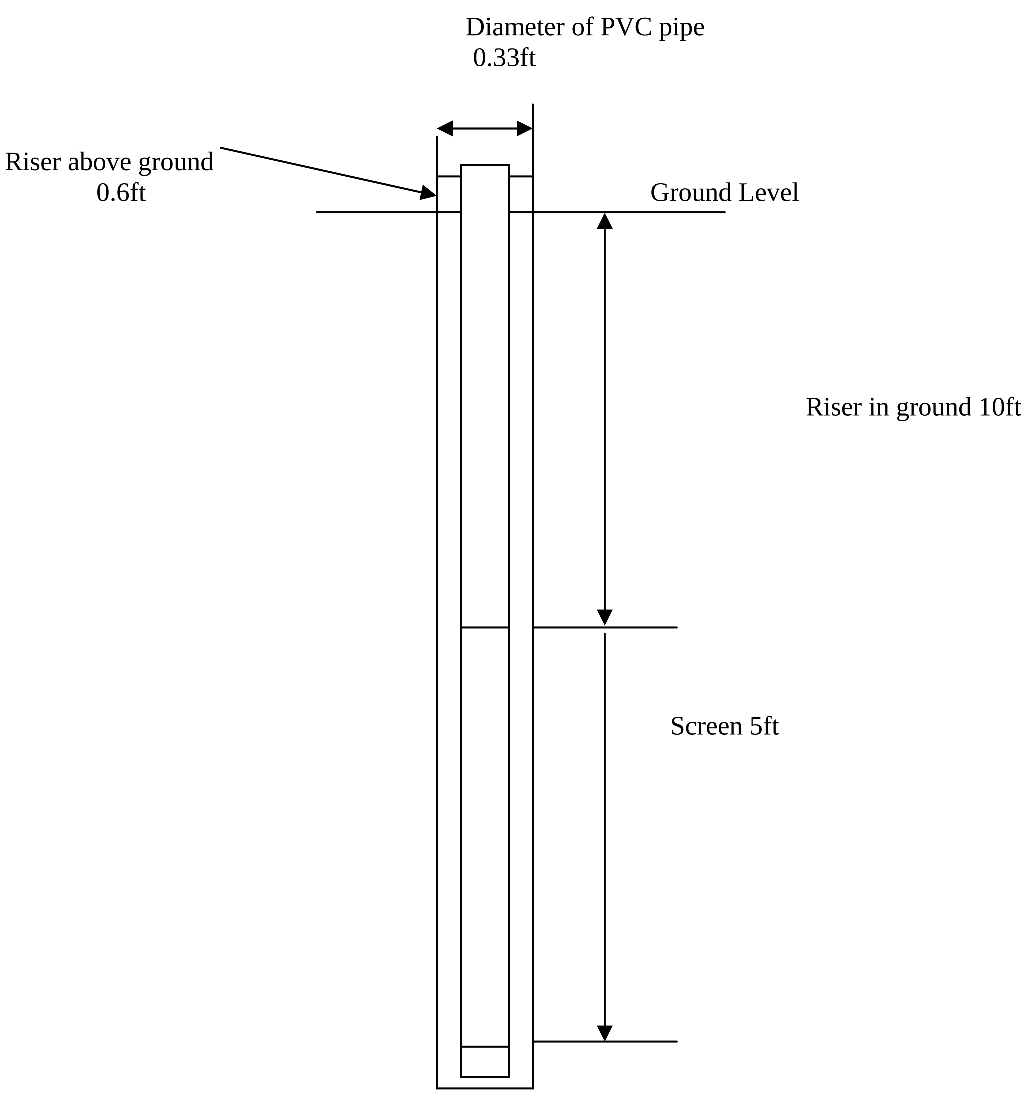
CONSTANT HEAD DATA FORM

PROJECT Huntington Flood Control Project DATE 28 March 2008 LOCATION: Huntington, VA

WELL ______DH 6A_______ LENGHT OF SCREEN 5 Ft RISER IN GROUND 10 ft
RISER ABOVE GROUND 0.6 ft INITIAL WATER LEVEL 5.8ft

REMARKS____

Time (mins)	Water added (gallons)	Water Level (feet)	Pumping Rate (gallons/min)
0	0	0.6	0
5	8	0.6	1.6
10	8	0.6	1.6
15	9	0.6	1.6
20	6	0.6	1.6



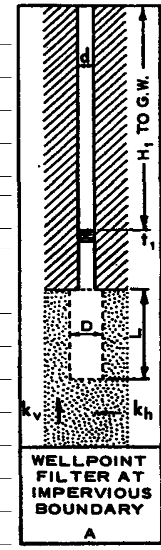
DRILL HOLE: DH-6

k equation for well with Impervious boundary above aquifer

$$k_h = \frac{q \ln\left[\frac{2mL}{D} + \sqrt{1 + \left(\frac{2mL}{D}\right)^2}\right]}{2\pi L H_c}$$

		inches	*Feet*
Screen Diameter	D =	4.00	0.33
Screen Length	L =		5.00
Diam:Length Ratio	L/D	15.00	
		gpm	*cfm*
Flow rate	q	1.55	0.21
Head (ft)	h	5.20	

Kh/Kv	**m**	**(2*mL/D)**	**Kh (ft/min)**	**Kh (cm/sec)**
1.00	1.00	30.00	5.18E-03	2.64E-03
5.00	2.24	67.08	6.20E-03	3.16E-03
10.00	3.16	94.87	6.64E-03	3.38E-03



DRILL HOLE: DH-6

k equation for well in uniform soil:

$$k_h = \frac{q \ln\left[\frac{mL}{D} + \sqrt{1 + \left(\frac{mL}{D}\right)^2}\right]}{2\pi L H_c}$$

		inches	*Feet*
Screen Diameter	D =	4.00	0.33
Screen Length	L =		5.00
Diam:Length Ratio	L/D	15.00	
		gpm	*cfm*
Flow rate	q	1.55	0.21
Head (ft)	h	5.20	

Kh/Kv	**m**	**(mL/D)**	**Kh (ft/min)**	**Kh (cm/sec)**
1.00	1.00	15.00	4.30E-03	2.20E-03
5.00	2.24	33.54	5.32E-03	2.71E-03
10.00	3.16	47.43	5.76E-03	2.94E-03