Appendix E

Implications of Soil Heterogeneities on Fate and Transport

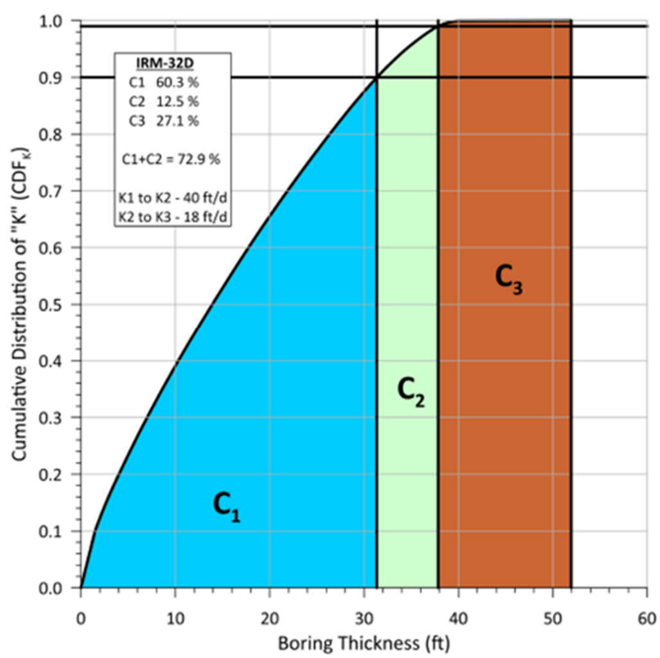
APPENDIX E – Implication of Soil Heterogeneities on Fate and Transport

I. Relationship Between Soil Heterogeneities and Fate and Transport

During implementation of the Phase II and Phase III IRM remediation and monitoring well networks, approximately 2,824 vertical feet of HPT boring was conducted at 54 different locations. Vertical depths ranged from approximately 22.08 feet (ft) below ground surface (bgs) to 85.05 feet bgs (-9.4 ft NAVD88 to -73.95 ft NAVD88). These borings were performed to obtain high-resolution hydraulic conductivity data within the Phase II and III IRM areas. This high-resolution IRM characterization information improved the understanding of site stratigraphic resolution and heterogeneities in the intermediate and deep water-bearing zones. The hydraulic conductivity response measured via HPT is obtained via minor injections of water from the tooling along the vertical extent of the boring, with concurrent measurements of downhole pressure change. This methodology has sufficient resolution to reliably identify hydraulic conductivity differences throughout the vertical extent of each boring. Outputs from the Phase II and III IRM HPT borings are included on **Figures E1** through **E33** and **Figures E34** through **E54**, respectively.

The data from individual high-resolution HPT borings are useful in understanding changes in relative permeability and apparent differences in boring-specific groundwater and Cr flux. A review of these individual borings also provides a clear indication that the migration of groundwater and Cr at Site 114 is not uniform. To support this analysis, the direct hydraulic conductivity data obtained from each HPT profile were sorted using a cumulative distribution function (CDF_K) plot to group individual aquifer fractions for relative permeability evaluation (see inset example at right) (Horst et al. 2017[1]). The CDF_K figures are an effective method to sort and understand the relative fraction of hydraulic conductivity distribution on the y-axis (0.0 to 1.0) with the corresponding boring thickness along the x-axis. This improves visualization of the order of magnitude differences in hydraulic conductivity data to identify the fraction of the groundwater flow (approximated from the hydraulic conductivity) that occurs across the boring thickness. Based on the relative hydraulic conductivities observed across each HPT profile, the order of magnitude differences in relative permeability are illustrated by sorting them from most permeable to least permeable into three compartments: C1, C2, and C3. Given the order of magnitude changes between each compartment, these compartments identify the overall fraction of the soil profile through which 90%, 9%, and 1%, respectively, of the groundwater flux moves through Site 114 soils. In the inset figure at right for boring 114-P2-IRM-32D, the C1 compartment representing 90% of the flux (CDF_K between 0.0 – 0.9) is encountered across

Cumulative distribution function plot for 114-P2-IRM-32D



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[1] Horst, J., S. Potter, M. Schnobrich, N. Welty, A. Gupta, and J. Quinan. 2017. *Advancing Contaminant Mass Flux Analysis to Focus Remediation: The Three-Compartment Model. Groundwater Monitoring & Remediation 37, no. 4, Fall.*

approximately 31 feet of the boring, the C2 compartment representing 9% of the flux (CDF_K between 0.90 – 0.99) is encountered across 7 feet of the boring, and the C3 compartment representing 1% of the flow (CDF_K between 0.99 – 1.0) is encountered across 14 feet of the boring.

C1 and C3 are separated by two orders of magnitude difference in relative permeability, which defines the difference between advection (C1) and diffusion (C3) transport processes (ESTCP 2012[2]). C2 resides between these two zones and is dominated by slow advection processes. Both advection-dominated zones (C1 and C2) can be considered permeable, whereas the diffusion-dominated zone (C3) can be considered to have little to no permeability. The net result for the inset example on the previous page is that 38 feet of the boring (73%) consists of permeable soils and 14 feet of the boring (27%) consists of soils with little to no permeability.

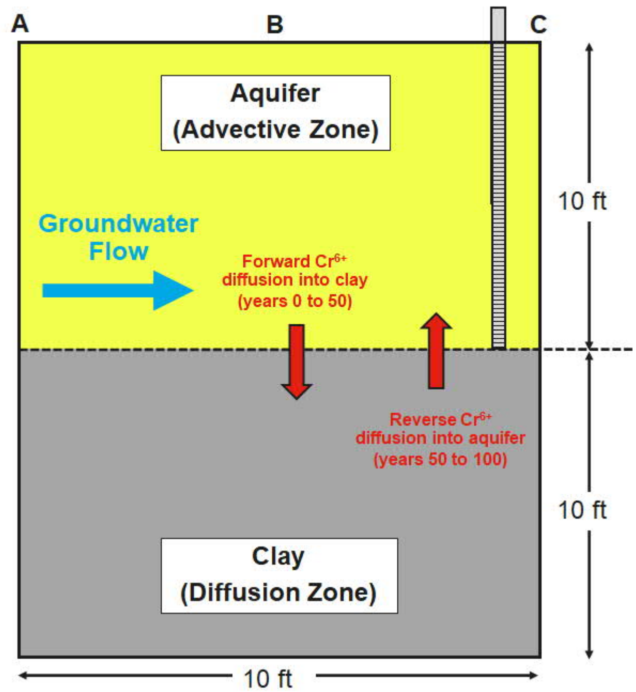
A summary of the CDF_K plot output metrics for each of the Phase II and III IRM borings are presented in **Tables E1** and **E2**. When the individual borings are sorted via the above methods, the total 1,560 feet of Phase II IRM HPT borings indicate that approximately 852 feet (55%) are identified as C1 soils, 306 feet (20%) are identified as C2 soils, and 401 feet (25%) are identified as C3 soils (**Table E1**). Similarly, the total 1,264 feet of Phase III IRM HPT borings indicate that approximately 693 feet (55%) are identified as C1 soils, 203 feet (16%) are identified as C2 soils, and 368 feet (29%) are identified as C3 soils (**Table E2**). The compiled totals for each zone in the Phase II and Phase III IRM borings are considered equivalent considering the heterogeneities of the GAG site soils. Combining all 2,824 feet of HPT boring information from both Phase II and III IRM areas, approximately 73% of the intermediate and deep water-bearing zones soils are considered permeable and 27% of these soils are characterized by little to no permeability.

[2] ESTCP, 2012. Farhat, S.K., C.J. Newell, T.C. Sale, D.S. Dandy, J.J. Wahlberg, M.A. Seyedabbasi, J.M. McDade, and N.T. Mahler. *Matrix Diffusion Toolkit, developed for the Environmental Security Technology Certification Program (ESTCP) by GSI Environmental Inc., Houston, Texas*. 2012.

II. Matrix Diffusion Modeling – Cr^{+6} Distribution and Future Transport

To understand the effects of diffusive Cr^{+6} mass discharge from the low permeability strata of the intermediate and deep water-bearing zones, two different matrix diffusion modeling methods were used to simulate both the loading and release phases between higher permeability and adjacent low permeability soils. These include a Numerical Diffusion Model developed by Arcadis as well as the Matrix Diffusion Toolkit (ESTCP 2012[3]). These models were designed to evaluate matrix diffusion relationships between soils of varied relative permeability. Both models leverage a loading phase wherein a groundwater analyte migrates via diffusion from a higher permeability advection zone into a lower permeability diffusion zone. The loading phase is then followed by a subsequent diffusion phase to assess: 1) mass discharge from the low permeability to the high permeability zone (i.e., back or reverse diffusion); and 2) continued diffusion deeper into the low permeability zone (i.e., forward diffusion).

Both models were set up using a range of parameters applicable to understanding diffusion at and near Site 114. The advective zone was assumed to be 10 feet (ft) thick with an average groundwater flow velocity of 0.01 ft/day. Groundwater velocity was determined within the sheet pile area using a hydraulic conductivity value of 5 ft per day, a gradient of 0.00025 ft per ft, and a mobile porosity of 12.5%. This slow flow rate is considered representative of flow within the sheet pile, but groundwater velocity does not have a significant bearing on the diffusion model outputs. The underlying mass storage zone was represented by a 10 ft thick clay unit with a total porosity (n) of 40% and no advective flow (Text Figure 1). While many of the clay sequences identified in the intermediate and deep water-bearing-zones are thinner than 10 ft, this thickness was selected to understand the extent of Cr^{+6} diffusion over the modeled durations knowing that the outputs can therefore be applied to any other clay sequence of comparable or thinner thickness. An effective diffusivity (D_e) term of 5.60E-6 cm^2/sec was assigned for Cr^{+6} based on the diffusivity (D) term of chloride in water value of 1.89E-5 cm^2/sec (Cussler, 1984[4]) using the equation $D_e = D*n^{1.33}$.



Text Figure 1 – Conceptual numerical model domain

To simulate the forward diffusion of Cr^{+6} from the advective zone to the mass storage zone, a fixed concentration of 100 milligrams per liter (mg/L) Cr^{+6} was simulated in the advective zone for a period of 50 years. The 100 mg/L Cr^{+6} concentration was selected as it applies to most of the impacted groundwater area at Site 114. Investigation data have demonstrated that Cr^{+6} concentrations are higher

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[3] ESTCP, 2012. Farhat, S.K., C.J. Newell, T.C. Sale, D.S. Dandy, J.J. Wahlberg, M.A. Seyedabbasi, J.M. McDade, and N.T. Mahler, 2012. Matrix Diffusion Toolkit, developed for the Environmental Security Technology Certification Program (ESTCP) by GSI Environmental Inc., Houston, Texas.

[4] Cussler, E.L. 1984. Diffusion: Mass transfer in fluid systems. Cambridge University Press.

than this in select areas of the site and have also demonstrated that Cr^{+6} attenuates in concentration with increased depth in other areas. Ultimately, the resulting outputs of the matrix diffusion modeling programs are proportional to the starting concentration, so can be easily modified based on the assumed starting concentration relative to that applied for the model. As an example, if 200 mg/L was used as the loading concentration, the model outputs would be two-fold higher than the concentration obtained using a 100 mg/L loading value. Given the spatial and vertical variability of Cr^{+6} at the site, the 100 mg/L number therefore serves as a representative midpoint of what is found at Site 114 and is easily scalable to guide interpretations. While chromite ore processing predates the assumed timeframe of the 50-year loading period, it is challenging to pinpoint exactly when dissolved Cr^{+6} migrated through the shallow zone, the meadow mat, and then the more permeable soils of the intermediate and deep water-bearing-zones where it began diffusing into lower permeability soils. Based on plume dynamics, it is expected that Cr^{+6} transport would have started at lower concentrations and then built in Cr^{+6} concentration over time. Given that the 50-year modeling duration assumes a stable Cr^{+6} concentration (100 mg/L) and that diffusion is concentration dependent, the 50-year duration was chosen to account for the dynamics of early Cr^{+6} plume invasion and to allow a long enough timeframe to understand matrix diffusion effects. Considering that the outputs of both models demonstrate that 50 years is sufficient longevity for Cr^{+6} diffusion through the 10-ft clay zone, variability around the 50-year timeframe does not substantively affect the analysis.

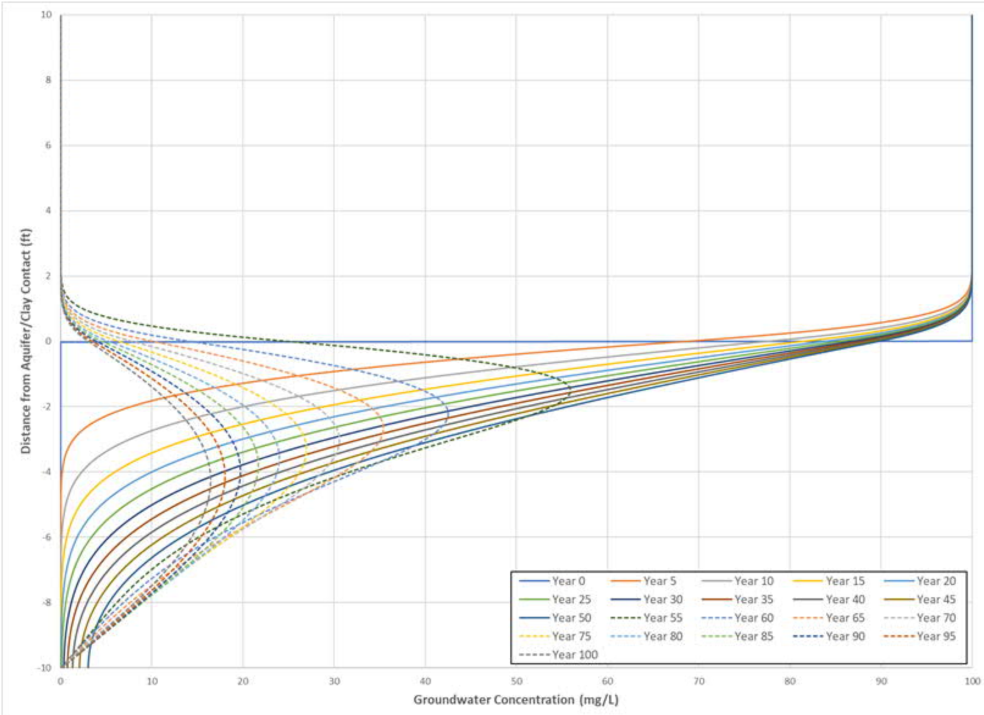
The final modeling step included a step governed by diffusion only. After the loading period of 50 years, the advective zone Cr^{+6} source concentration in both models was set to 0 mg/L to allow projection of the future mass discharge of Cr^{+6} from the low permeability soils back into the advective zone. This reverse modeling portion was run for an additional 50 years. The outputs of both models employed are outlined in the sections below.

Numerical Modeling Approach

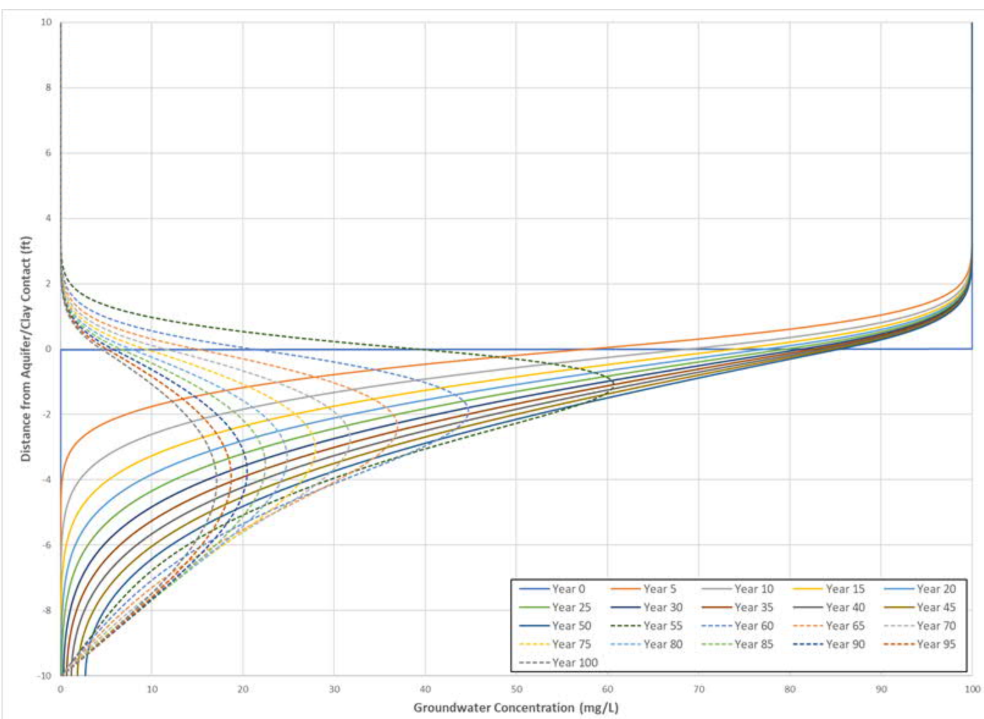
For the numerical modeling simulation, the model domain established as outlined on the previous page and used to simulate 100 years of diffusion split between both the forward and reverse diffusion stages. The model was constructed in accordance with Text Figure 1 and with the model parameters stated on the previous page to allow evaluation of differences in diffusion profiles along a plume flow path (locations B and C) downgradient of the initial source (location A).

The results profiles for locations B and C are plotted on the following page. Solid lines represent incremental 5-year intervals during the forward diffusion phase and dashed lines represent the projections once the Cr^{+6} concentration in the permeable zone is reduced to 0 mg/L after year 50.

The profiles on Text Figures 2 and 3 show that during the 50-year loading period, Cr^{+6} concentrations are expected to gradually diffuse into at least 10 feet of lower permeability soils where they decline in concentration with depth. Following reduction of the Cr^{+6} concentration to 0 mg/L after year 50, the reverse diffusion period begins and lower concentrations of Cr^{+6} are predicted within the advective zone just above the interface. The highest mass discharge from the low permeability zone into the advective zone occurs immediately following source removal (years 51 through 55), following which mass discharge release from the low permeability soils declines. This decrease in mass discharge occurs due to the reduced concentrations of Cr^{+6} at the diffusion zone interface associated with the loss of Cr^{+6} from the low to high permeability zones and the further diffusion of Cr^{+6} deeper into the low permeability zone. This pattern progresses with time, with sequential declines in mass discharge from low to high permeability zones and the gradual downward migration of the center of Cr^{+6} mass into the low permeability zone where it stabilizes. While modeled for a 10-foot sequence of low permeability zone soils, this same relative pattern would be expected in zones that are both narrower or thicker in vertical thickness.

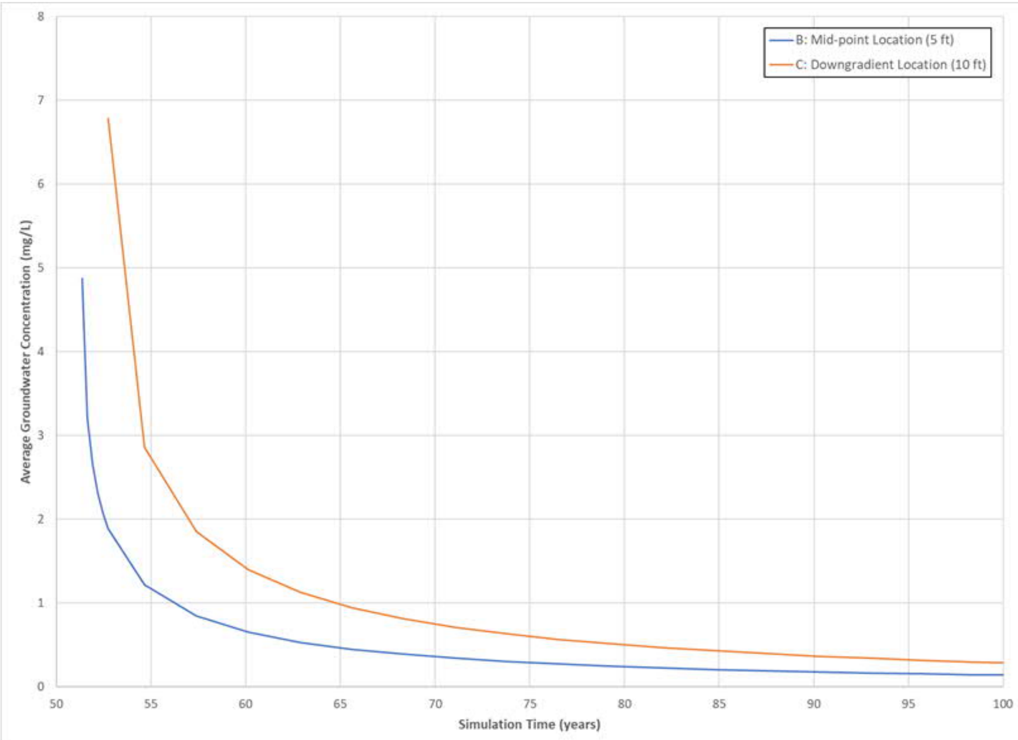


Text Figure 2 – Forward and reverse diffusion projections for 100-year model duration 5 ft downgradient from source (B).



Text Figure 3 – Forward and reverse diffusion projections for 100-year model duration 10 ft downgradient from source (C).

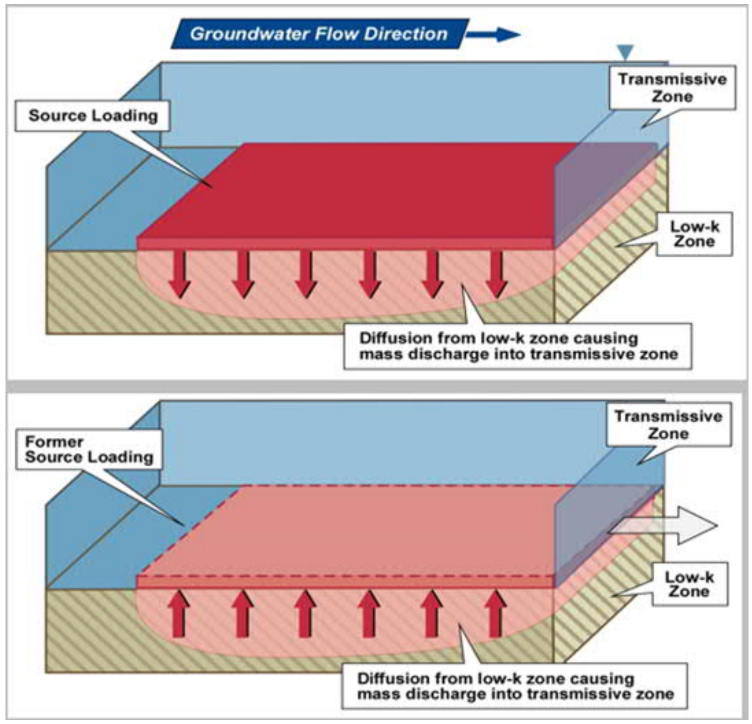
The mass discharge profiles modeled on the previous page can be leveraged to calculate the expected Cr^{+6} concentration in advection zone groundwater for each of the 5-year time periods between year 50 and 100. The graph presented on Text Figure 4 includes the predicted concentration in a theoretical monitoring well installed at both locations B and C and screened across 10 ft of the advection zone.



Text Figure 4 – Predicted Cr^{+6} concentrations at two theoretical monitoring wells installed at locations 5 ft (B) and 10 ft (C) within the model domain.

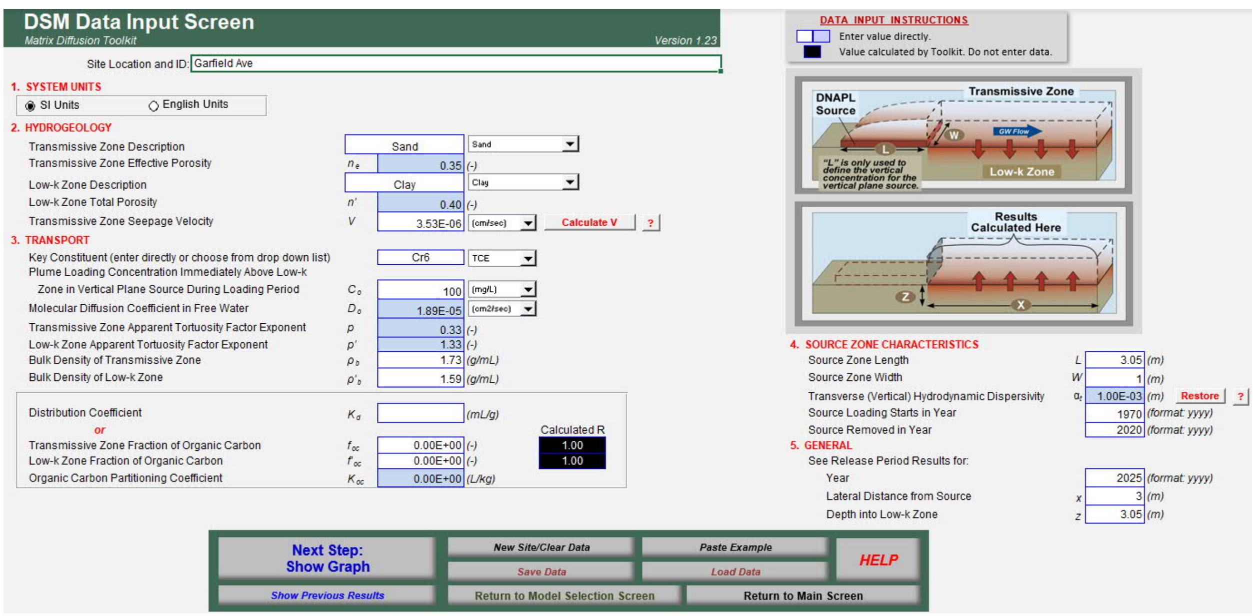
Matrix Diffusion Toolkit Application

The second model used to assess both forward and reverse Cr^{+6} diffusion was the Matrix Diffusion Toolkit, which is an industry-accepted and publicly available method served to validate the simulations of the first modeling approach. The estimates were developed using the square root model input parameters, the same model domain size specifications, and the same source Cr^{+6} concentration as outlined in the preceding section. The modeling process adhered to the guidance provided and used the Dandy-Sale Model (DSM) approach. The conceptual modeling approach related to both source loading and diffusion phases is outlined on Text Figure 5 at right.



Text Figure 5 - Dandy-Sale Model Domain

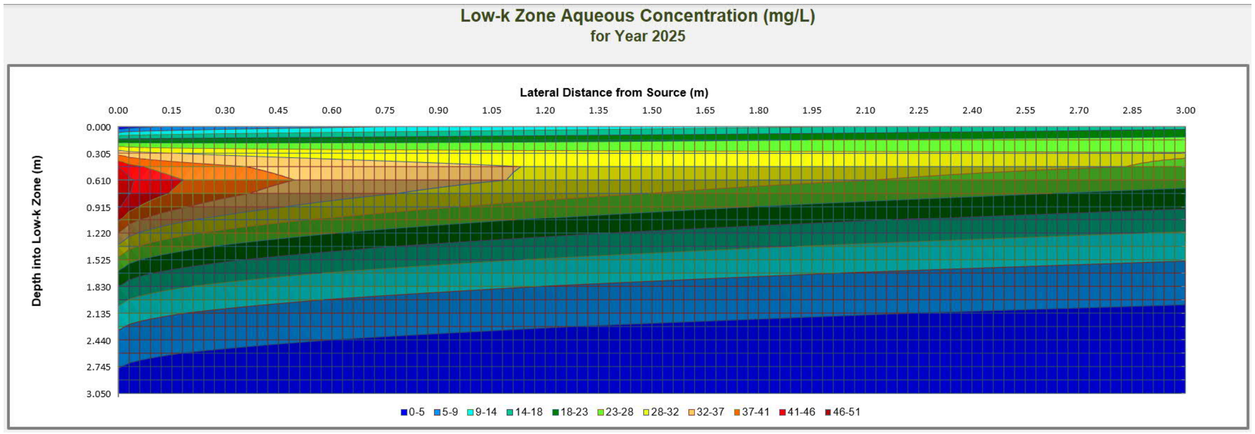
A summary of the model data input parameters used as a basis for diffusion simulation are included in Text Figure 6. These utilized the same value for molecular diffusion, assumed no sorption, and assumed a source concentration of 100 mg/L.



Text Figure 6 - Matrix Diffusion Toolkit assumptions and input parameters

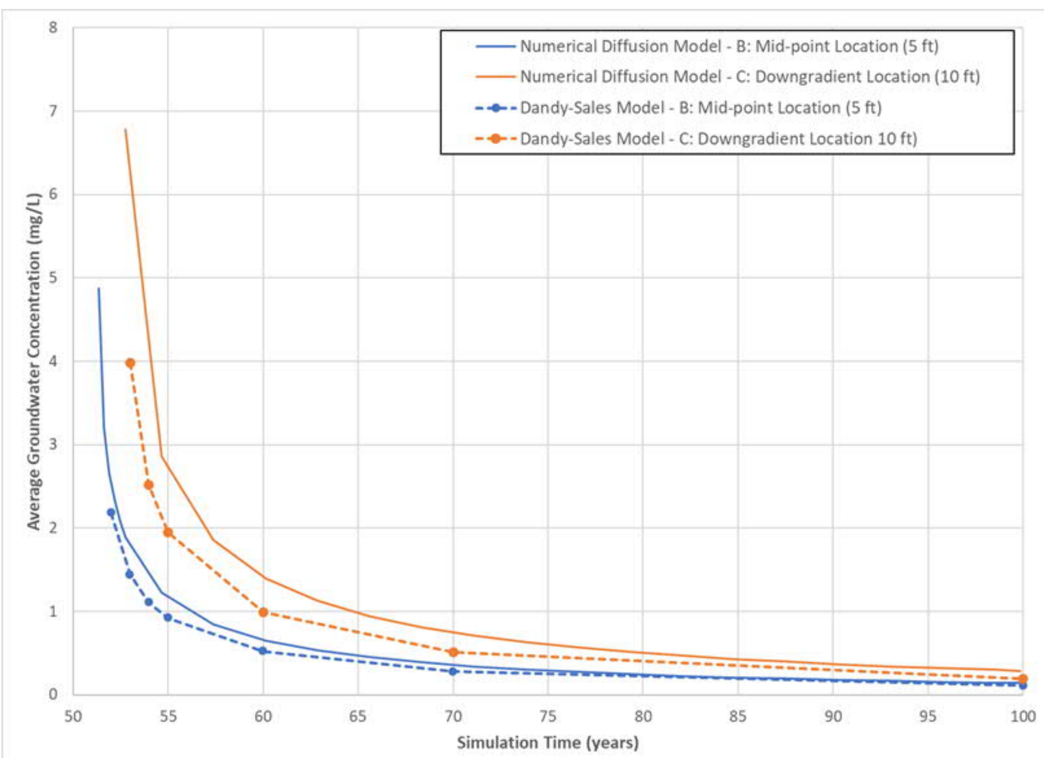
Similar to the outputs of the first numerical model, the DSM methodology allows estimation of the potential diffusion depths of Cr^{+6} during the initial 50-year loading period and then allows time-based estimates of the advective zone concentrations following source removal. Using the input entries from the

DSM interface on the preceding page, the plots for Cr^{+6} diffusion into the low permeability zone and an example profile for Cr^{+6} concentrations within the advective zone are included on Text Figure 7.



Text Figure 7 - Projected Cr^{+6} concentrations in low permeability soils during year 55, 5 years following source elimination.

The Matrix Diffusion Toolkit approach does not allow outputs of multiple time series data over a prolonged timeframe similar to Text Figure 4; therefore, the data from the individual time periods (e.g., years 55, 60, 65, etc) were compiled from the 50- to 100-year durations to develop profiles for comparison both modeling approaches. Text Figure 8 is therefore provided the compare the predicted Cr^{+6} concentrations within the advection zone in a theoretical 10-ft monitoring well for both modeling approaches.



Text Figure 8 - Predicted Cr^{+6} concentrations at theoretical monitoring wells within modeled domains.

Diffusion Model Summary

Separate modeling runs were conducted in two different modeling packages to assess consistency of the results. The concentrations of Cr^{+6} predicted in monitoring wells installed at the diffusion interface from both models are in good general agreement. Both models predicted that the highest Cr^{+6} rate of diffusion-based Cr^{+6} discharge occurs within the first 5 to 10 years after removing the Cr^{+6} model source (55 to 60 years from beginning of loading), following which they gradually decline to less than 1 mg/L by year 15 (65 years from beginning of loading) (Text Figure 8).

The diffusion modeling provides information useful to understanding the relative distribution of Cr^{+6} within lower permeability soils and its expected behavior following source removal in the more permeable zone soils. These are conceptualized in Section I as the C1 and C2 compartments which are dominated by advection, and the C3 compartment which is dominated by diffusion. In conjunction with the HPT CDF_K analysis from Site 114, these collective findings have the following implications for the Conceptual Site Model and remedy development:

- Low permeability materials account for approximately 27% of the intermediate and deep water-bearing zones and are expected to contain Cr^{+6} concentrations that are within one order of magnitude less than the concentrations measured in the adjacent higher permeability zones (prior to any treatment). The Cr^{+6} concentrations within these low permeability soils decline with increased vertical thickness, and diffusion gradients limit migration deeper into the soil column.

- The models predicted that dissolved Cr^{+6} is expected to reside in the low permeability soils for an extended period (at least an additional 50 years), but also demonstrate that the slow rate of diffusion serves to immobilize Cr^{+6} within these soils, limits future migration of Cr^{+6}, and stabilizes Cr^{+6} within the aquifer.

- The expected release of Cr^{+6} from the low permeability zone will be highest within the first several years following Cr^{+6} treatment, following which mass discharge from low to high permeability zones will decline significantly within 5 to 10 years.

Attachments

Table E1	Phase II IRM CDF_K Summary Metrics
Table E2	Phase III IRM CDF_K Summary Metrics

Figure E1	114-P2-MW-1D
Figure E2	114-P2-MW-2D
Figure E3	114-P2-MW-3D
Figure E4	114-P2-MW-4D
Figure E5	114-P2-MW-5D
Figure E6	114-P2-MW-6D
Figure E7	114-P2-MW-7D
Figure E8	114-P2-MW-8I
Figure E9	114-P2-MW-9D
Figure E10	114-P2-MW-10I
Figure E11	114-P2-MW-11I
Figure E12	114-P2-MW-12D
Figure E13	114-P2-IRM-1I
Figure E14	114-P2-IRM-5D
Figure E15	114-P2-IRM-11D
Figure E16	114-P2-IRM-15D
Figure E17	114-P2-IRM-17D
Figure E18	114-P2-IRM-29D
Figure E19	114-P2-IRM-32D
Figure E20	114-P2-IRM-35I
Figure E21	114-P2-IRM-42D
Figure E22	114-P2-IRM-53I
Figure E23	114-P2-IRM-55I
Figure E24	114-P2-IRM-69I
Figure E25	114-P2-IRM-74I
Figure E26	114-P2-IRM-76D
Figure E27	114-P2-IRM-87D
Figure E28	114-P2-IRM-89D
Figure E29	114-P2-IRM-92DR
Figure E30	114-P2-IRM-94I
Figure E31	114-P2-IRM-96I
Figure E32	114-P2-IRM-97I
Figure E33	114-P2-IRM-92D-2
Figure E34	P3-IRM-VAP01
Figure E35	P3-IRM-VAP02
Figure E36	P3-IRM-VAP03
Figure E37	P3-IRM-VAP04
Figure E38	P3-IRM-VAP05
Figure E39	P3-IRM-VAP06
Figure E40	P3-IRM-VAP07
Figure E41	P3-IRM-VAP08
Figure E42	P3-IRM-VAP09
Figure E43	P3-IRM-VAP10
Figure E44	P3-IRM-VAP11
Figure E45	P3-IRM-VAP12
Figure E46	P3-IRM-VAP13
Figure E47	P3-IRM-VAP14
Figure E48	P3-IRM-VAP15
Figure E49	P3-IRM-VAP16
Figure E50	P3-IRM-VAP17
Figure E51	P3-IRM-VAP18
Figure E52	P3-IRM-VAP19
Figure E53	199-SS1
Figure E54	199-SS2

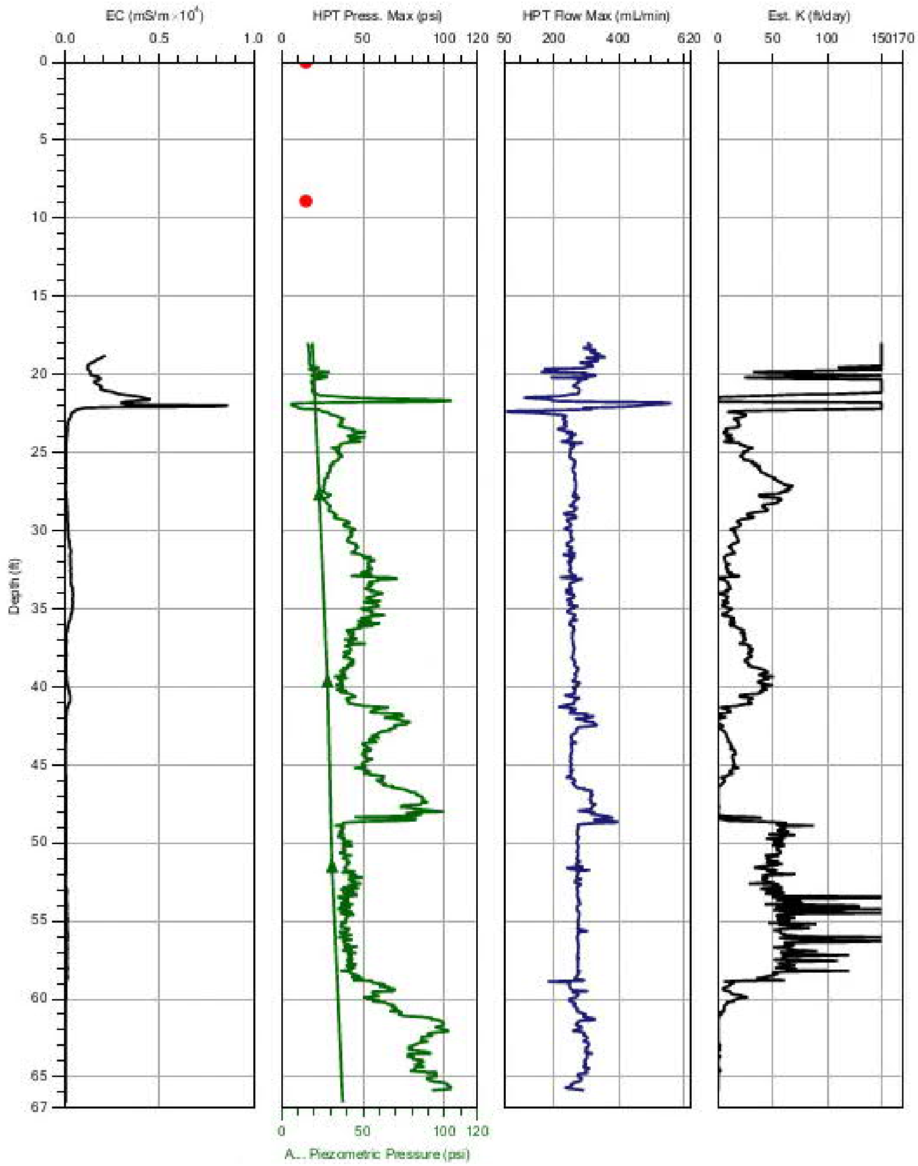
Phase II IRM Well ID		Zone of Relative Permeability		
		C1	**C2**	**C3**
MW-1D	Thickness (ft)	22.7	13.9	11.3
	% of Boring	47%	29%	24%
MW-2D	Thickness (ft)	29.6	7.8	7.0
	% of Boring	67%	18%	16%
MW-3D	Thickness (ft)	33.8	8.1	6.8
	% of Boring	69%	17%	14%
MW-4D	Thickness (ft)	18.3	11.4	16.0
	% of Boring	40%	25%	35%
MW-5D	Thickness (ft)	27.2	10.1	13.3
	% of Boring	54%	20%	26%
MW-6D	Thickness (ft)	39.1	10.0	5.2
	% of Boring	72%	18%	10%
MW-7D	Thickness (ft)	34.4	9.1	8.8
	% of Boring	66%	17%	17%
MW-8I	Thickness (ft)	28.0	11.9	24.3
	% of Boring	44%	18%	38%
MW-9D	Thickness (ft)	31.0	8.9	9.6
	% of Boring	63%	18%	19%
MW-10I	Thickness (ft)	30.2	7.1	14.0
	% of Boring	59%	14%	27%
MW-11I	Thickness (ft)	40.8	9.4	13.5
	% of Boring	64%	15%	21%
MW-12D	Thickness (ft)	29.7	6.3	15.1
	% of Boring	58%	12%	30%
IRM-1I	% of Boring	22.0	8.3	13.3
	Thickness (ft)	50%	19%	30%
IRM-5D	% of Boring	29.4	12.0	7.7
	Thickness (ft)	60%	24%	16%
IRM-11D	% of Boring	27.5	10.0	9.4
	Thickness (ft)	59%	21%	20%
IRM-15D	% of Boring	30.7	12.7	15.6
	Thickness (ft)	52%	22%	26%
IRM-17D	% of Boring	35.8	9.7	2.0
	Thickness (ft)	76%	20%	4%
IRM-29D	% of Boring	28.8	8.3	13.8
	Thickness (ft)	57%	16%	27%
IRM-32D	% of Boring	31.4	6.5	14.1
	Thickness (ft)	60%	13%	27%
IRM-35I	% of Boring	8.9	1.9	12.1
	Thickness (ft)	39%	8%	53%
IRM-42D	% of Boring	31.1	11.1	11.1
	Thickness (ft)	58%	21%	21%
IRM-53I	% of Boring	22.3	13.5	11.3
	Thickness (ft)	47%	29%	24%
IRM-55I	% of Boring	29.9	6.9	14.5
	Thickness (ft)	58%	13%	28%
IRM-69I	% of Boring	20.5	7.7	8.0
	% of Boring	57%	21%	22%
IRM-74I	Thickness (ft)	21.9	13.3	15.8
	% of Boring	43%	26%	31%
IRM-76D	Thickness (ft)	17.1	8.5	10.6
	% of Boring	47%	23%	29%
IRM-87D	Thickness (ft)	21.1	9.6	14.3
	% of Boring	47%	21%	32%
IRM-92DR	Thickness (ft)	14.1	6.5	3.8
	% of Boring	58%	27%	16%
IRM-94I	Thickness (ft)	29.9	10.9	11.0
	% of Boring	58%	21%	21%
IRM-96I	Thickness (ft)	25.8	6.5	19.1
	% of Boring	50%	13%	37%
IRM-97I	Thickness (ft)	28.5	5.8	16.8
	% of Boring	56%	11%	33%
IRM-89D	Thickness (ft)	15.1	9.4	17.0
	% of Boring	36%	23%	41%
IRM-92D-2	Thickness (ft)	18.7	5.3	1.7
	% of Boring	73%	21%	6%
Combined	Thickness (ft)	**851.9**	**306.5**	**401.7**
	% of Boring	**54.6%**	**19.6%**	**25.7%**

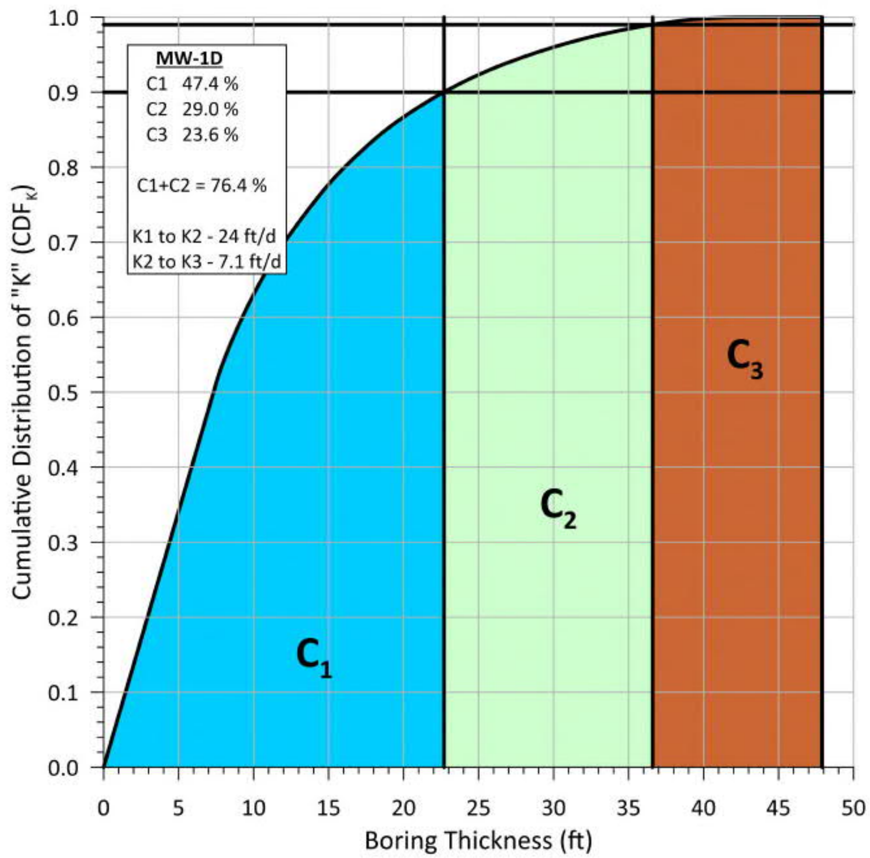
Table E2 - Phase III IRM CDFK Summary Metrics

Phase III IRM VAP ID		Zone of Relative Permeability		
		C1	C2	C3
P3-IRM-VAP01	Thickness (ft)	24.3	5.9	5.1
	% of Boring	69%	17%	14%
P3-IRM-VAP02	Thickness (ft)	27.6	11.0	13.0
	% of Boring	53%	21%	25%
P3-IRM-VAP03	Thickness (ft)	26.3	10.1	23.1
	% of Boring	44%	17%	39%
P3-IRM-VAP04	Thickness (ft)	42.1	9.7	19.7
	% of Boring	59%	14%	28%
P3-IRM-VAP05	Thickness (ft)	41.2	10.2	21.6
	% of Boring	56%	14%	30%
P3-IRM-VAP06	Thickness (ft)	44.3	13.1	4.4
	% of Boring	72%	21%	7%
P3-IRM-VAP07	Thickness (ft)	34.7	9.2	17.4
	% of Boring	57%	15%	28%
P3-IRM-VAP08	Thickness (ft)	36.7	9.0	25.5
	% of Boring	51%	13%	36%
P3-IRM-VAP09	Thickness (ft)	26.9	9.5	29.1
	% of Boring	41%	14%	44%
P3-IRM-VAP10	Thickness (ft)	34.3	9.4	22.4
	% of Boring	52%	14%	34%
P3-IRM-VAP11	Thickness (ft)	38.9	16.7	26.8
	% of Boring	47%	20%	33%
P3-IRM-VAP12	Thickness (ft)	43.9	11.3	29.8
	% of Boring	52%	13%	35%
P3-IRM-VAP13	% of Boring	29.2	8.5	31.3
	Thickness (ft)	42%	12%	45%
P3-IRM-VAP14	% of Boring	34.6	8.5	21.5
	Thickness (ft)	54%	13%	33%
P3-IRM-VAP15	% of Boring	26.5	6.3	18.4
	Thickness (ft)	52%	12%	36%
P3-IRM-VAP16	% of Boring	34.1	8.8	15.5
	Thickness (ft)	58%	15%	27%
P3-IRM-VAP17	% of Boring	40.0	11.0	2.9
	Thickness (ft)	74%	20%	5%
P3-IRM-VAP18	% of Boring	29.3	10.8	4.6
	Thickness (ft)	65%	24%	10%
P3-IRM-VAP19	% of Boring	28.1	8.3	4.1
	Thickness (ft)	69%	21%	10%
199-SS1[1]	% of Boring	21.85	5.15	14.75
	Thickness (ft)	52%	12%	35%
199-SS2[1]	% of Boring	28.15	10.65	16.65
	Thickness (ft)	51%	19%	30%
Combined	Thickness (ft)	**692.8**	**203.4**	**368.0**
	% of Boring	**54.8%**	**16.1%**	**29.1%**

Notes:

1 Site 199 borings were advanced concurrent with the Phase III IRM borings so have been combined with the Phase III IRM locations for data review.





Notes:
C1 – most permeable soils, dominated by advective transport
C2 – moderately permeable soils, dominated by slow advection
C3 – low permeability soils, dominated by diffusion

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114-P2-MW-1D

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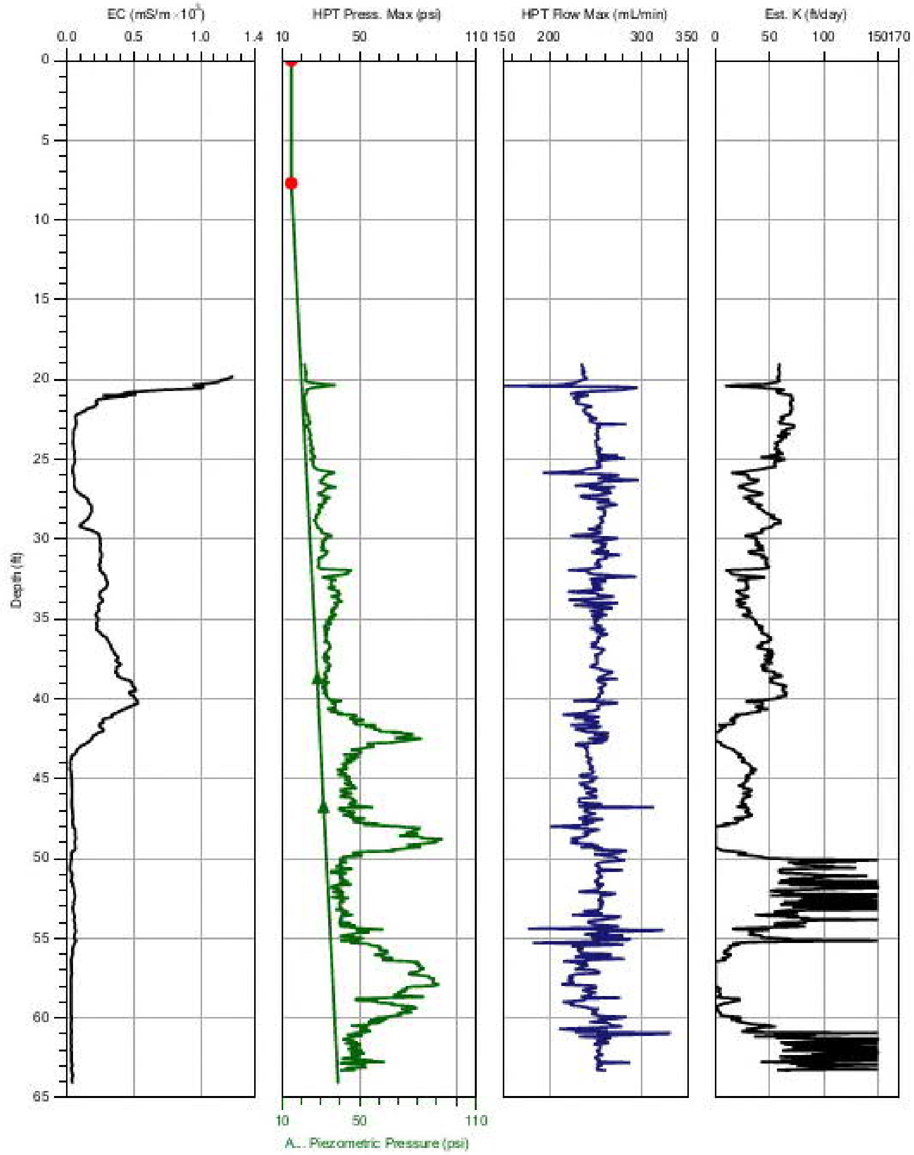
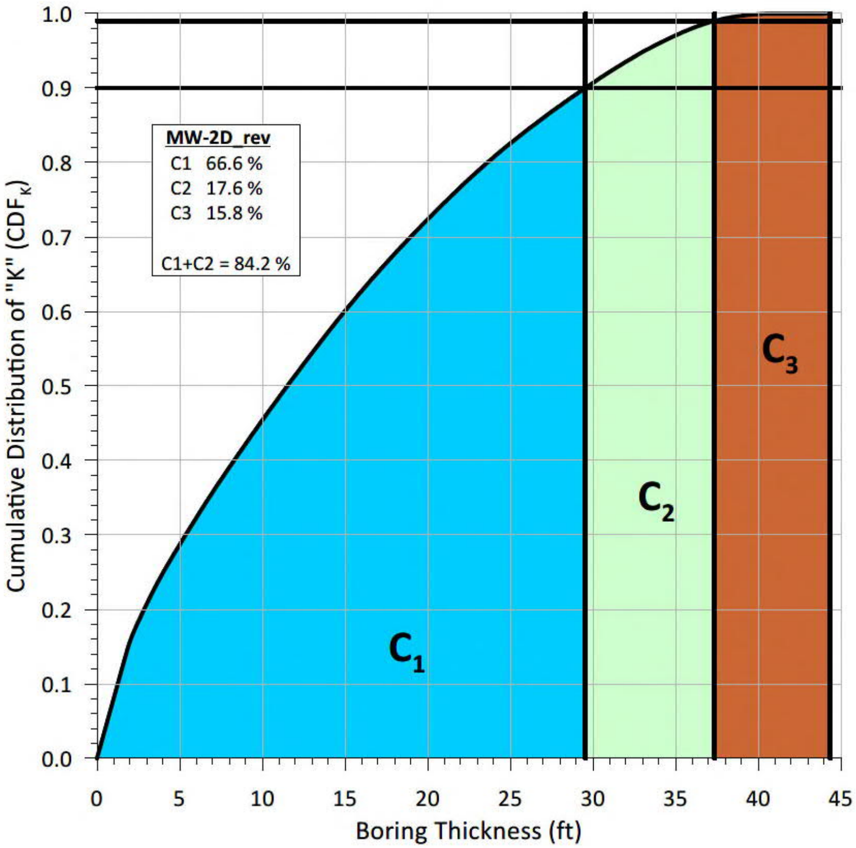
FIGURE
E1





Notes:
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114-P2-MW-2D

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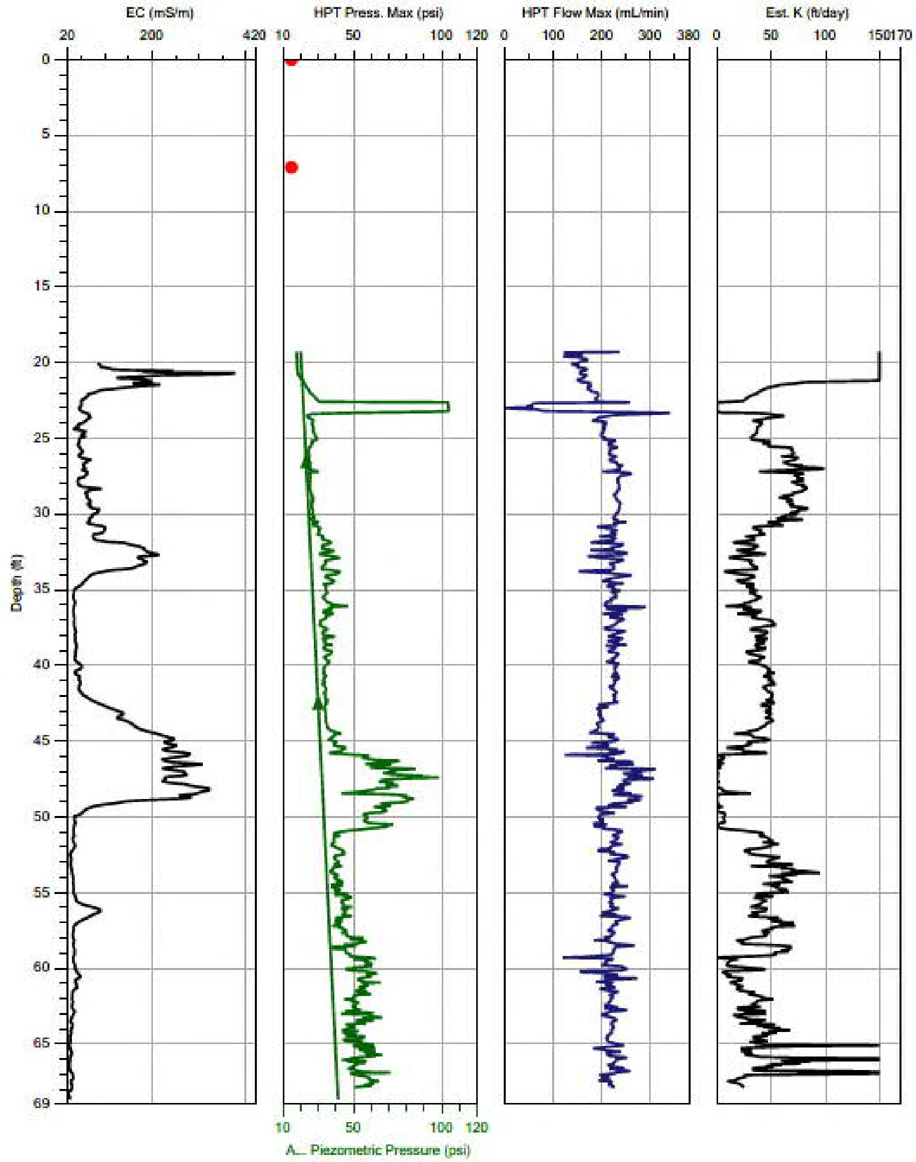
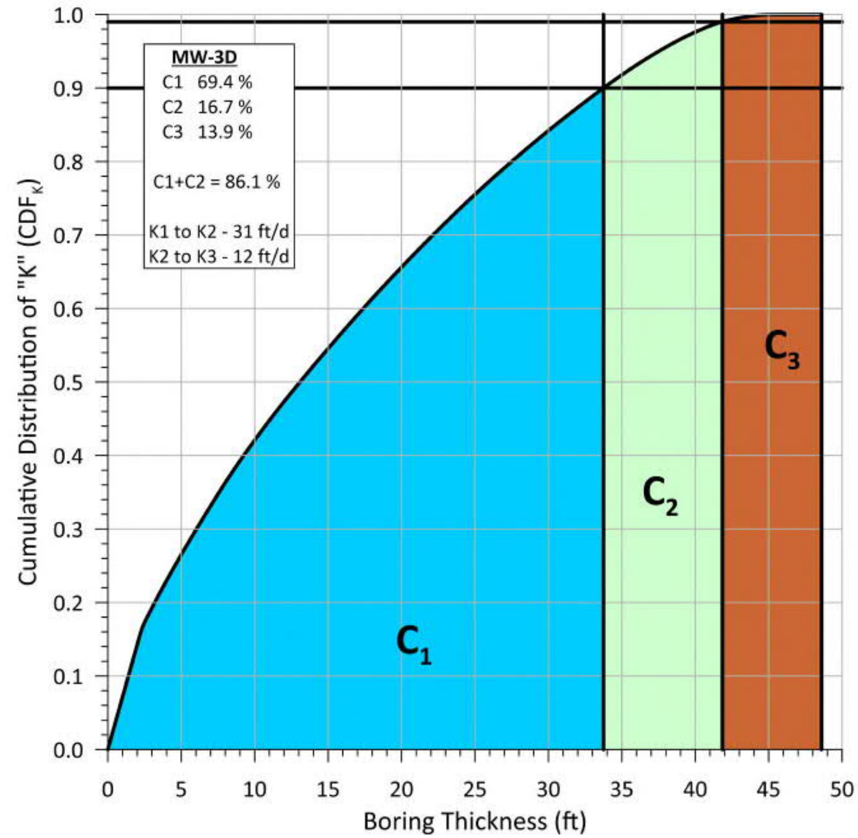
FIGURE
E2





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114-P2-MW-3D

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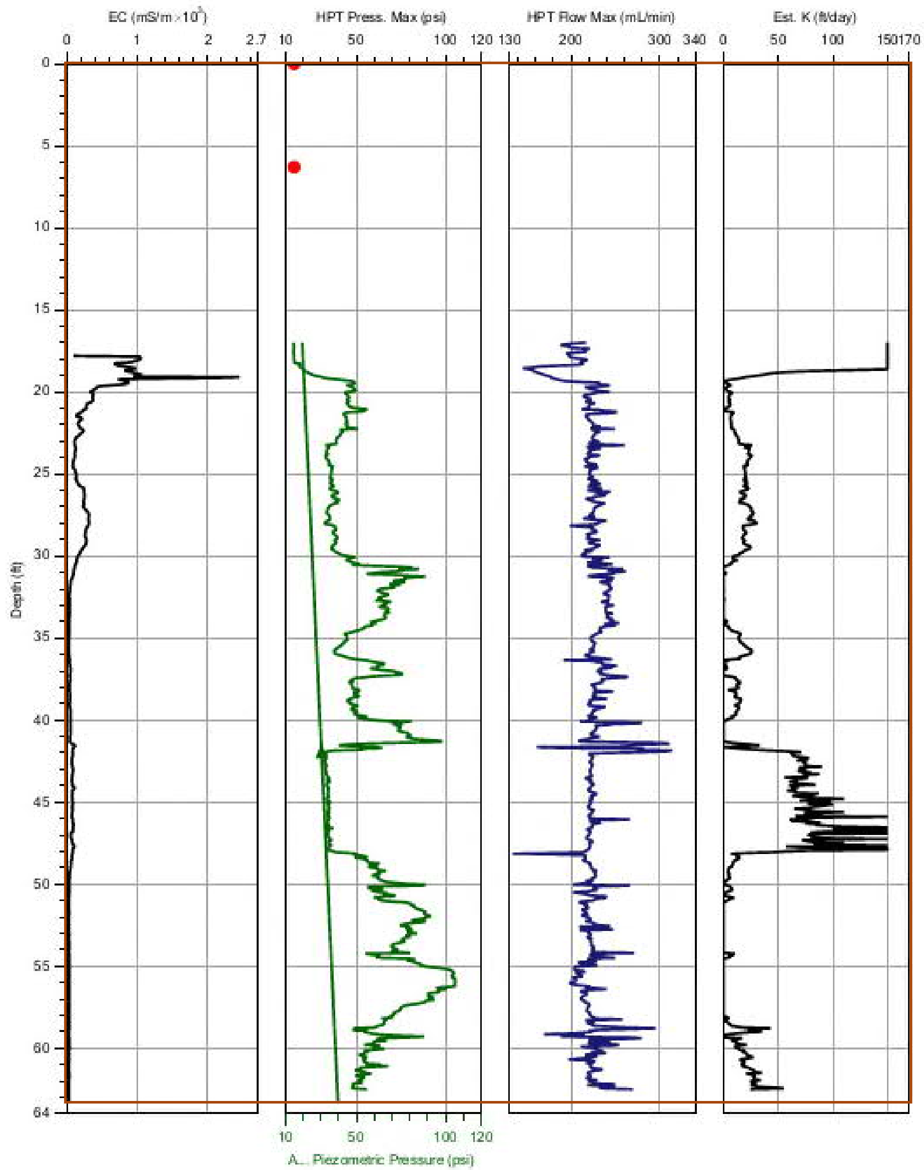
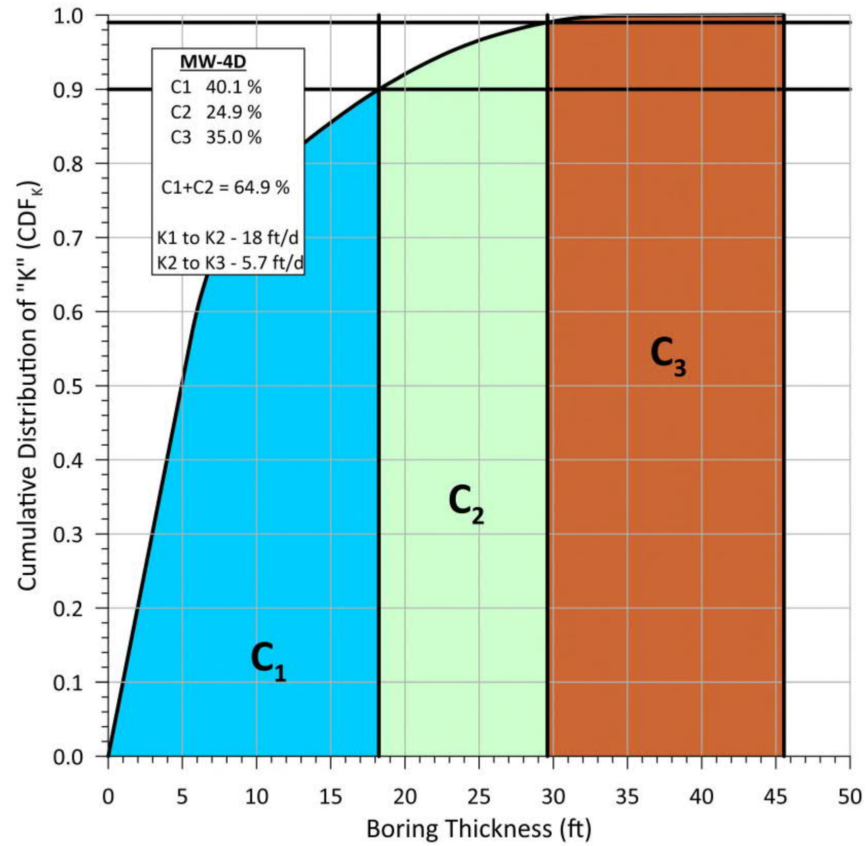
FIGURE
E3





Notes:
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114-P2-MW-4D

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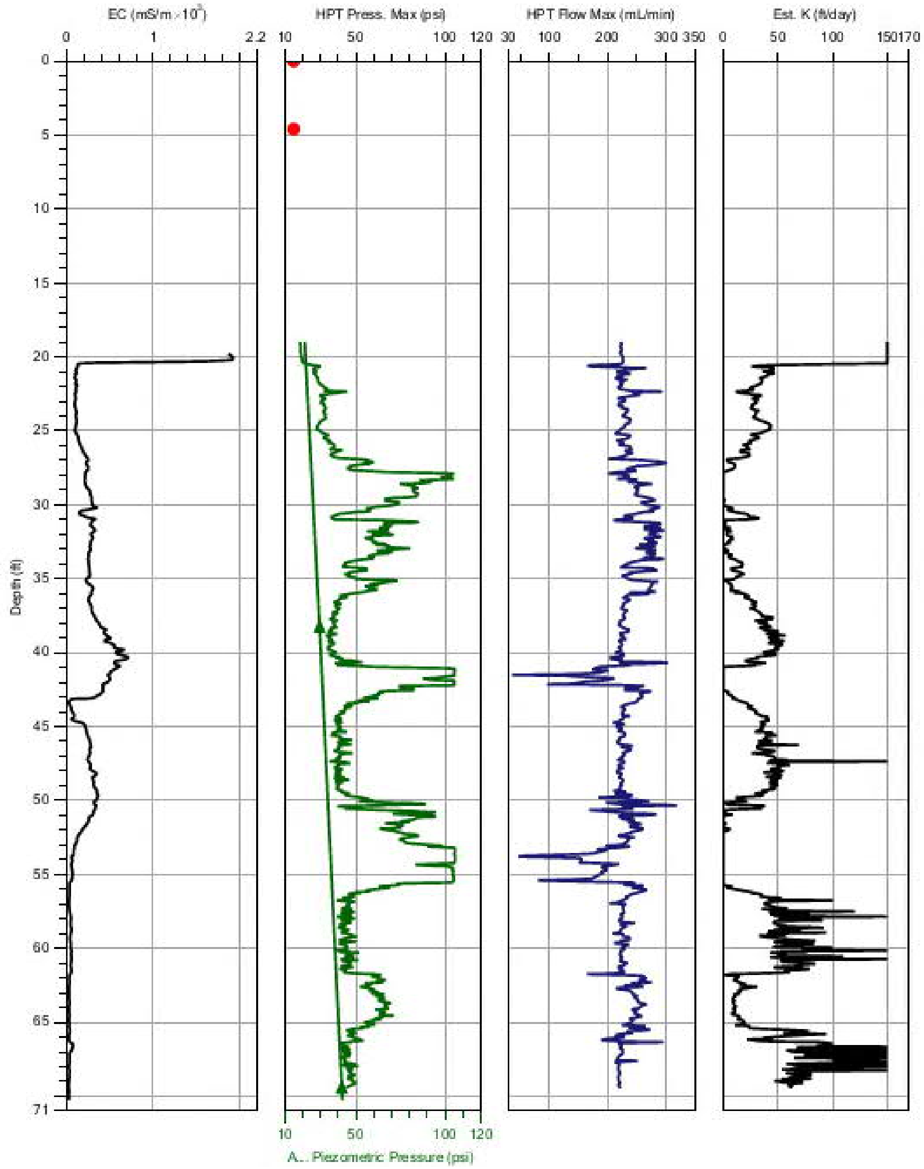
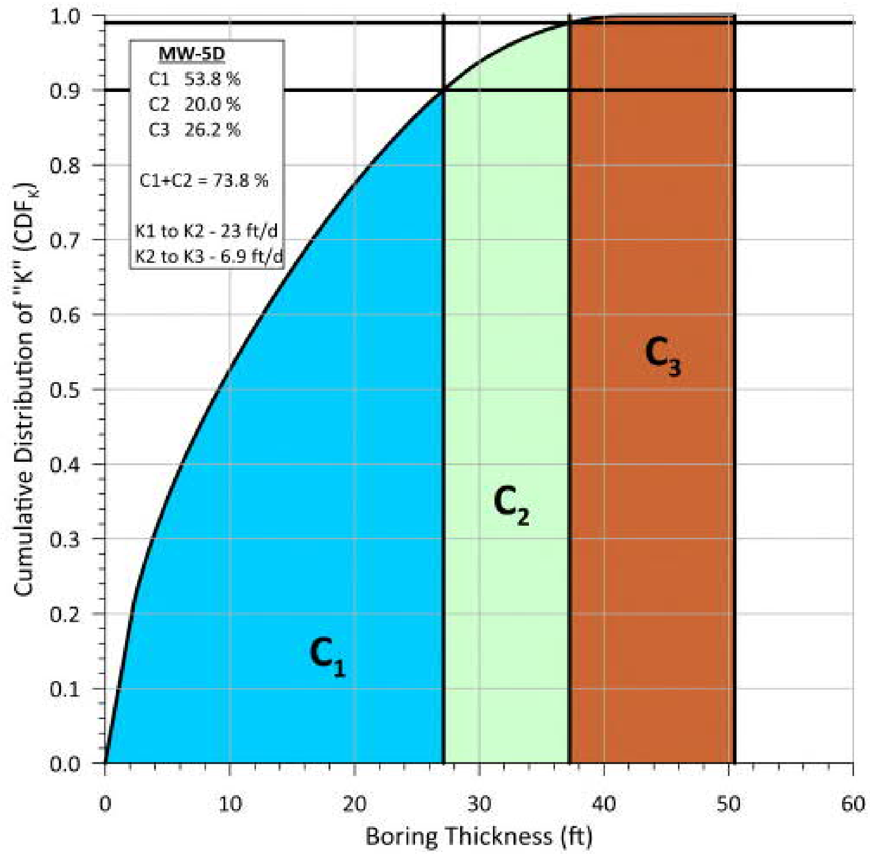
FIGURE
E4





Notes:
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114-P2-MW-5D

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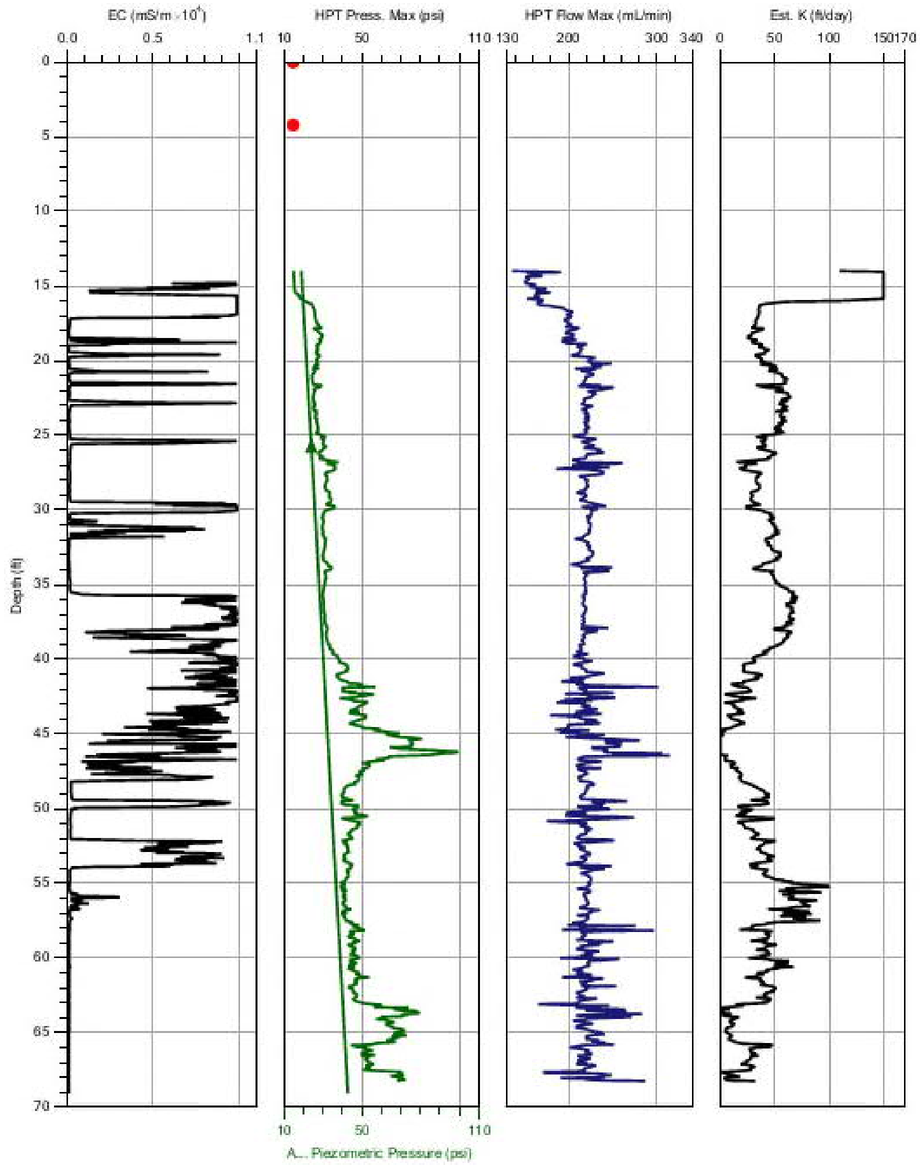
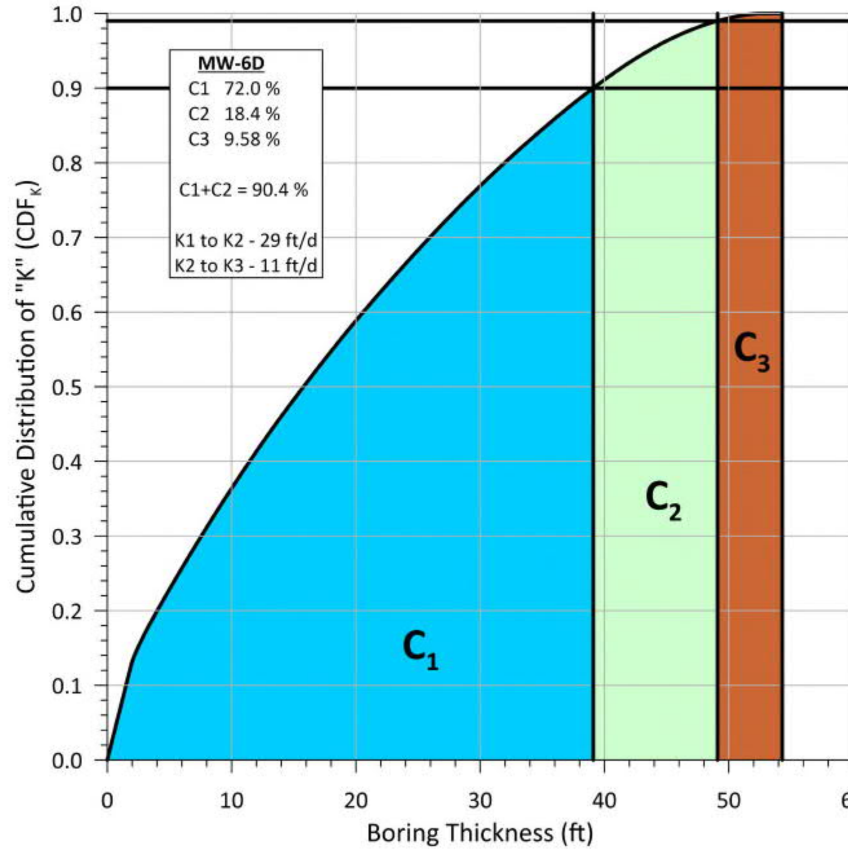
FIGURE
E5





Notes:
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114-P2-MW-6D

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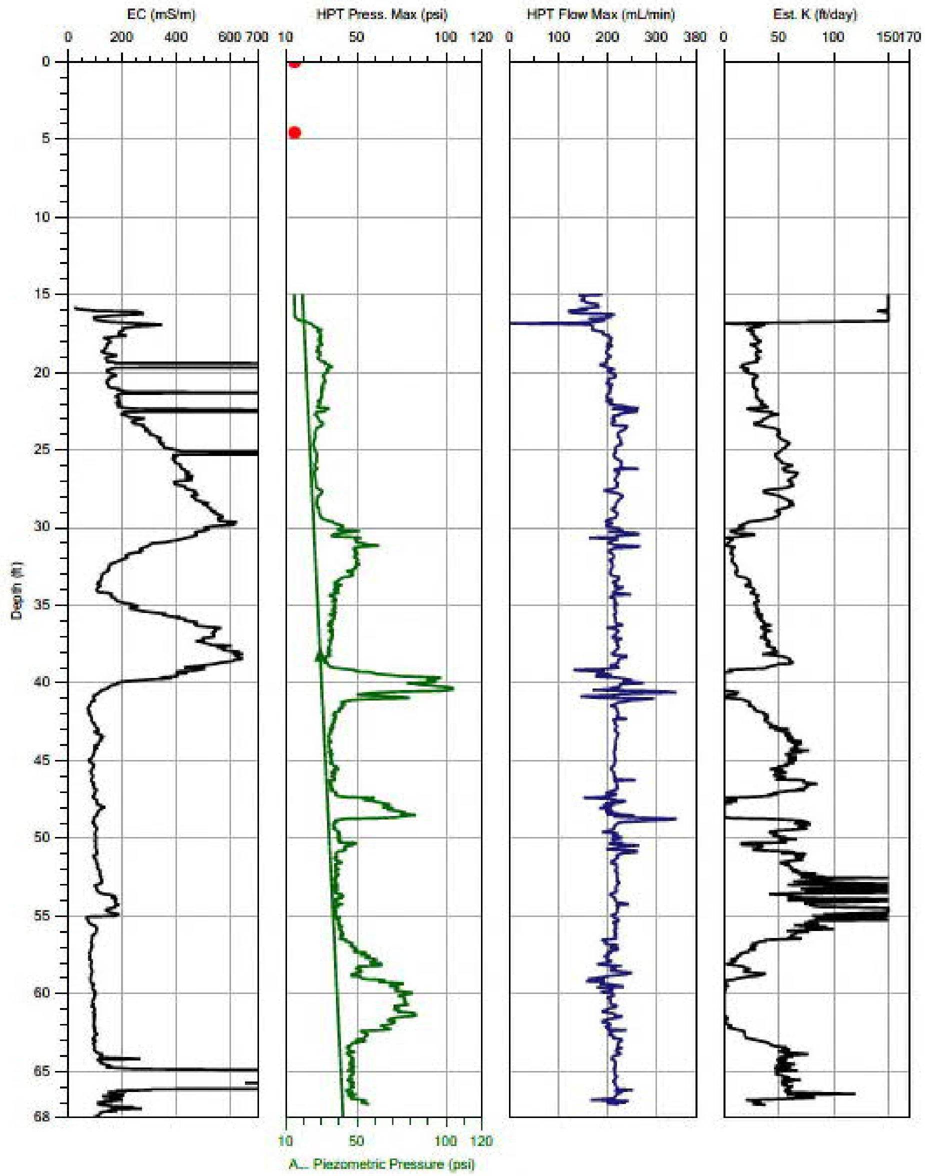
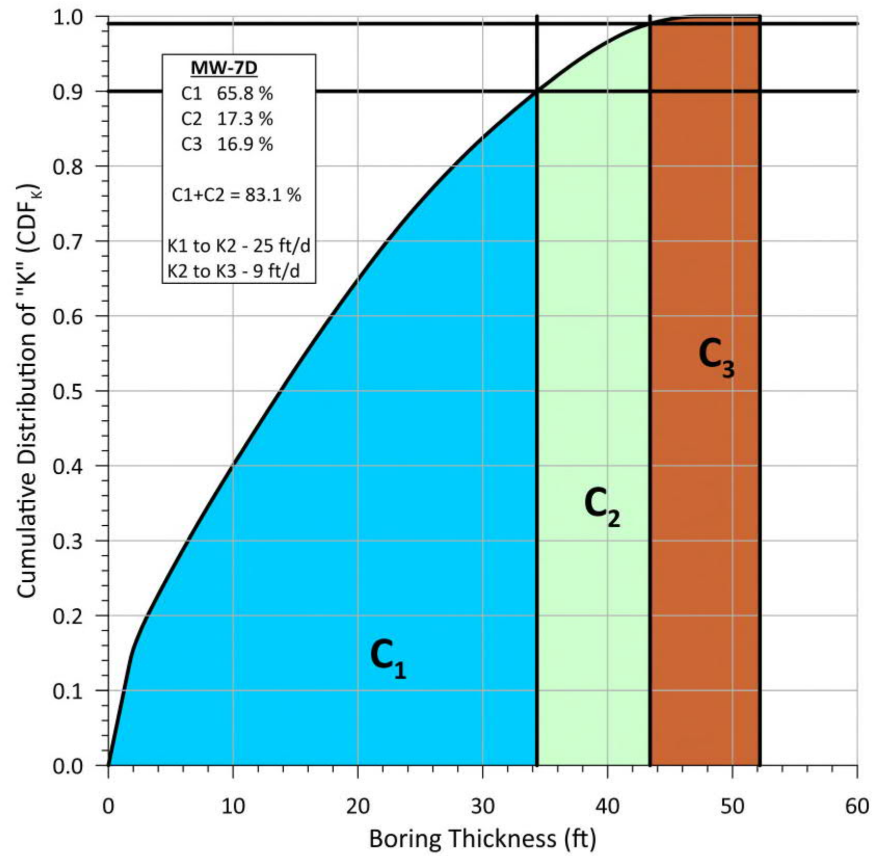
FIGURE
E6





Notes:

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114-P2-MW-7D

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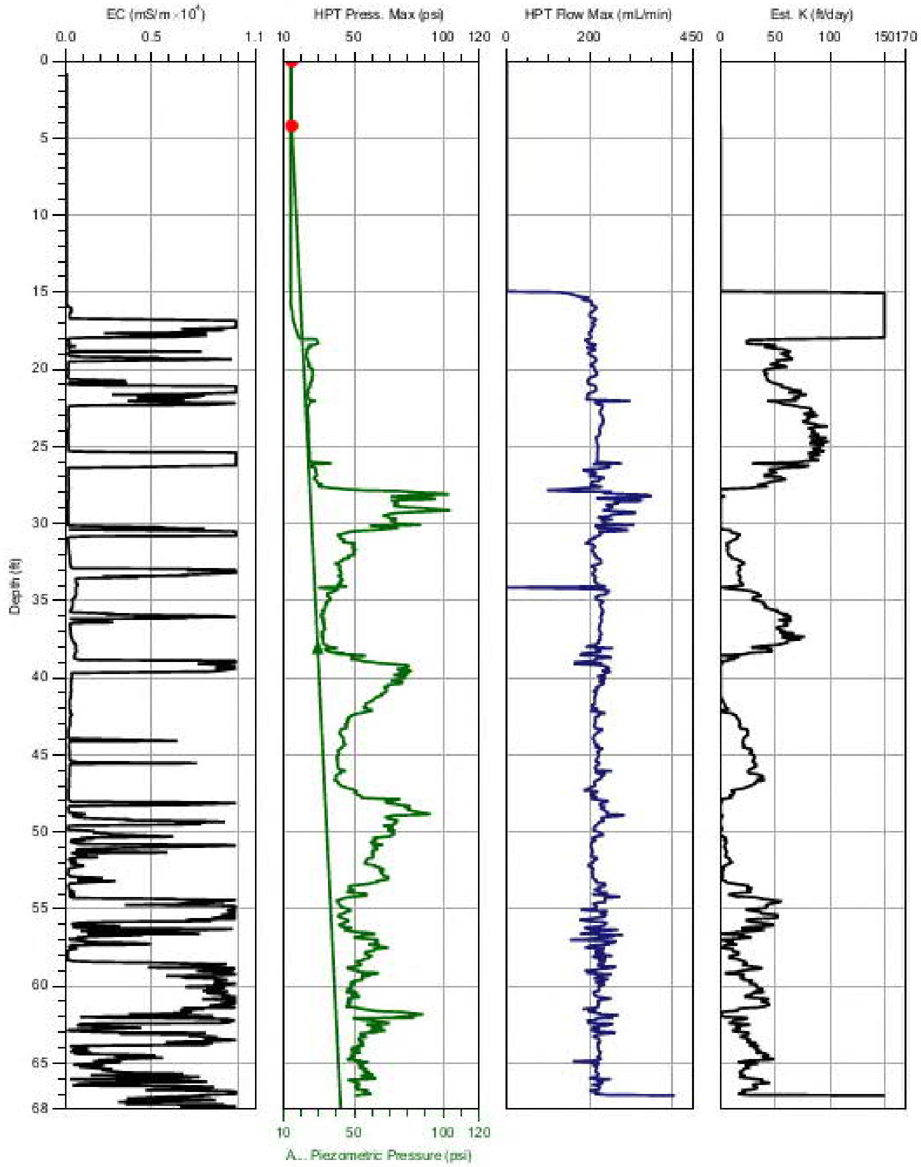
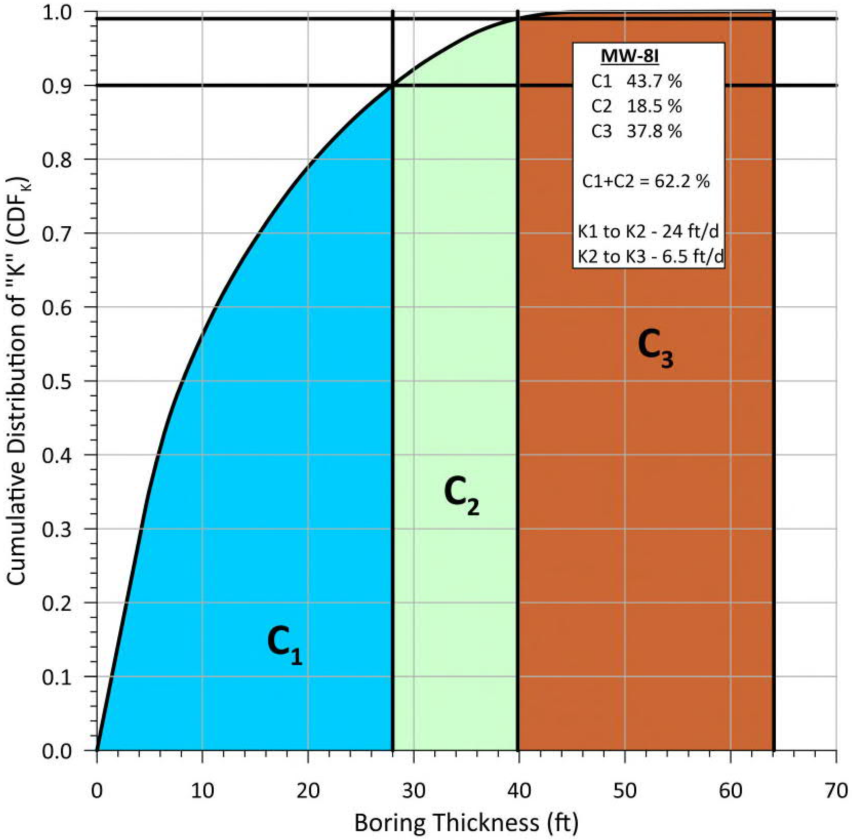
FIGURE
E7





Notes:
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114-P2-MW-8I

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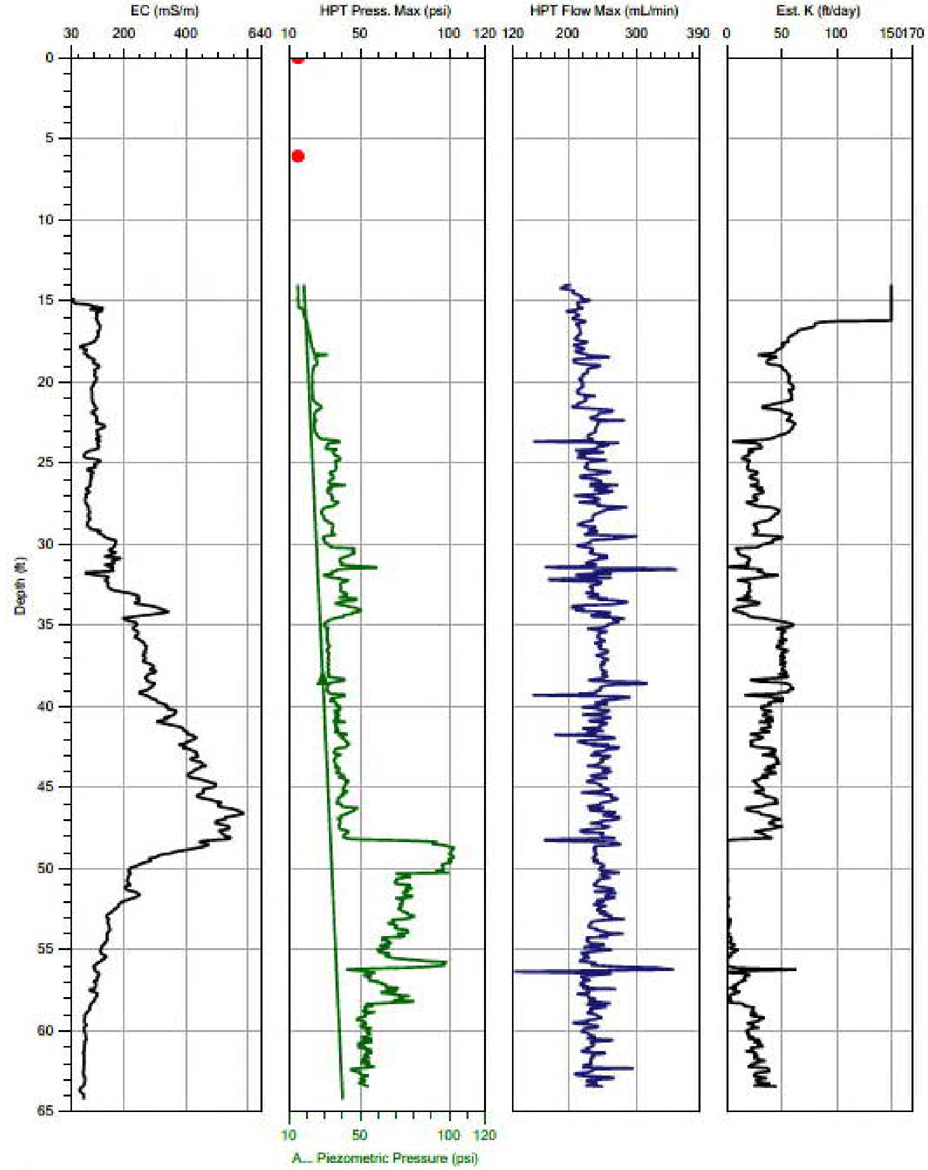
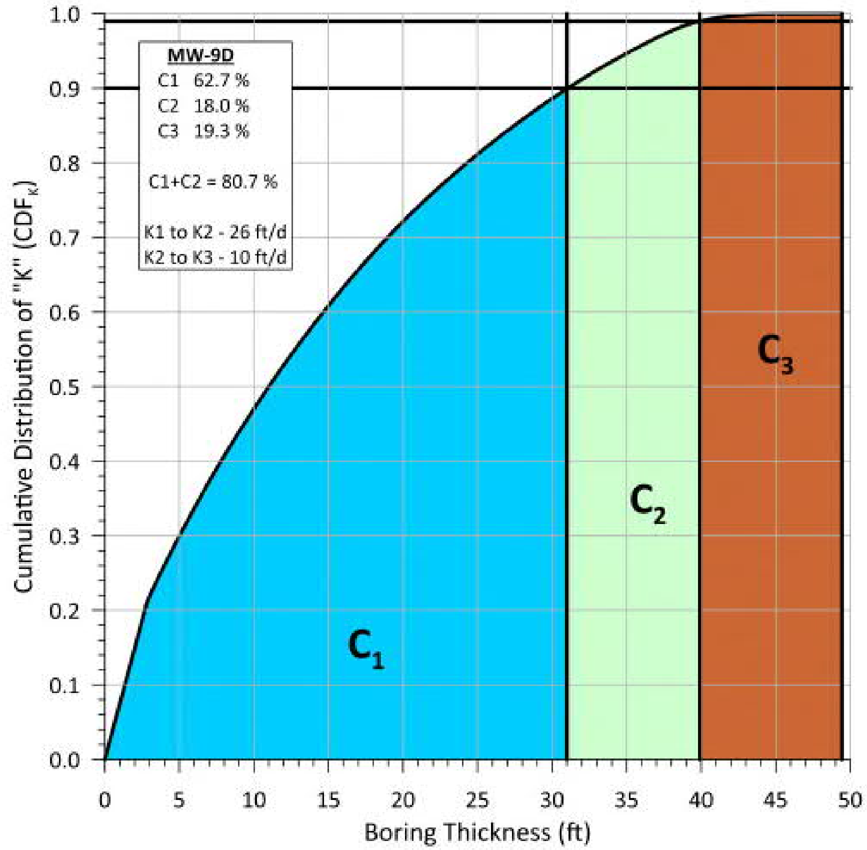
FIGURE
E8





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114-P2-MW-9D

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FIGURE E9

Notes:
C1 – most permeable soils, dominated by advective transport
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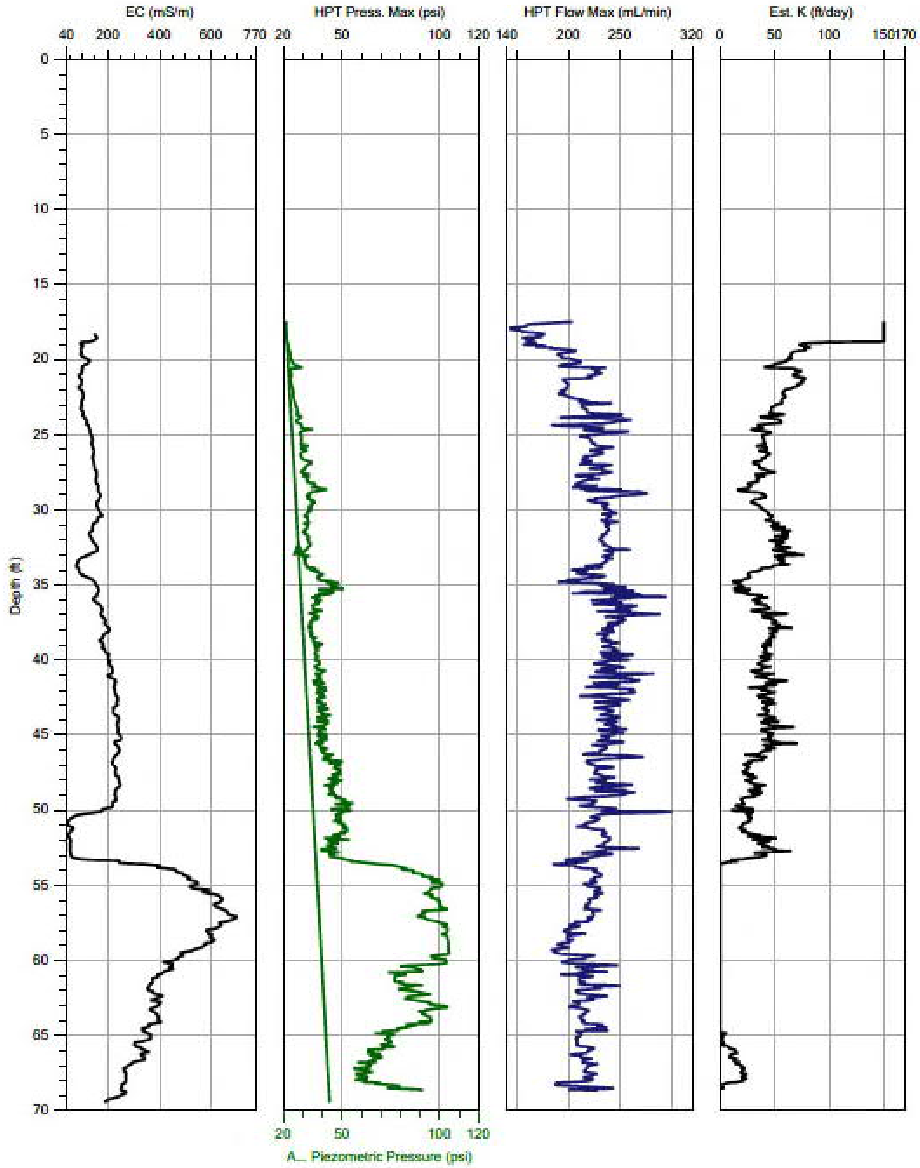

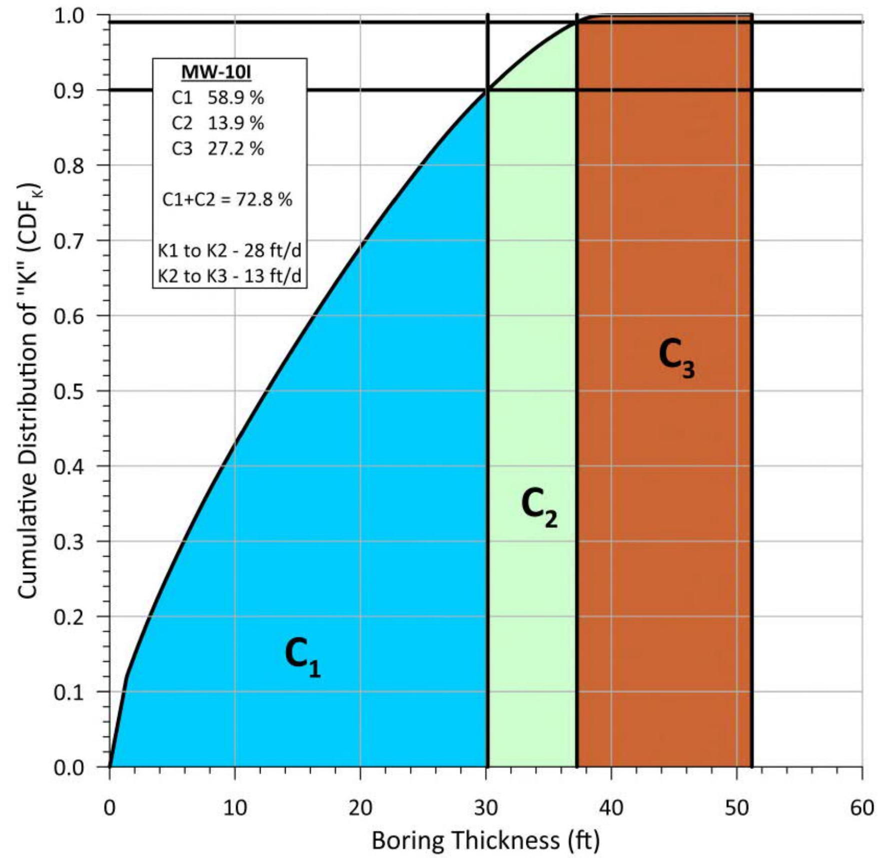

Notes:
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GARFIELD AVENUE GROUP SITES
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114-P2-MW-10I

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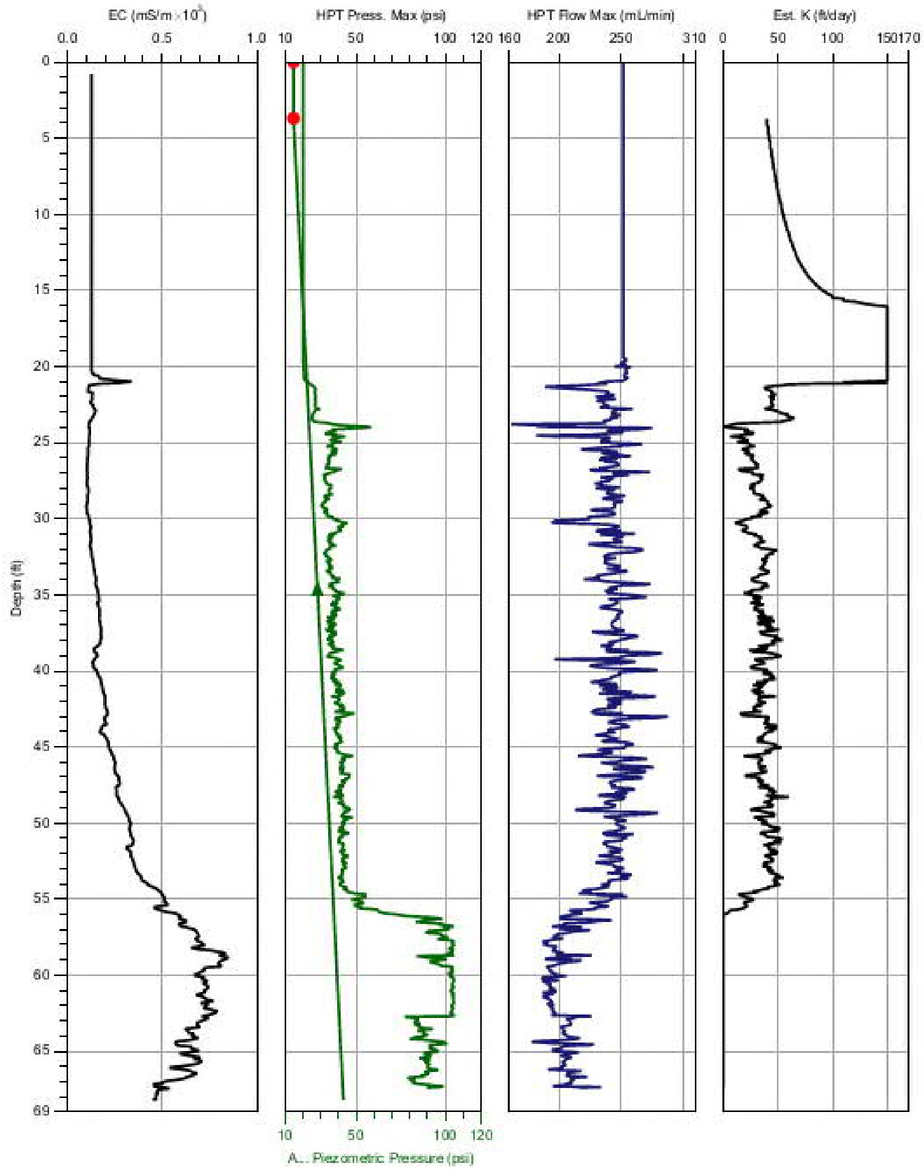
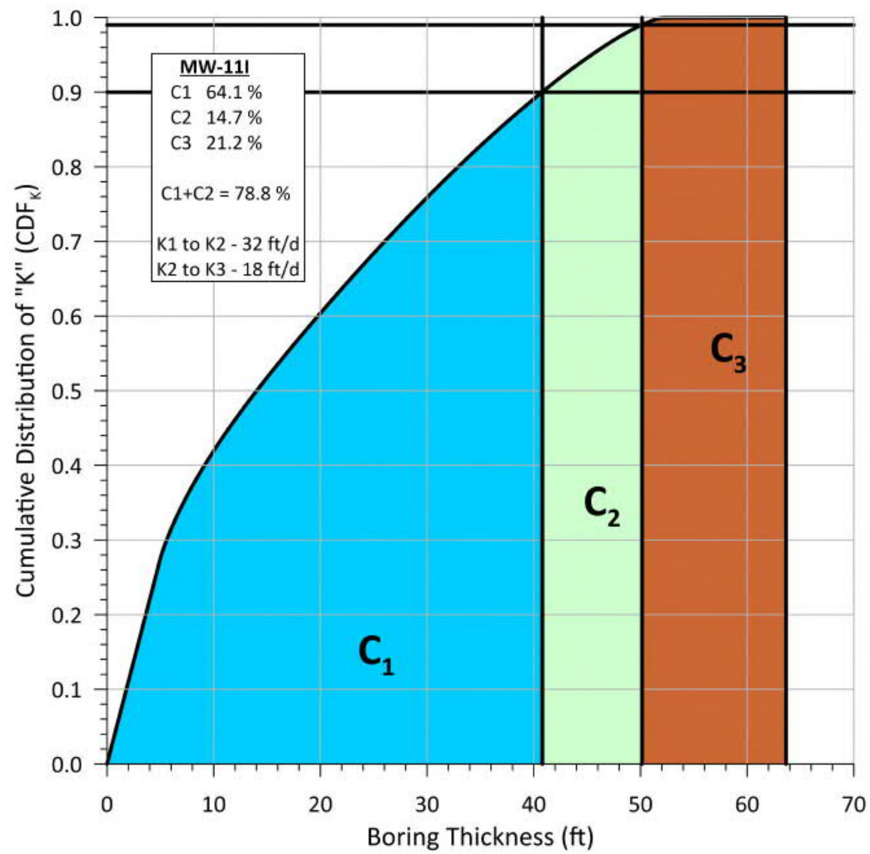
FIGURE
E10





Notes:
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114-P2-MW-11I

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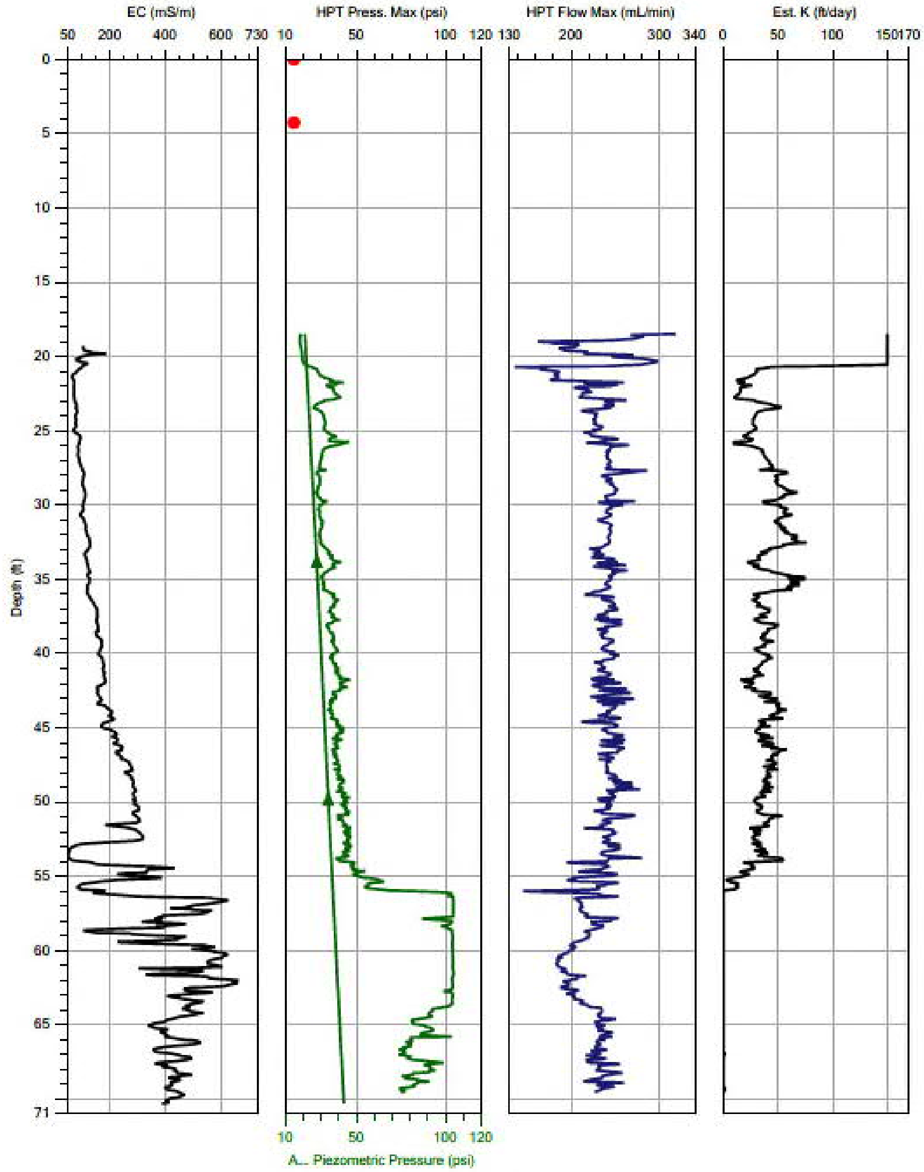
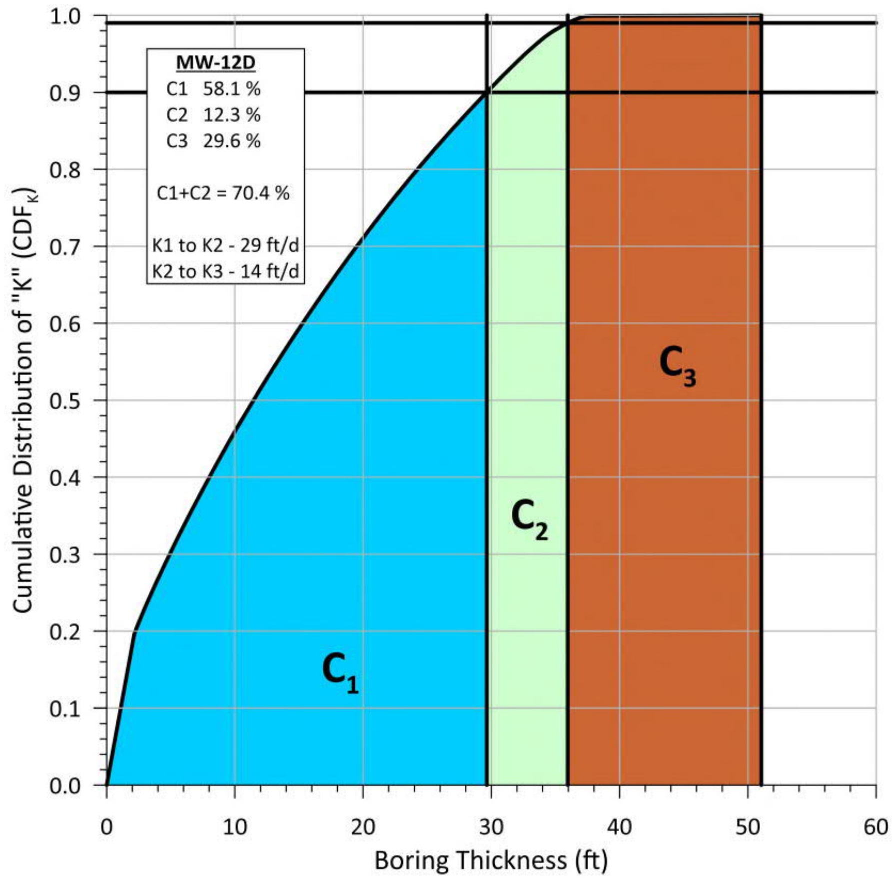
FIGURE
E11





Notes:
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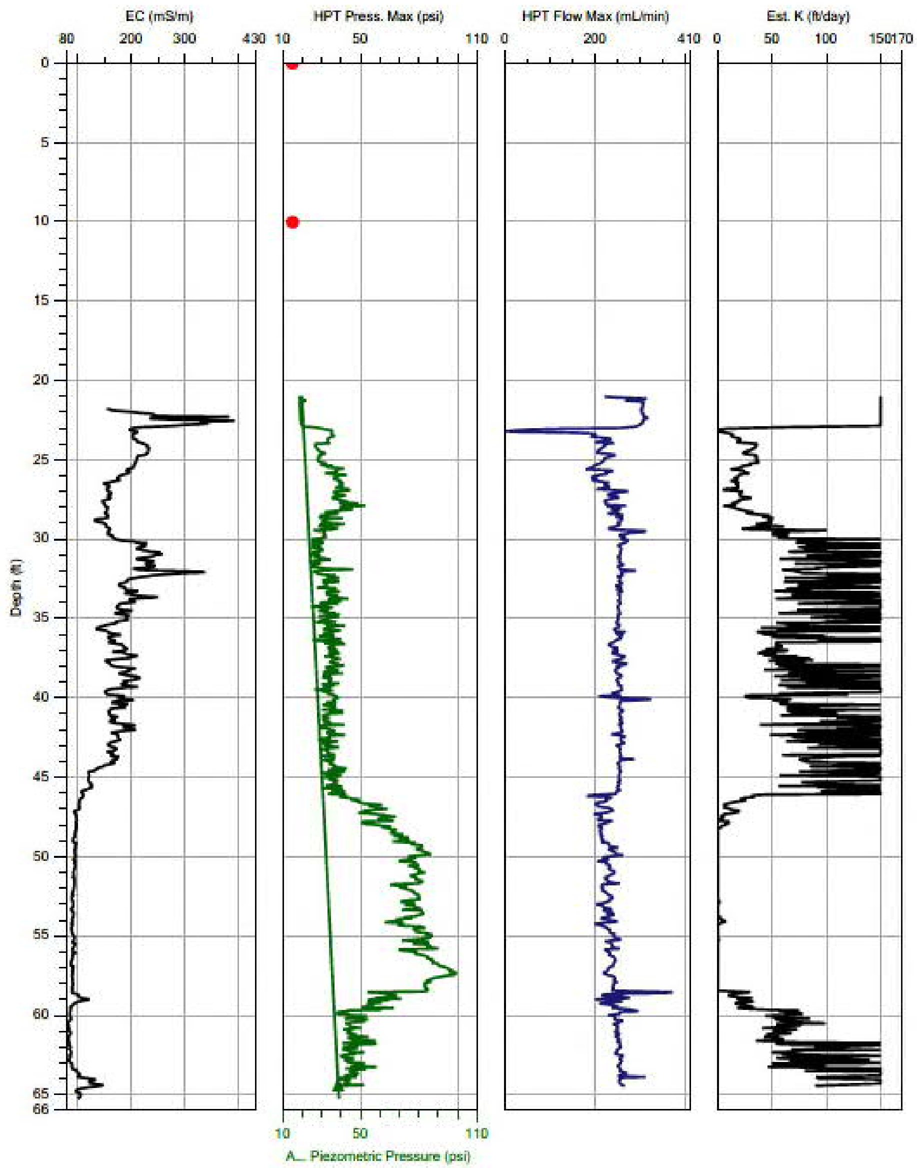
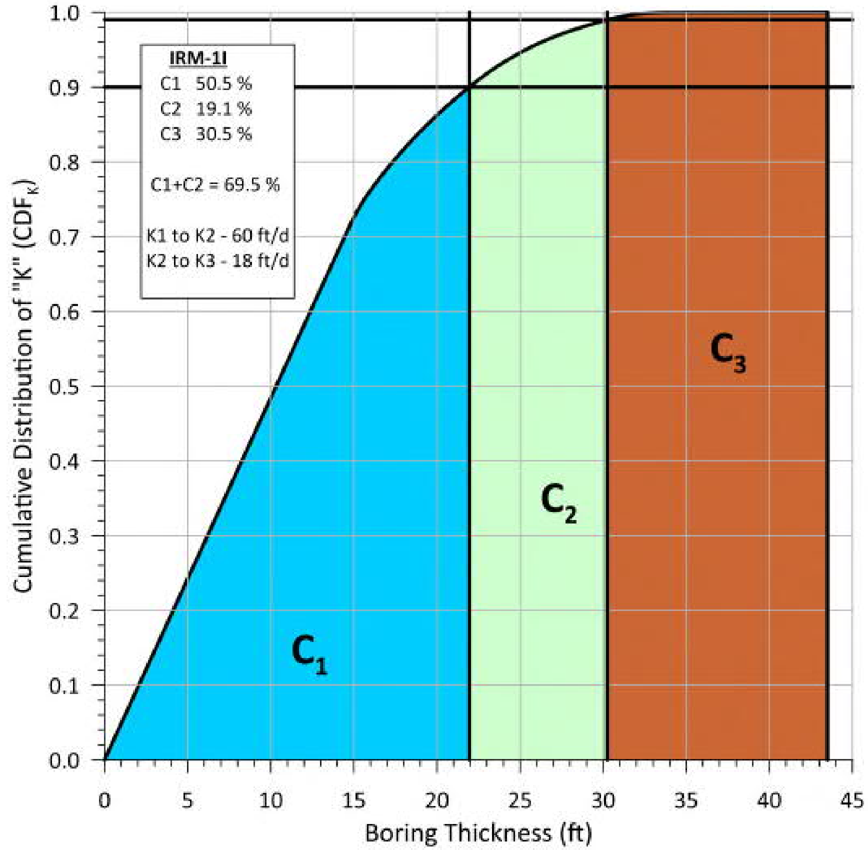
PPG INDUSTRIES GARFIELD AVENUE GROUP SITES JERSEY CITY, NEW JERSEY
114-P2-MW-12D
ARCADIS Design & Consultancy for natural and built assets — FIGURE E12





Notes:

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GARFIELD AVENUE GROUP SITES
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114-P2-IRM-1I

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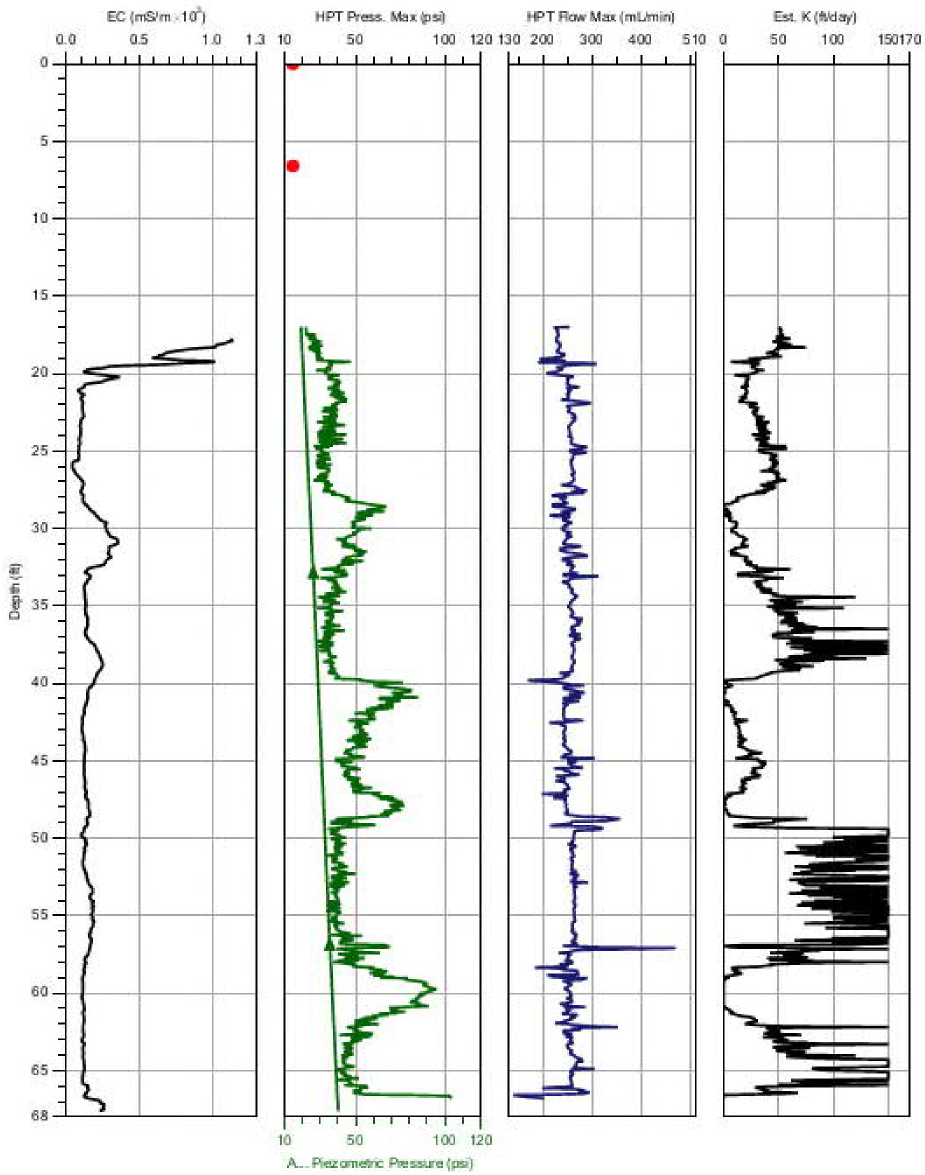
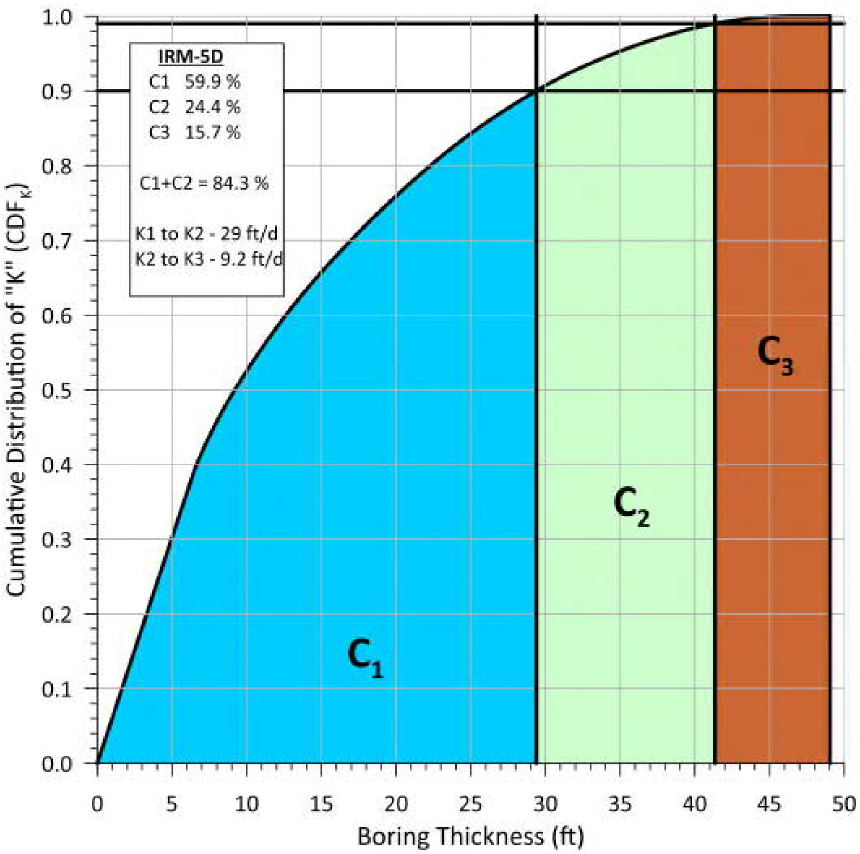
FIGURE
E13





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114-P2-IRM-5D

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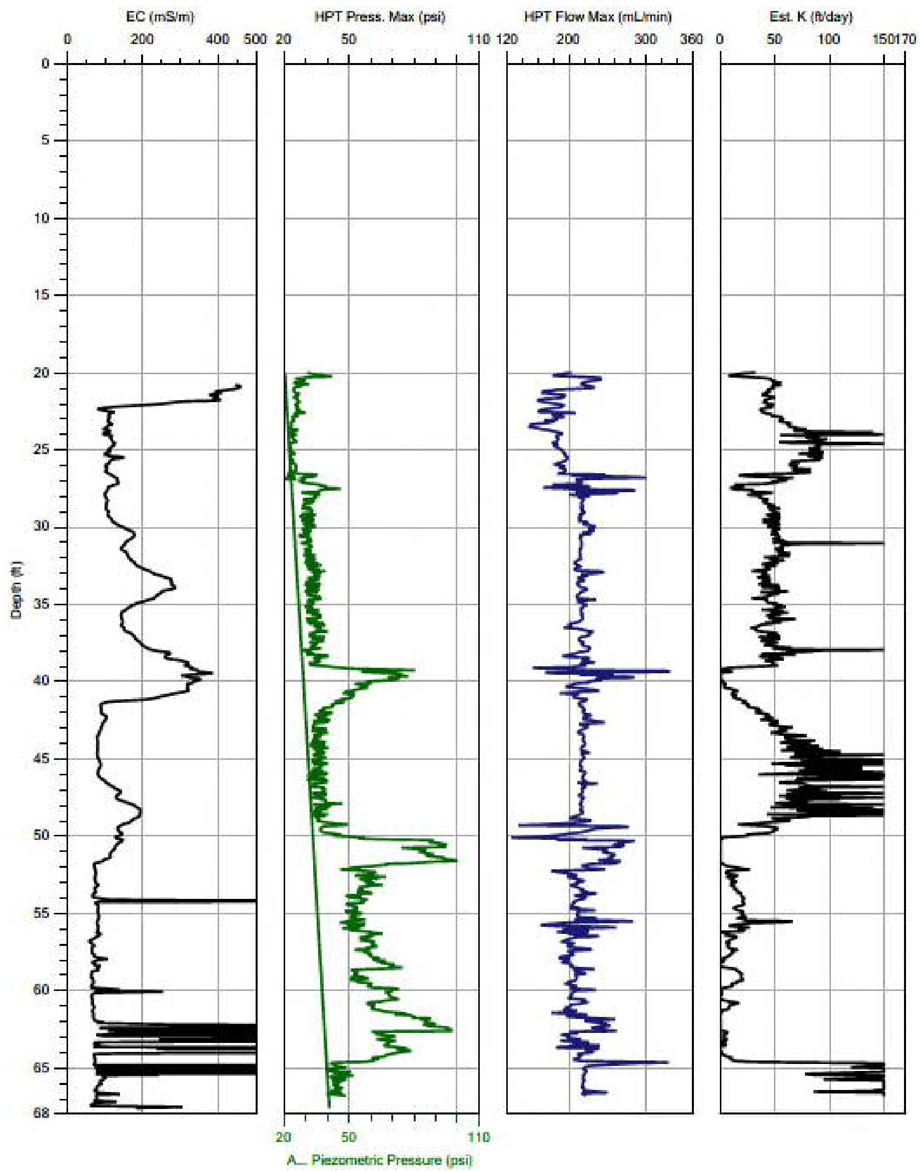
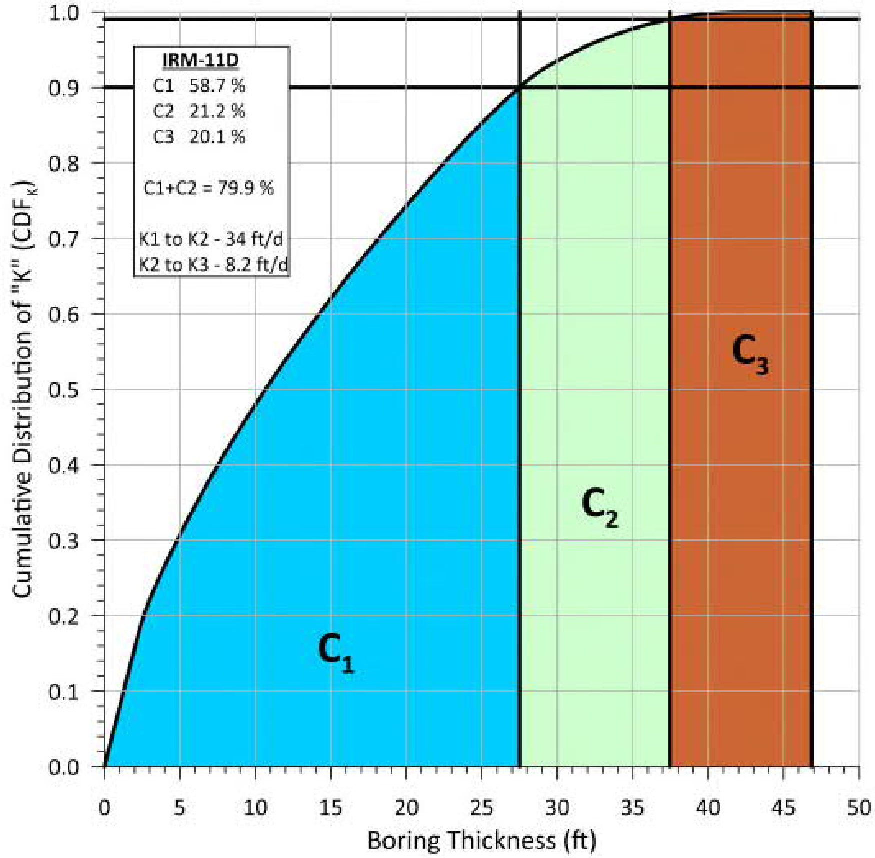
FIGURE
E14





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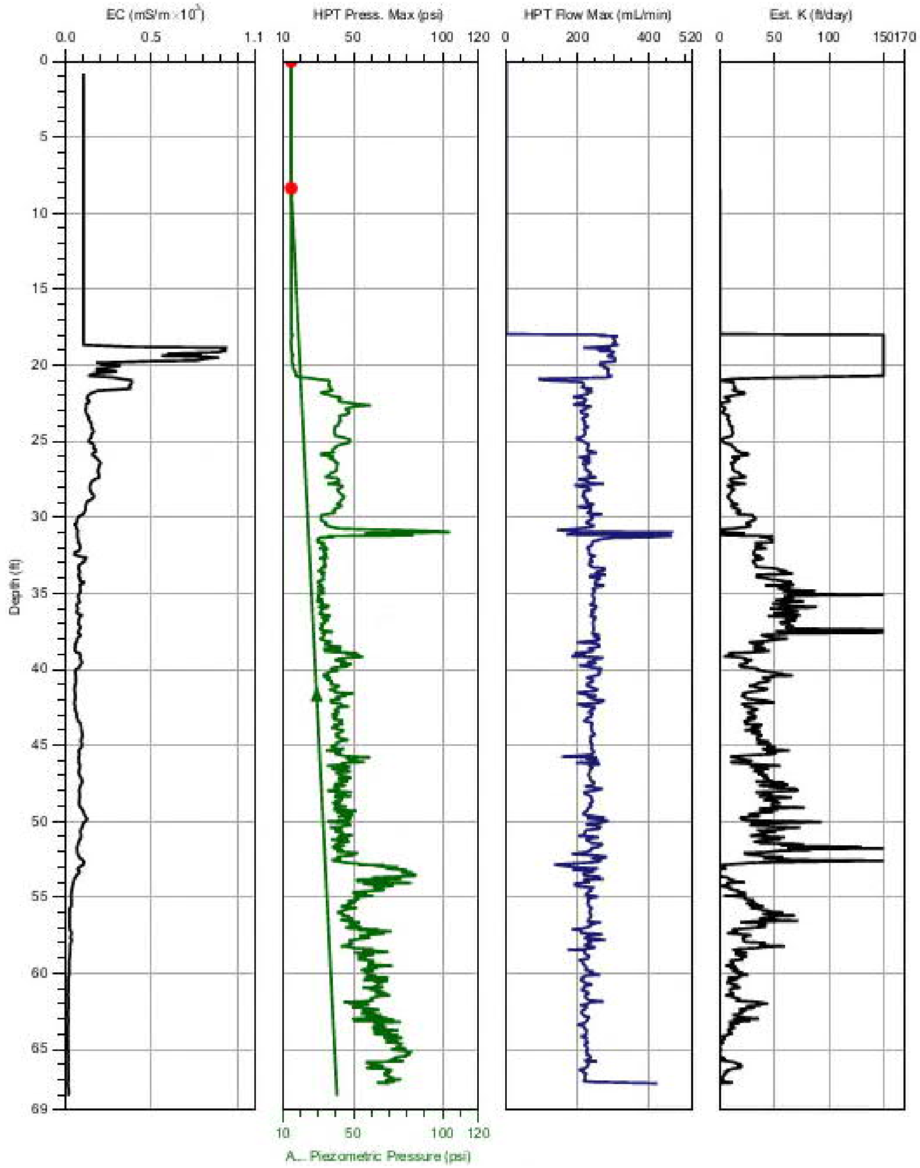
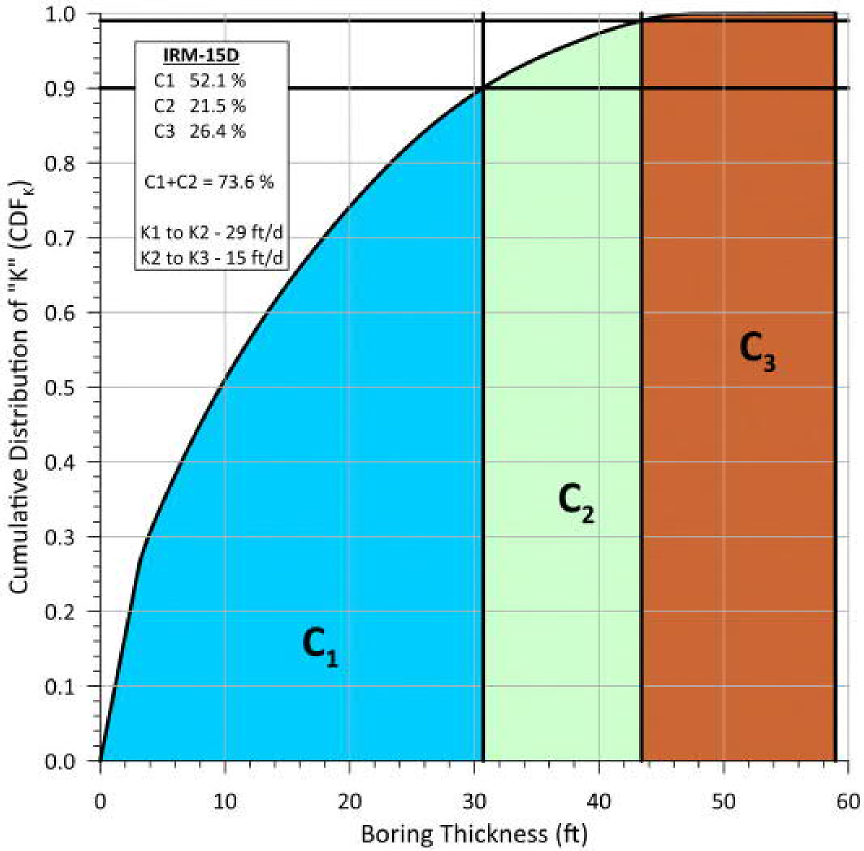
114-P2-IRM-11D

ARCADIS Design & Consultancy for natural and built assets

FIGURE
E15





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114-P2-IRM-15D

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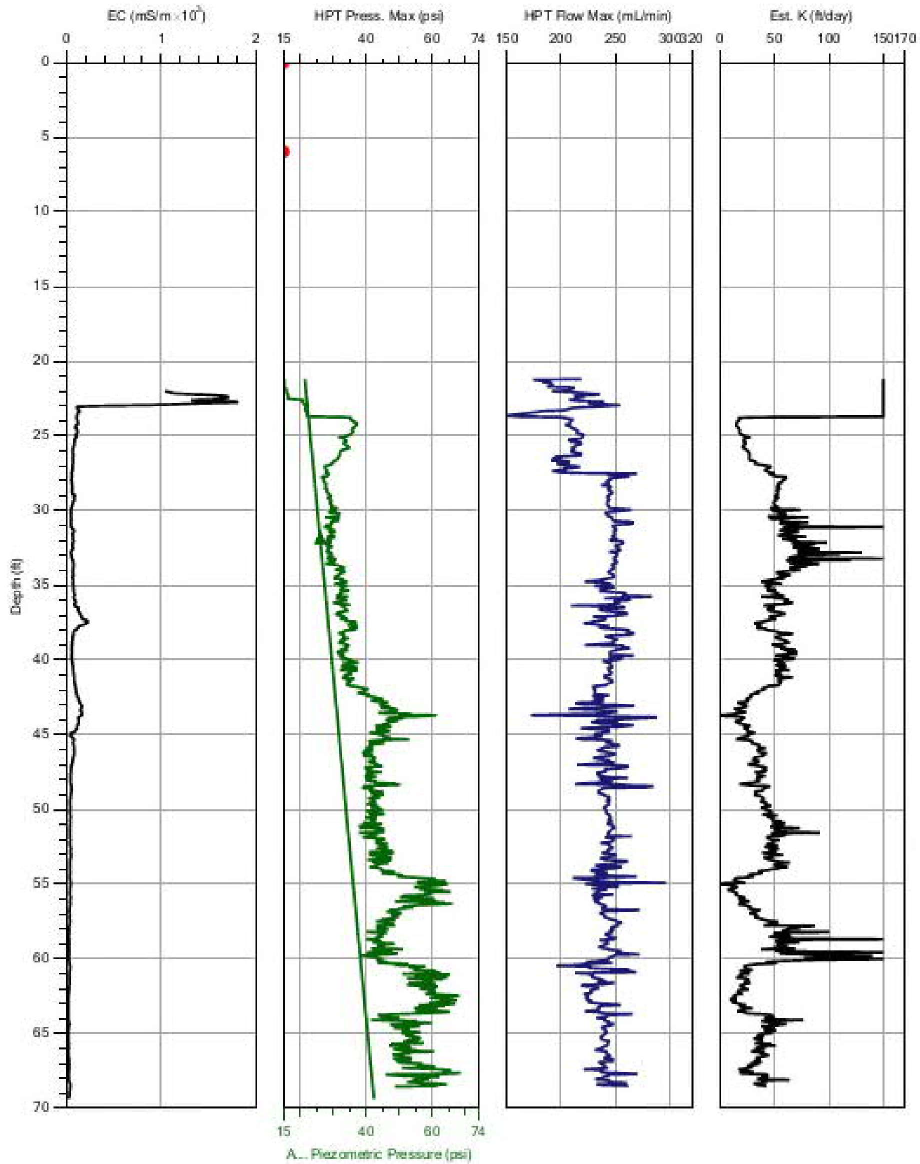
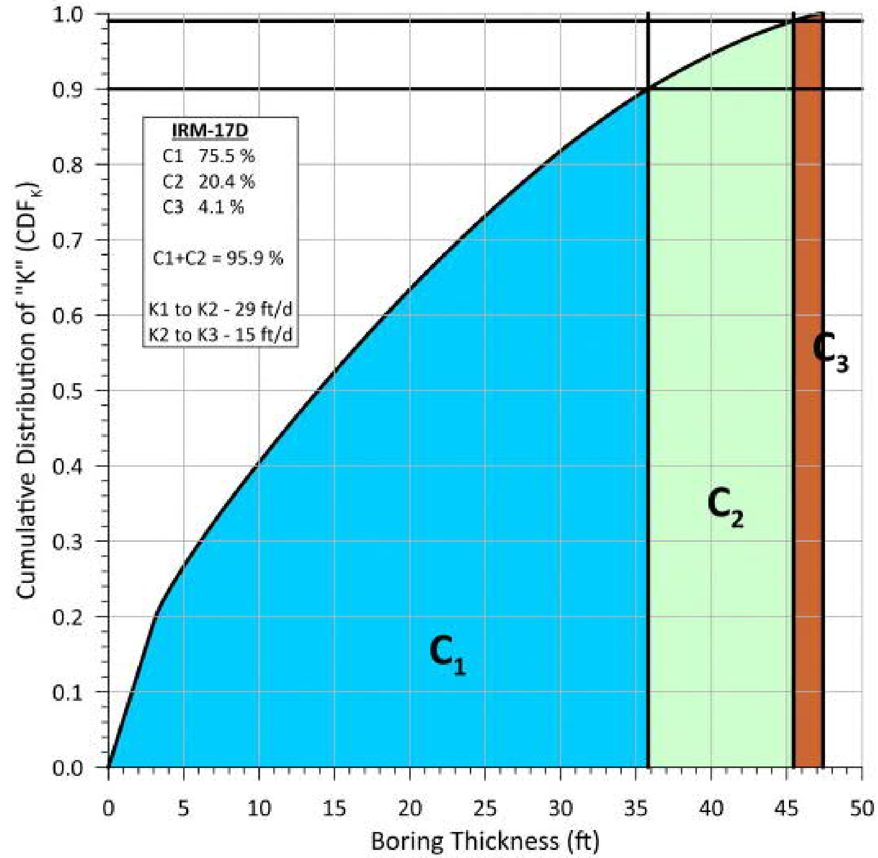
FIGURE
E16





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114-P2-IRM-17D

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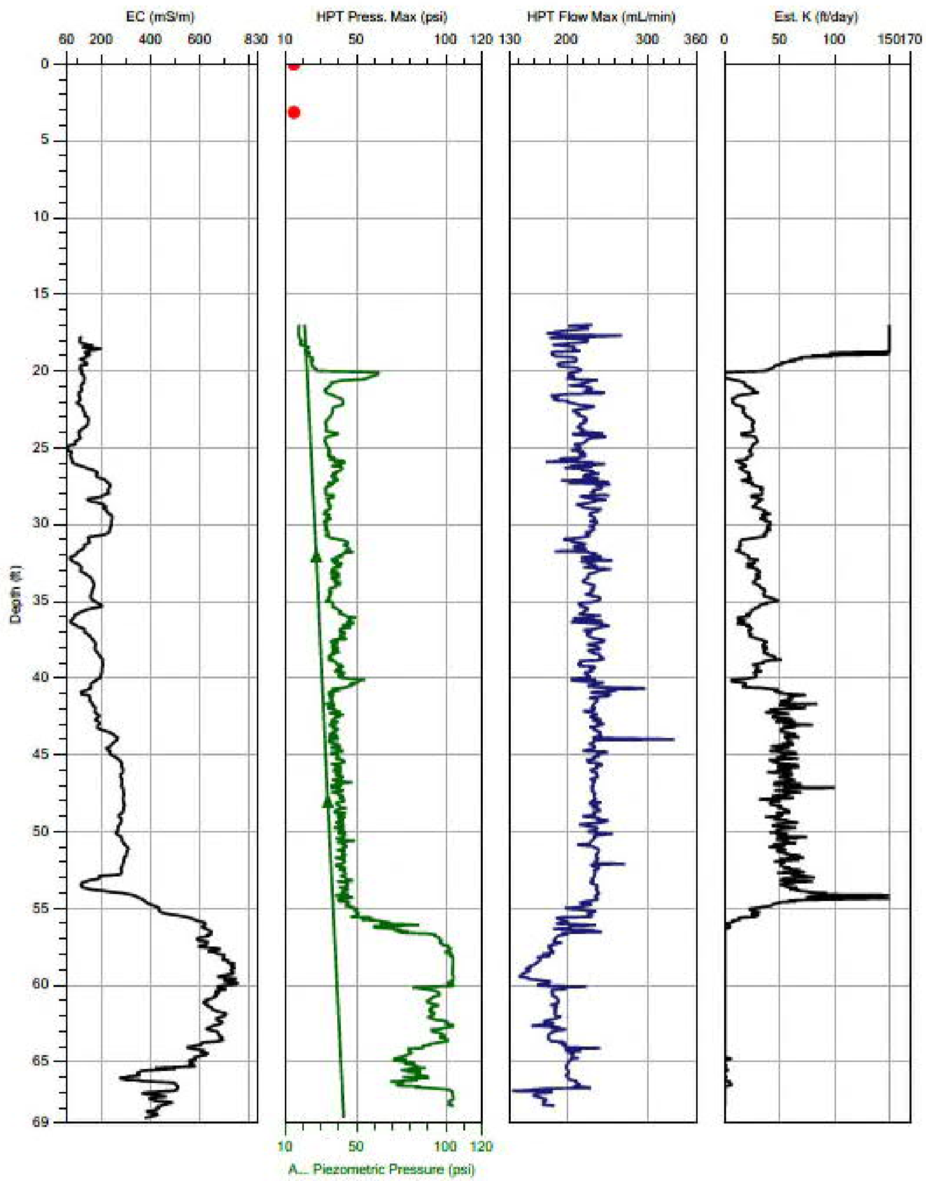
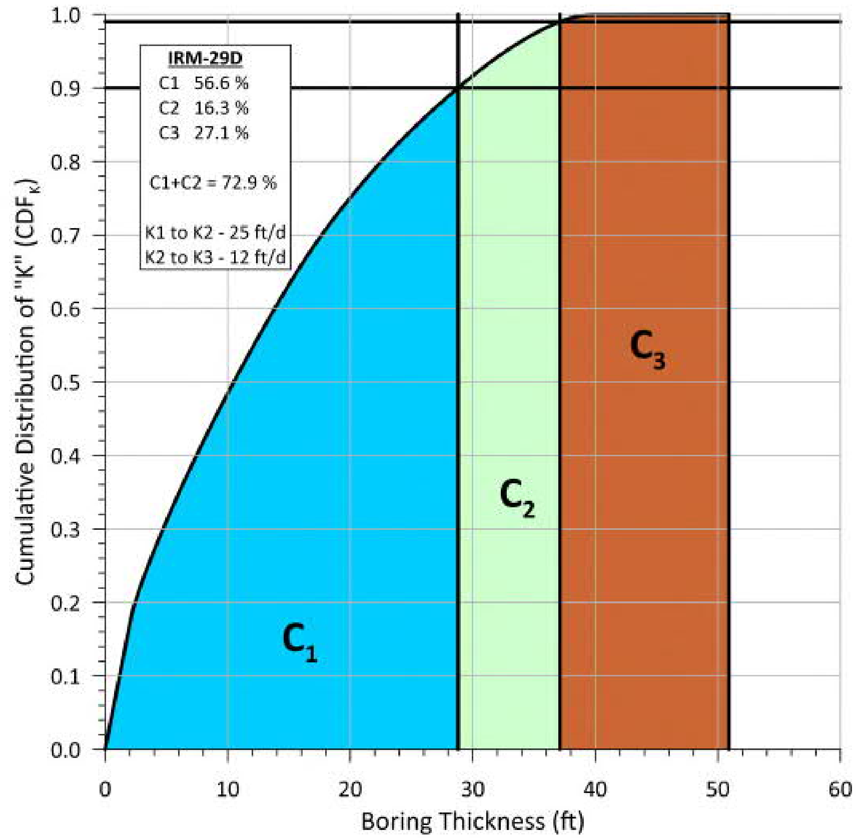
FIGURE
E17





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114-P2-IRM-29D

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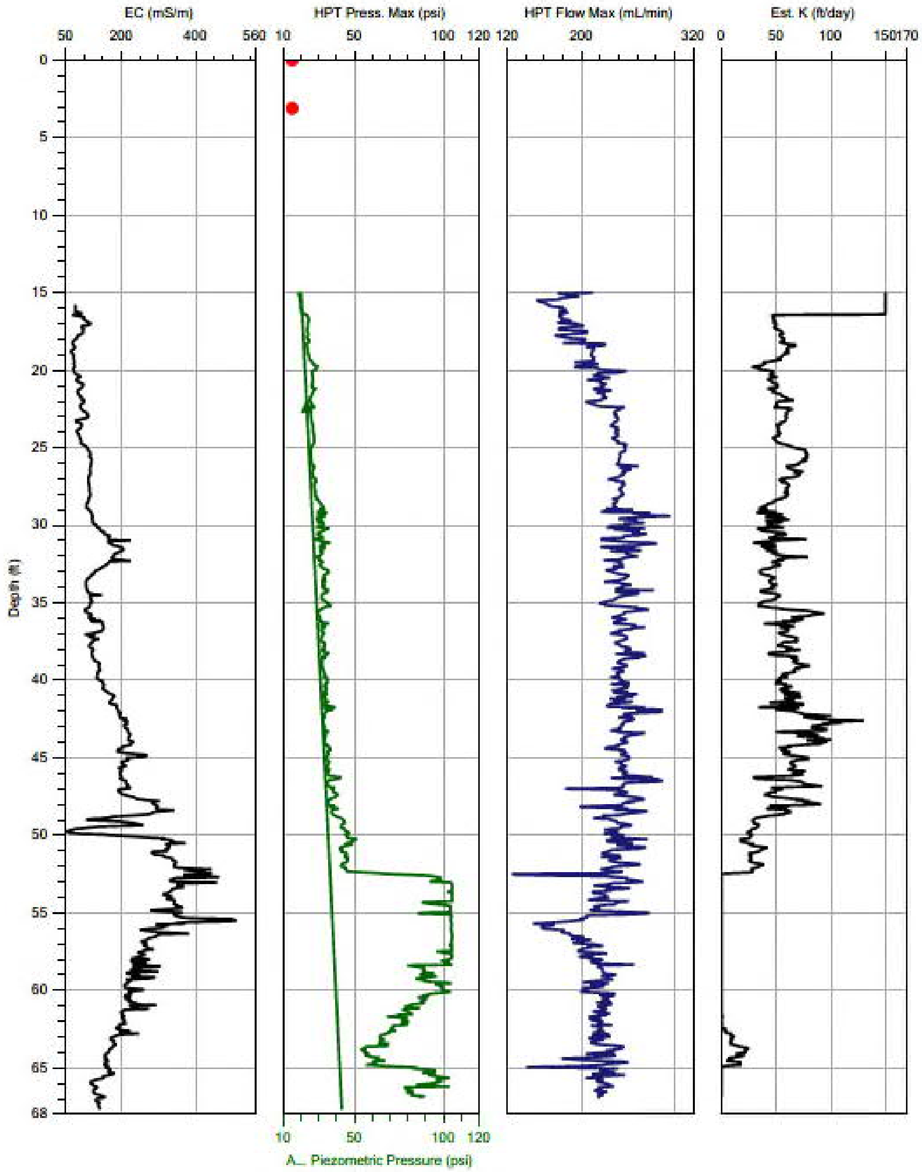
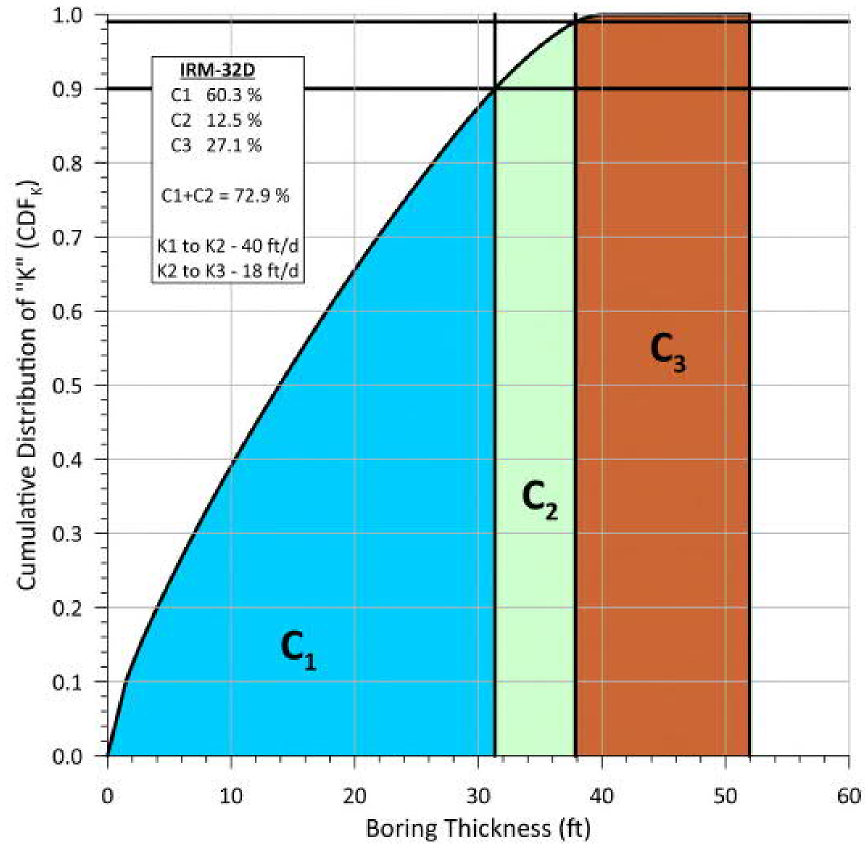
FIGURE
E18





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114-P2-IRM-32D

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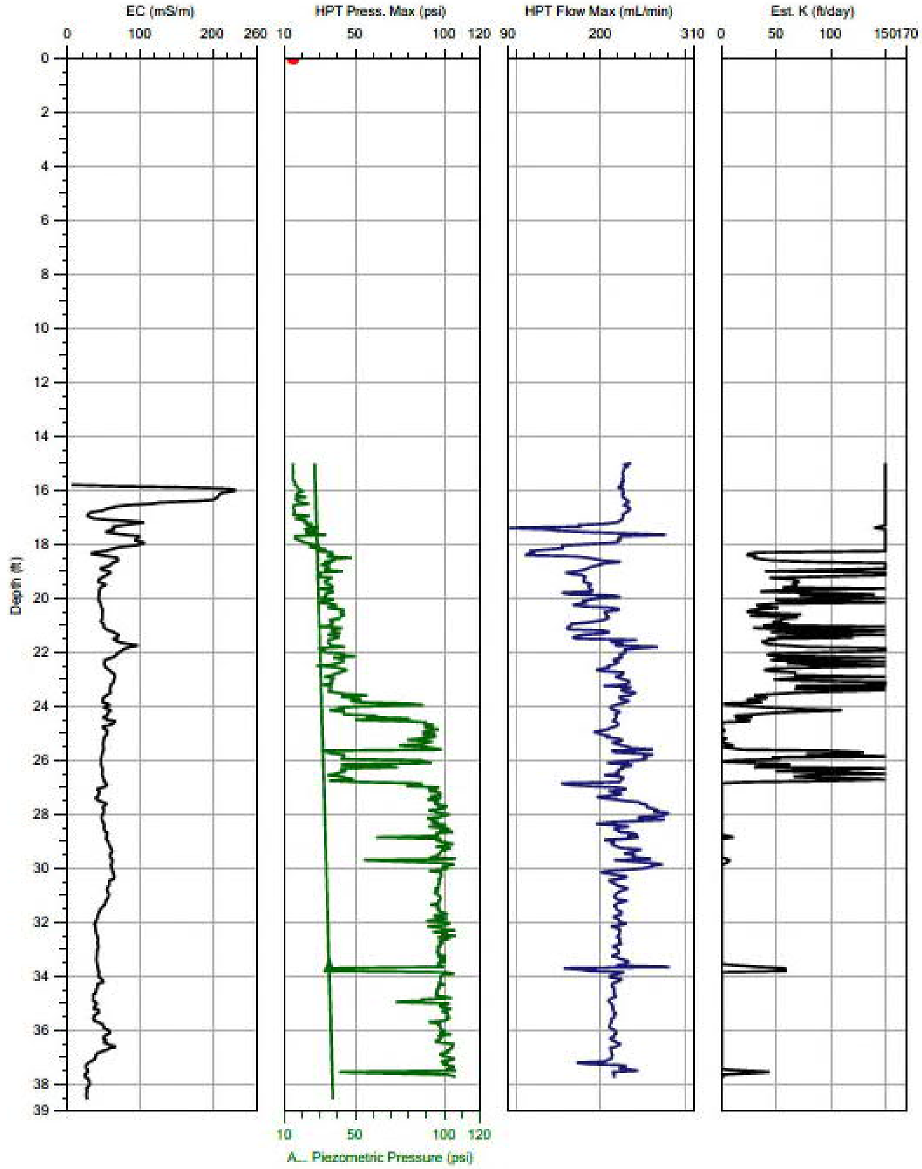
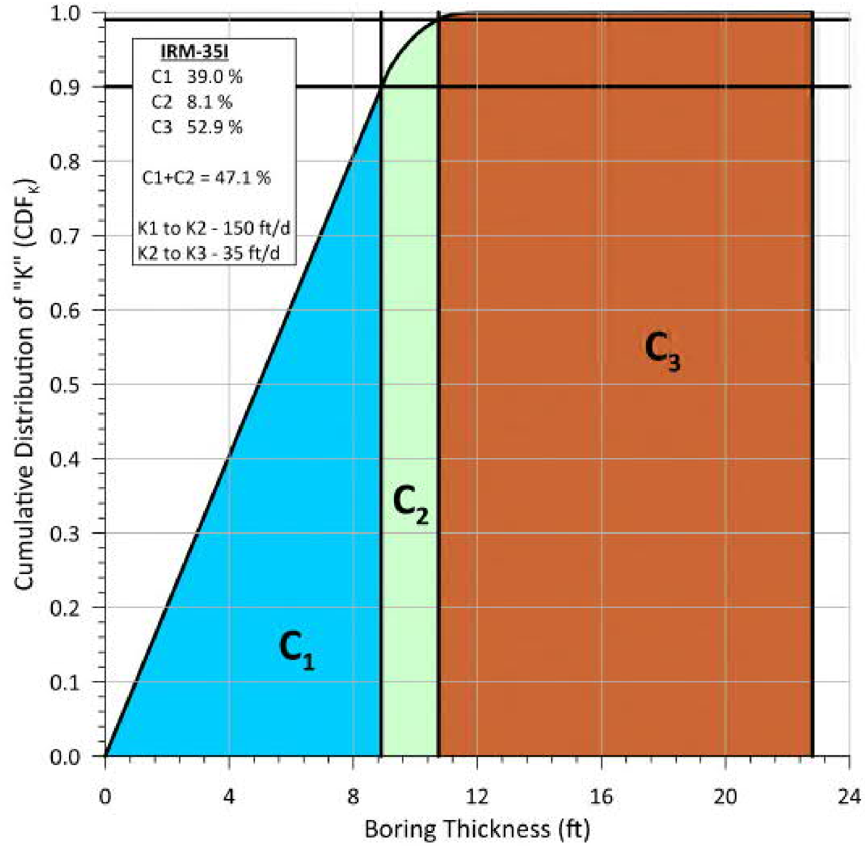
FIGURE
E19





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114-P2-IRM-35I

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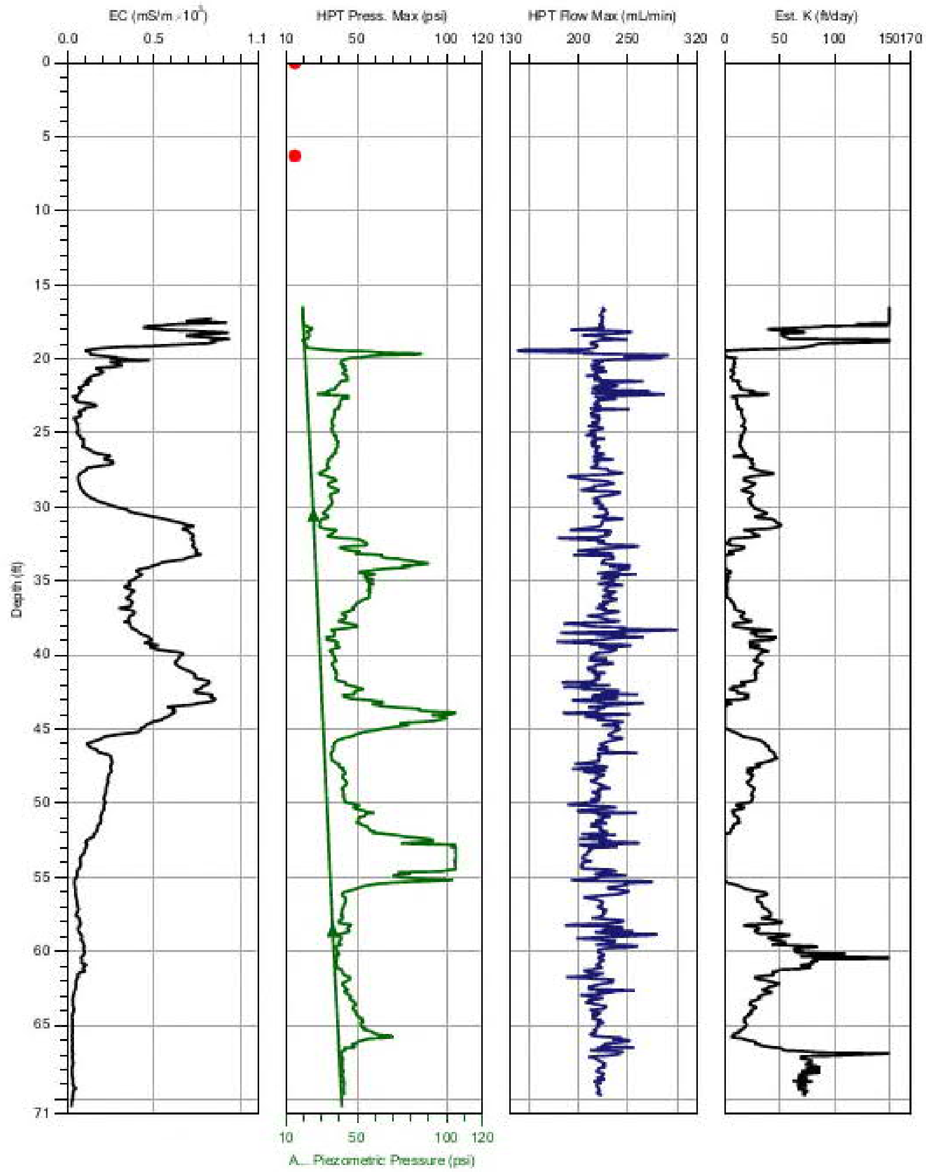
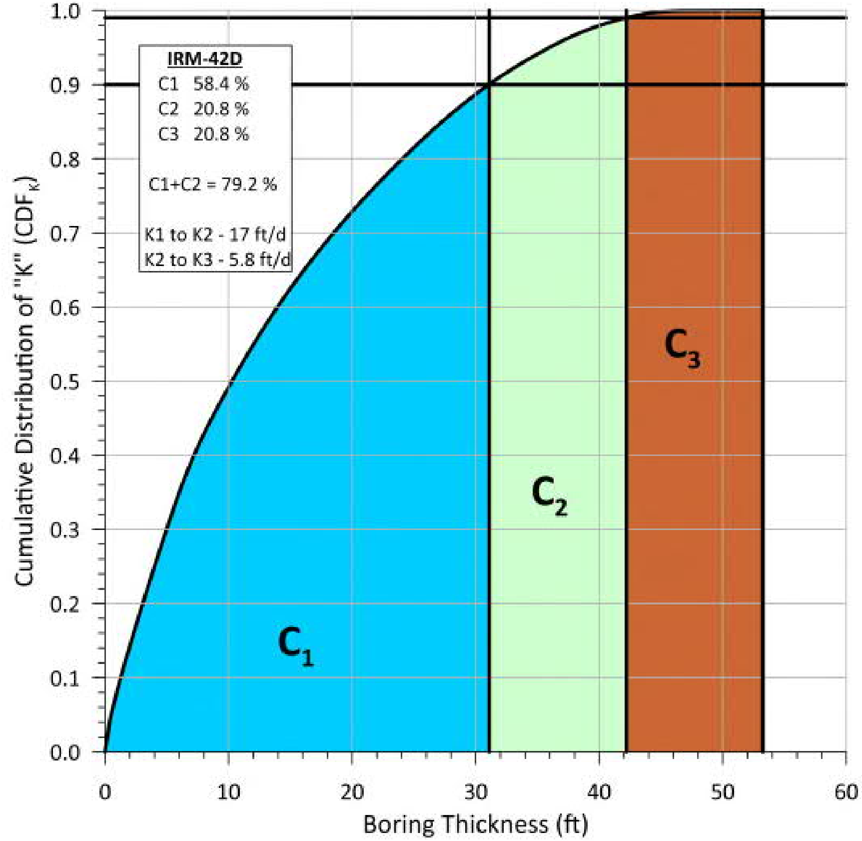
FIGURE
E20





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PPG INDUSTRIES
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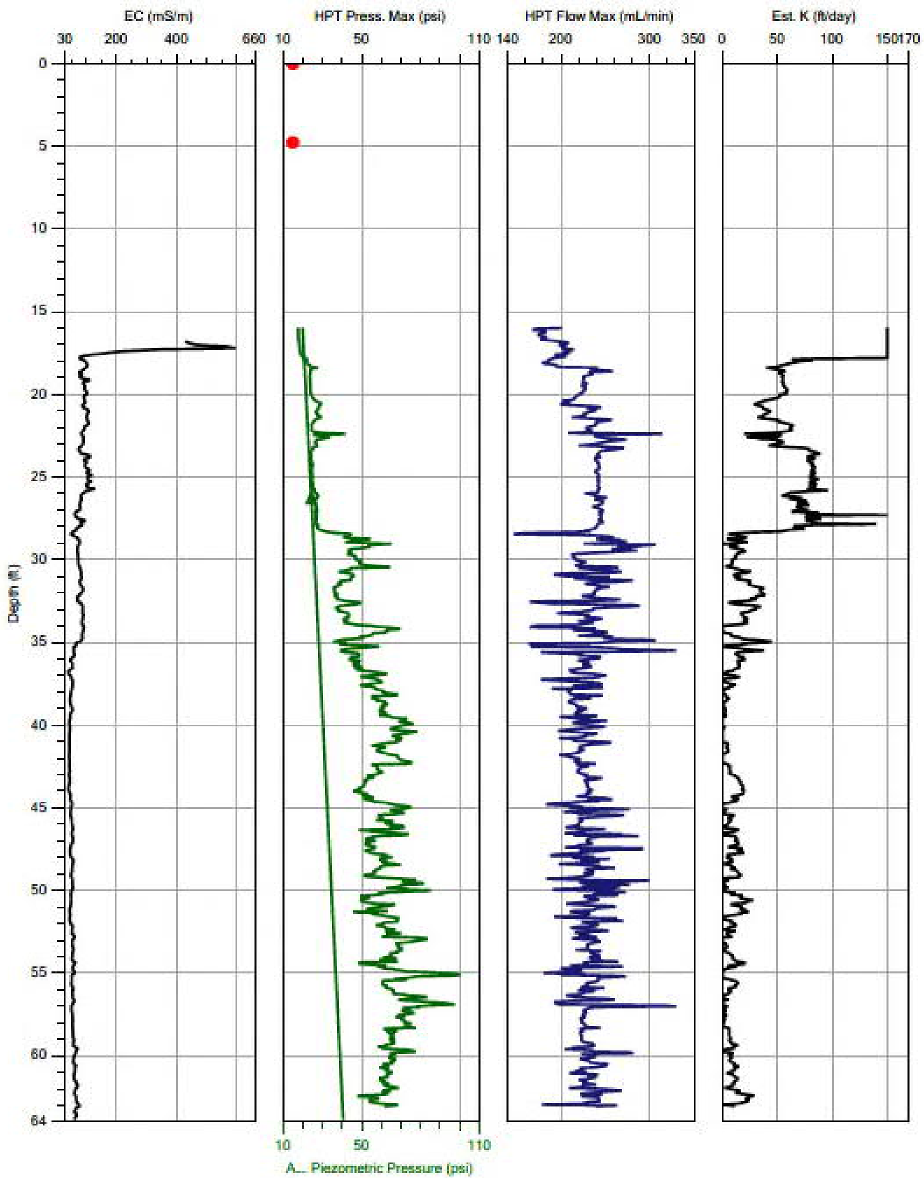
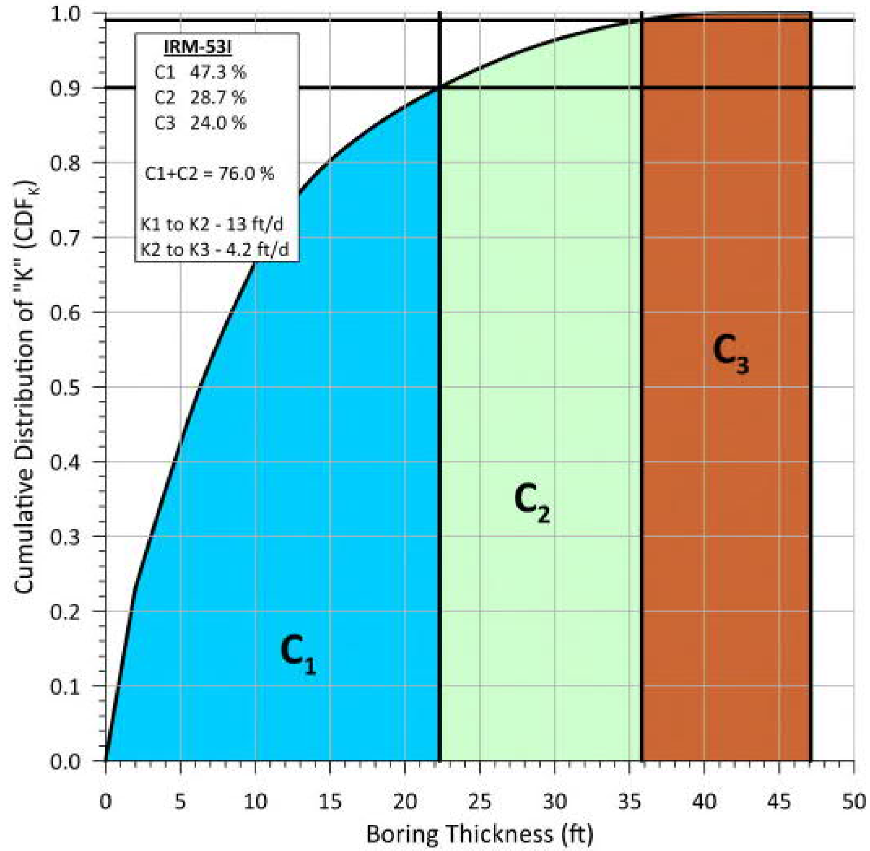
114-P2-IRM-42D

ARCADIS Design & Consultancy for natural and built assets

FIGURE
E21





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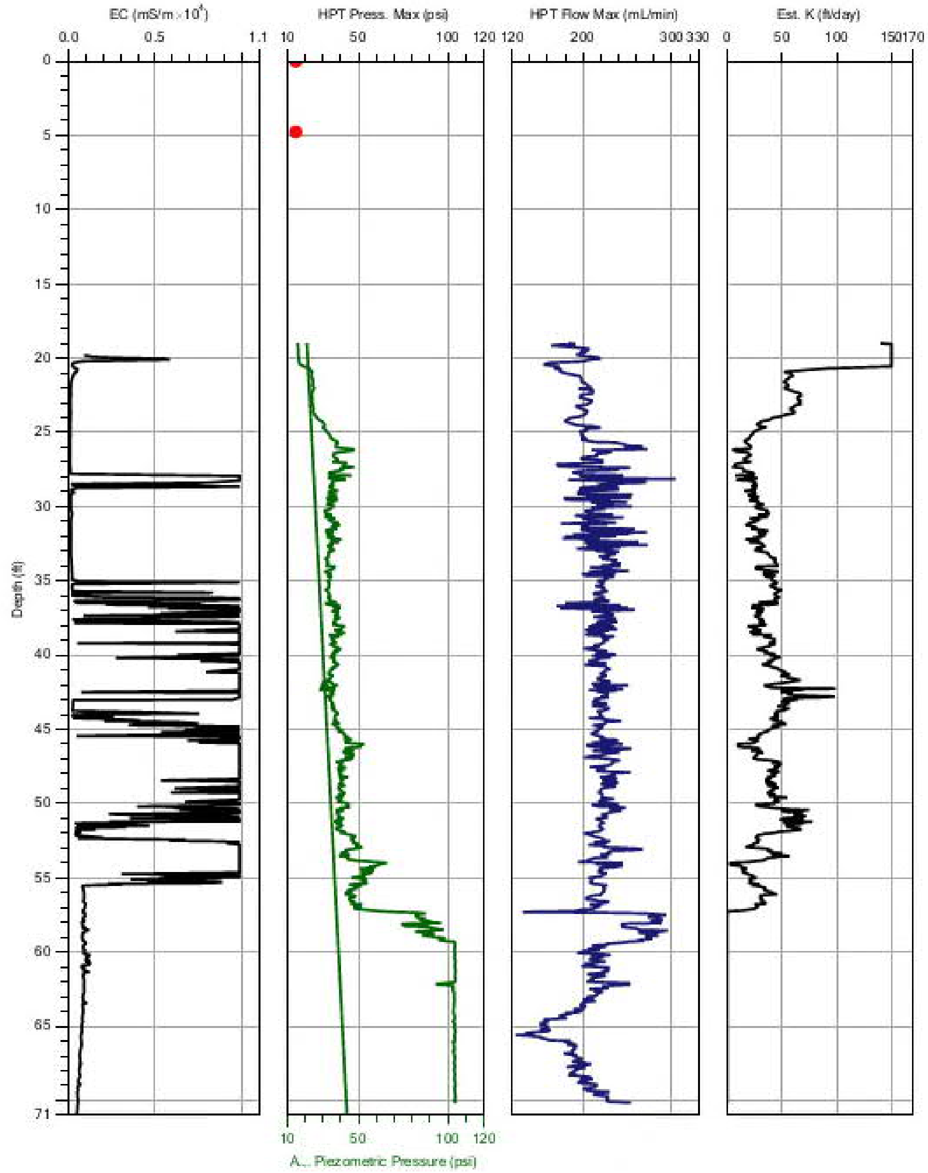
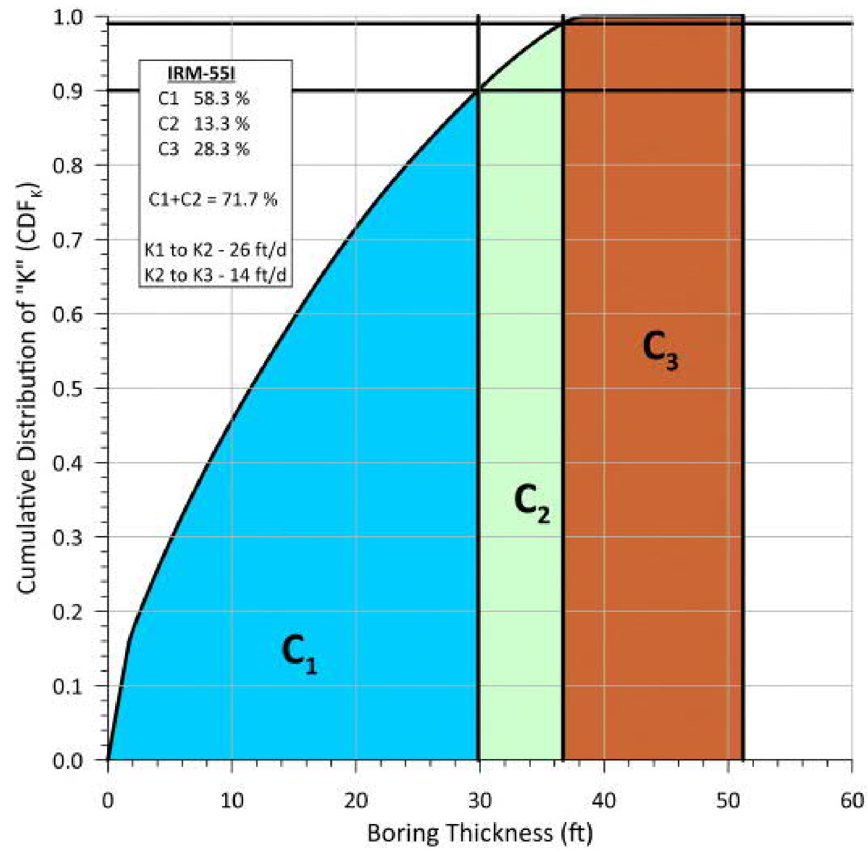
114-P2-IRM-53I

ARCADIS Design & Consultancy for natural and built assets

FIGURE
E22





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114-P2-IRM-55I

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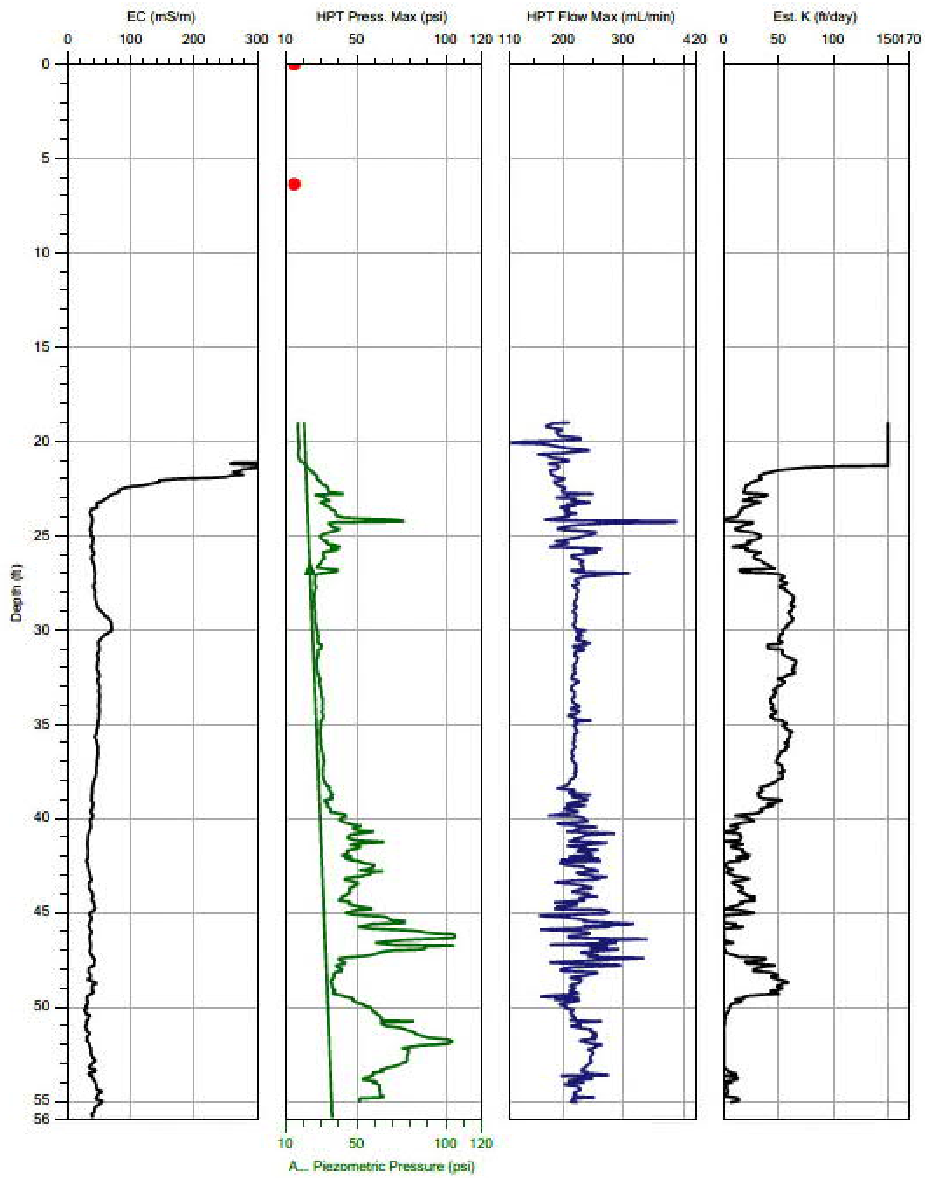
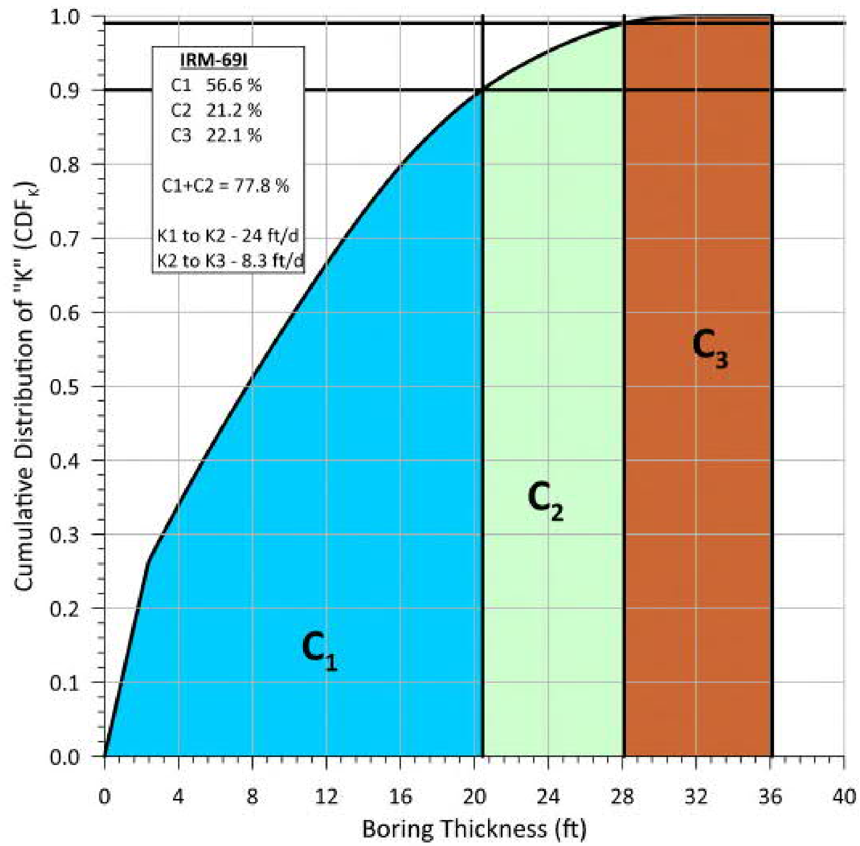
FIGURE
E23





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114-P2-IRM-69I

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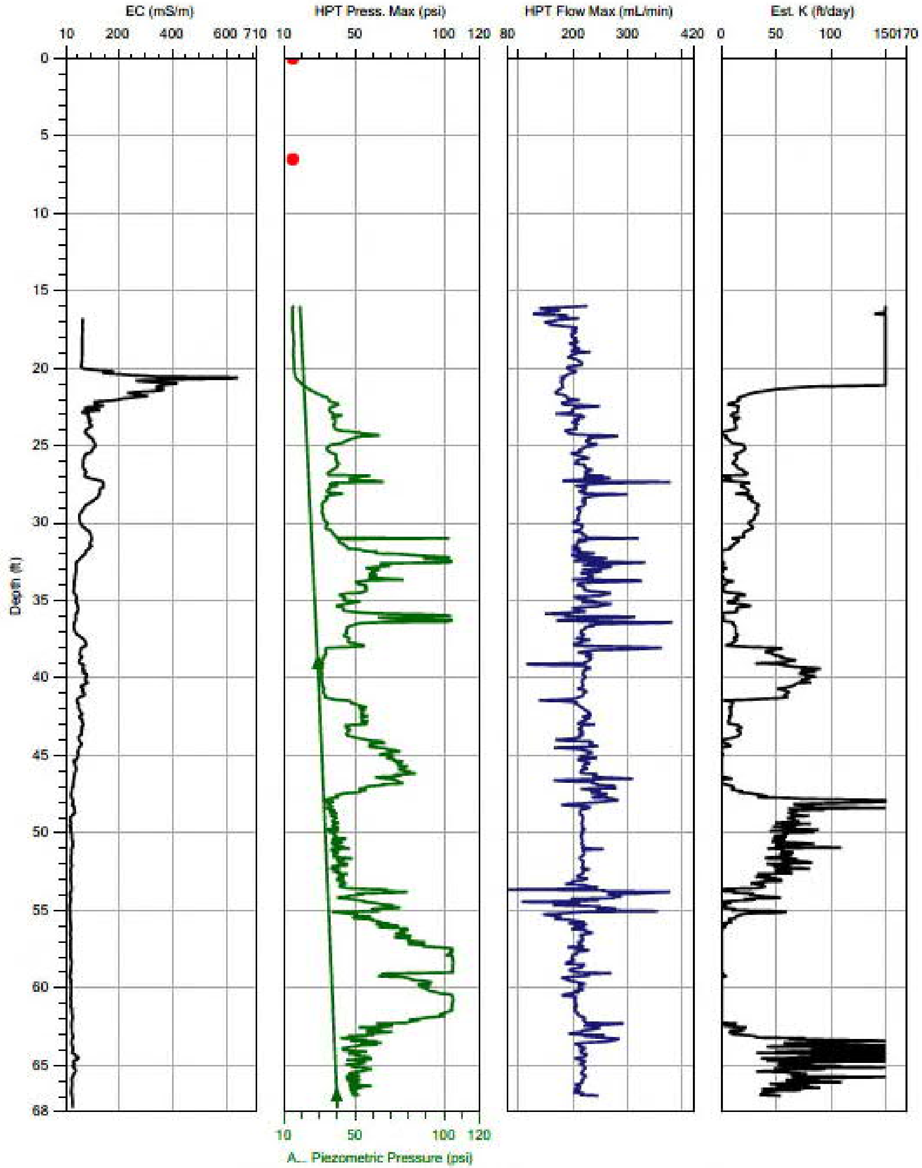
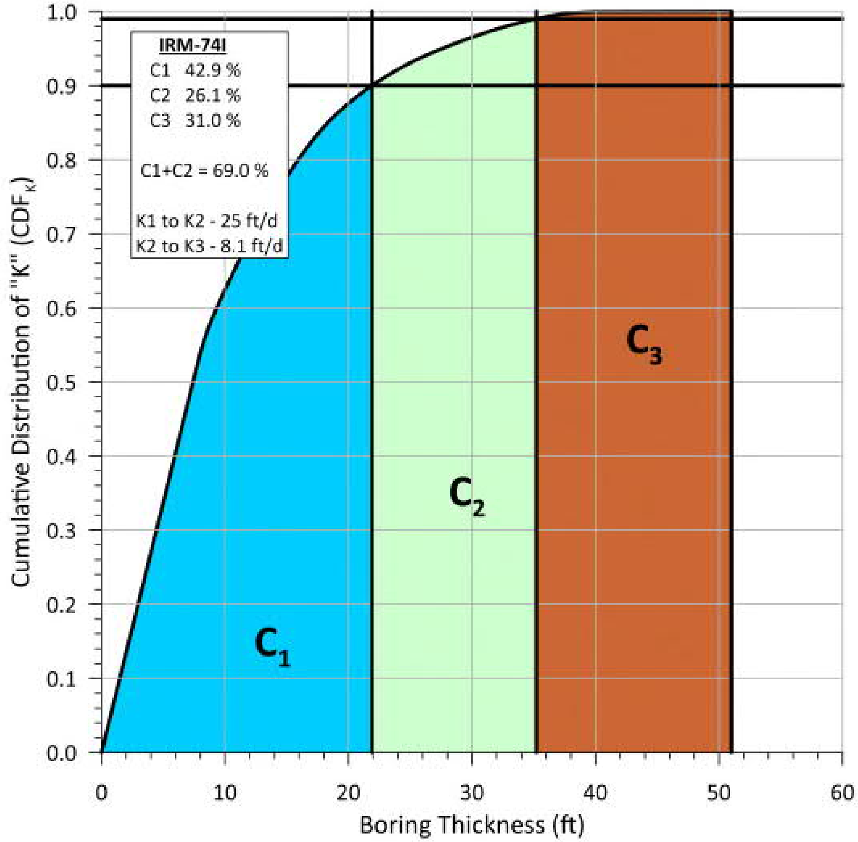
FIGURE
E24





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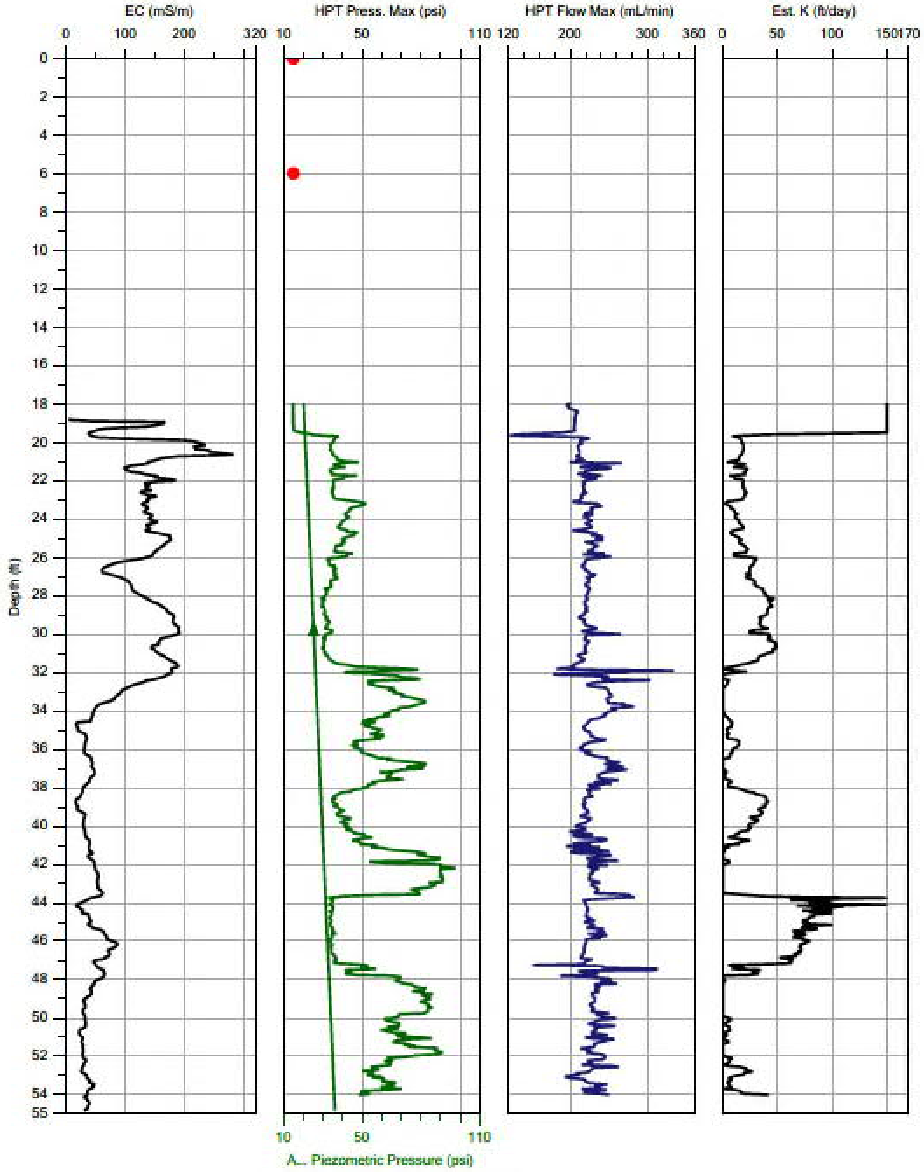
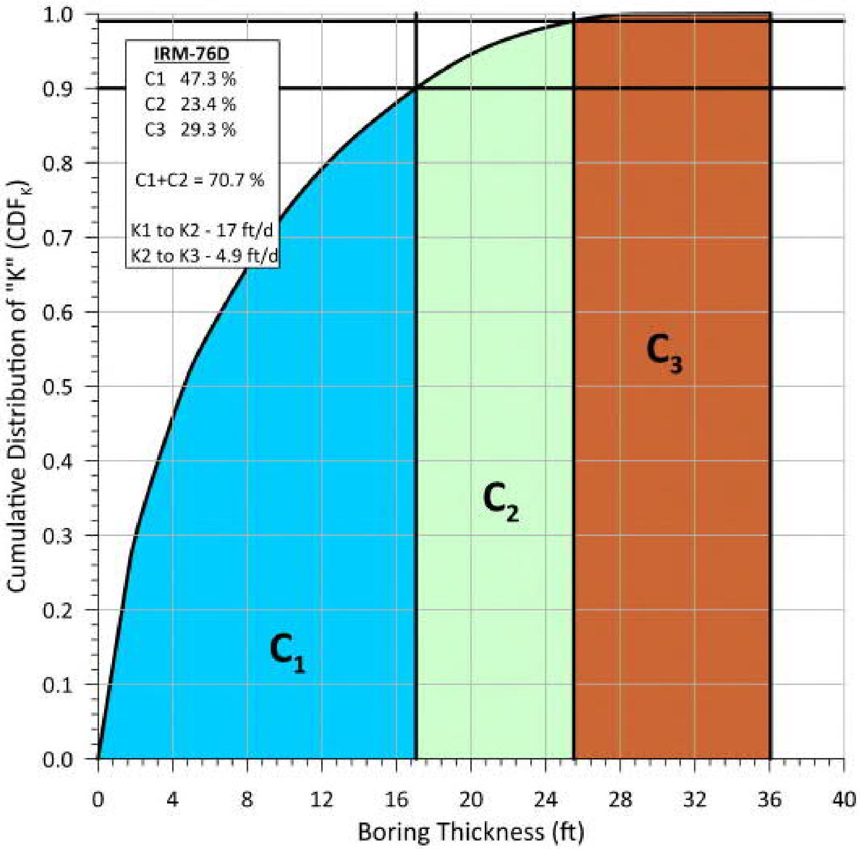
114-P2-IRM-74I

ARCADIS Design & Consultancy for natural and built assets

FIGURE
E25





Notes:
C1 – most permeable soils, dominated by advective transport
C2 – moderately permeable soils, dominated by slow advection
C3 – low permeability soils, dominated by diffusion

PPG INDUSTRIES
GARFIELD AVENUE GROUP SITES
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114-P2-IRM-76D

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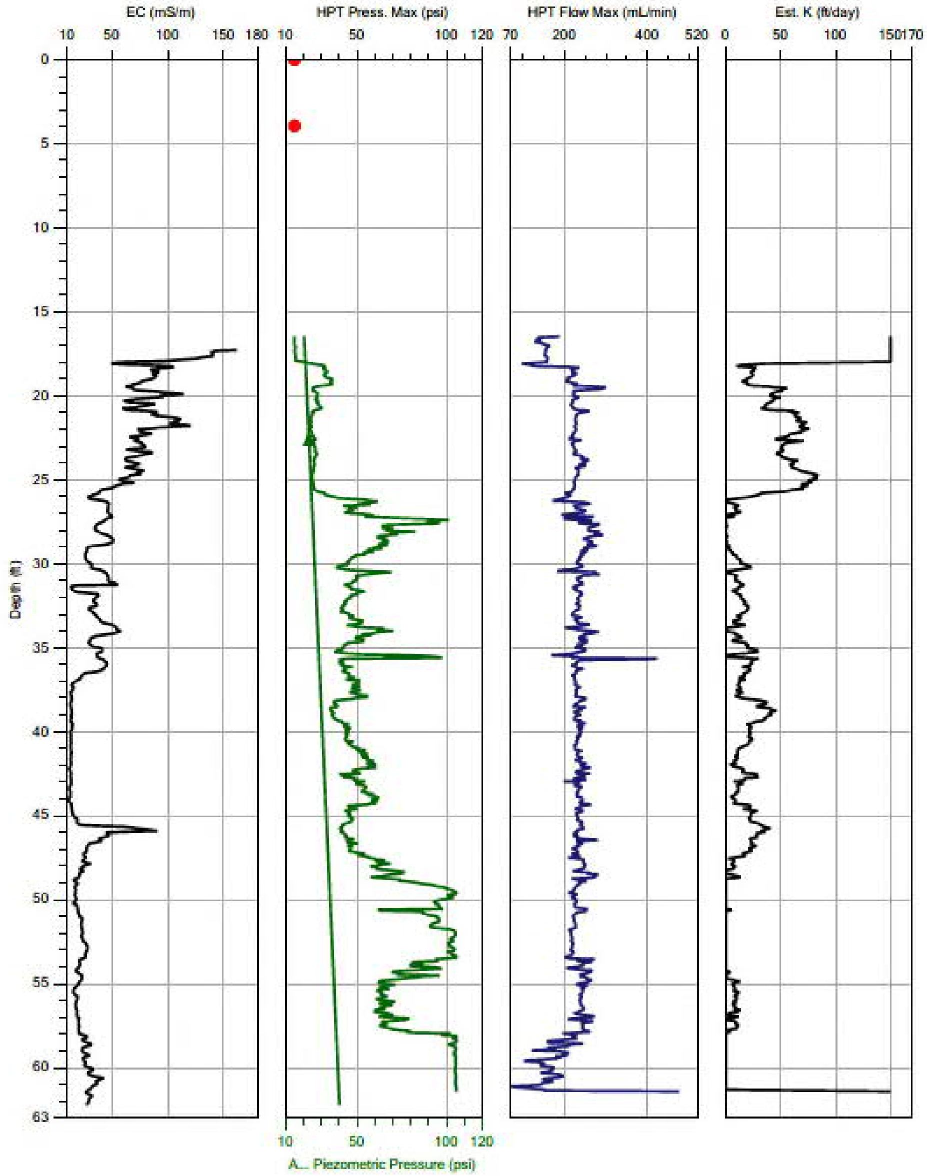
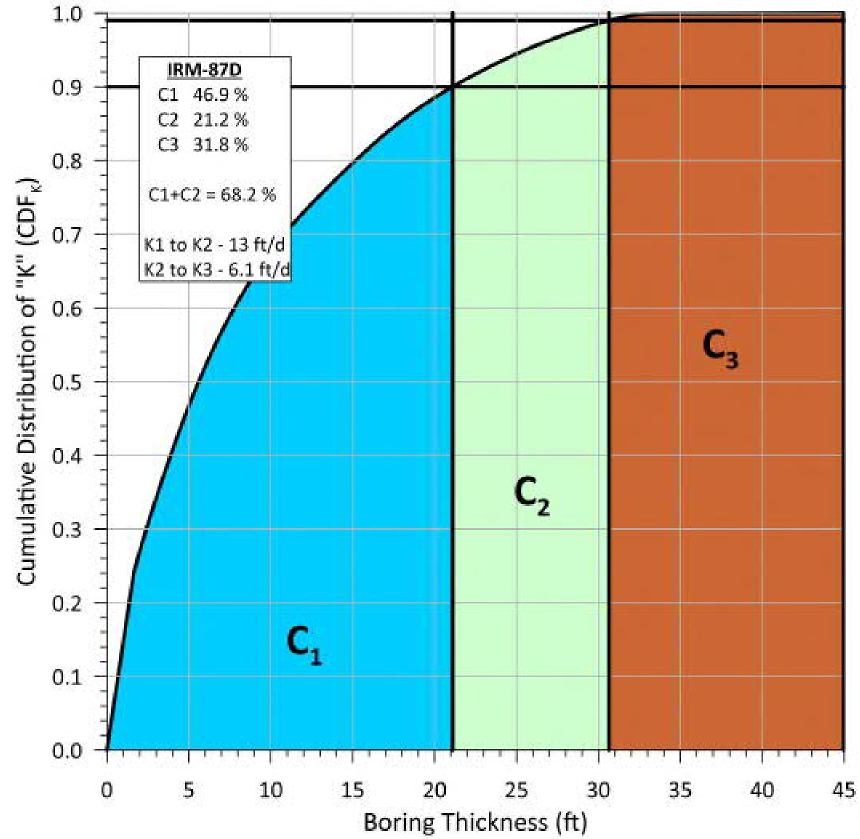
FIGURE
E26





Notes:

C1 – most permeable soils, dominated by advective transport

C2 – moderately permeable soils, dominated by slow advection

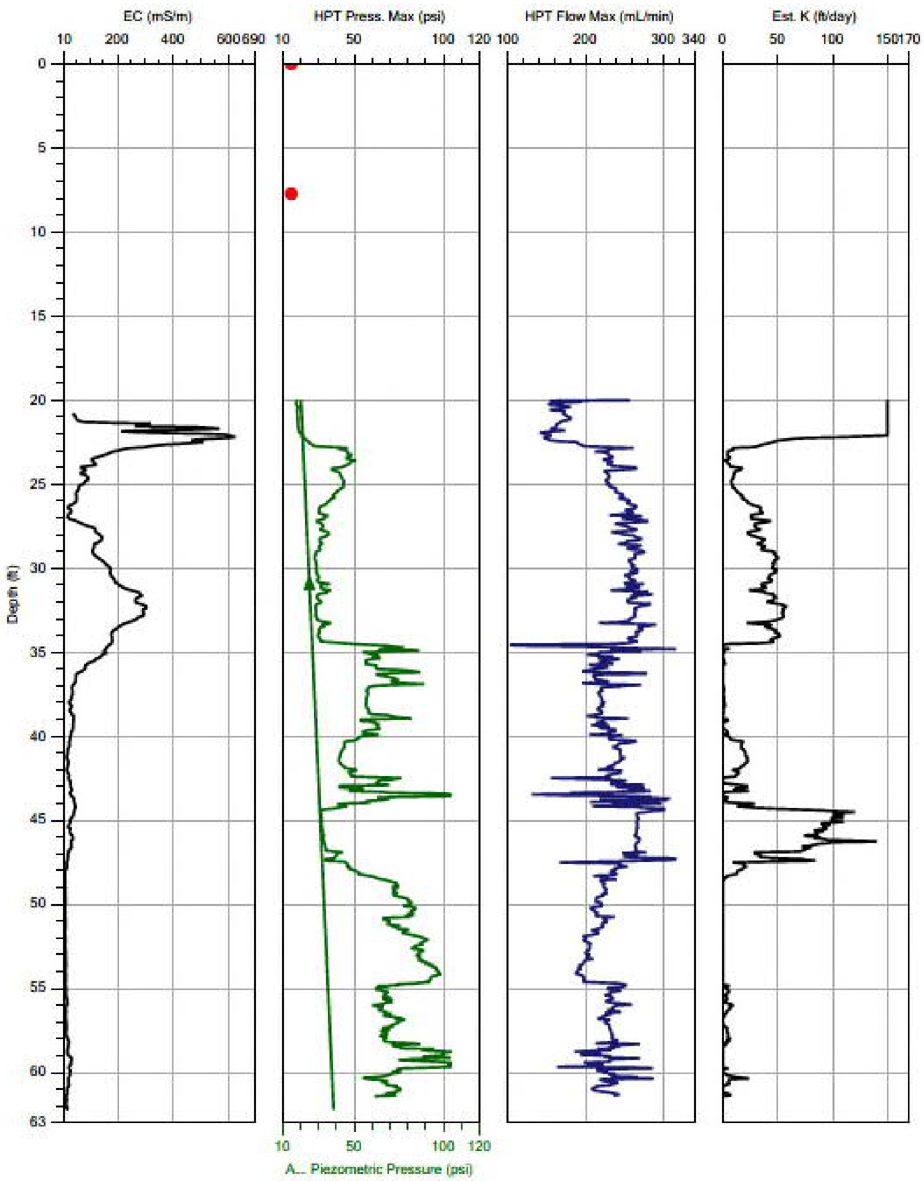
C3 – low permeability soils, dominated by diffusion

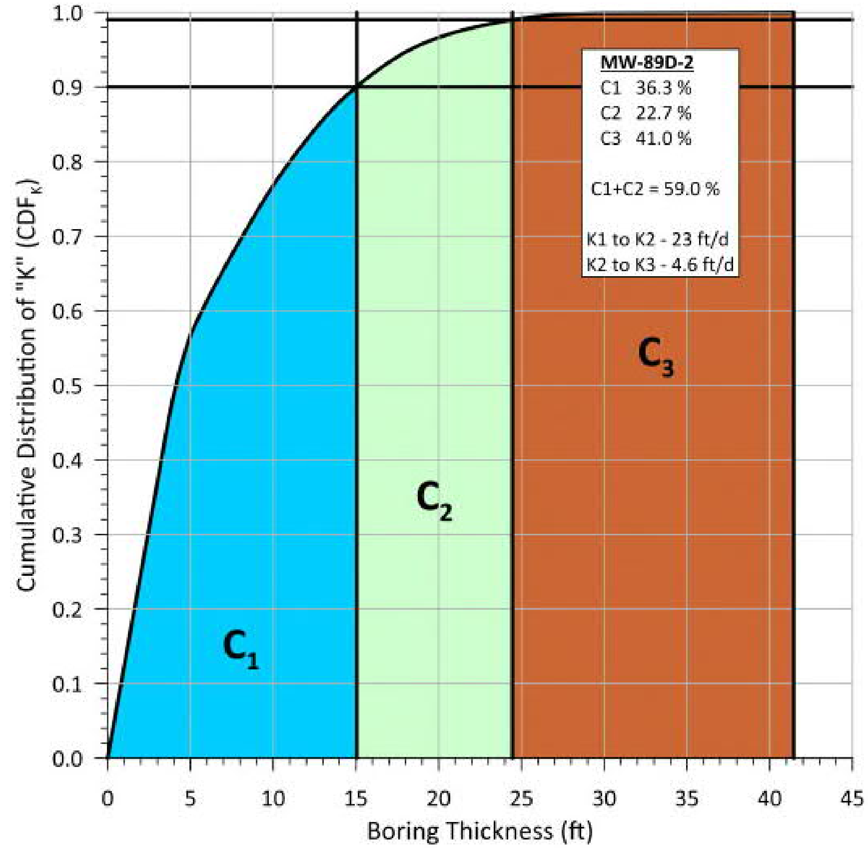
PPG INDUSTRIES
GARFIELD AVENUE GROUP SITES
JERSEY CITY, NEW JERSEY

114-P2-IRM-87D

ARCADIS Design & Consultancy for natural and built assets

FIGURE
E27





Notes:
C1 – most permeable soils, dominated by advective transport
C2 – moderately permeable soils, dominated by slow advection
C3 – low permeability soils, dominated by diffusion

PPG INDUSTRIES
GARFIELD AVENUE GROUP SITES
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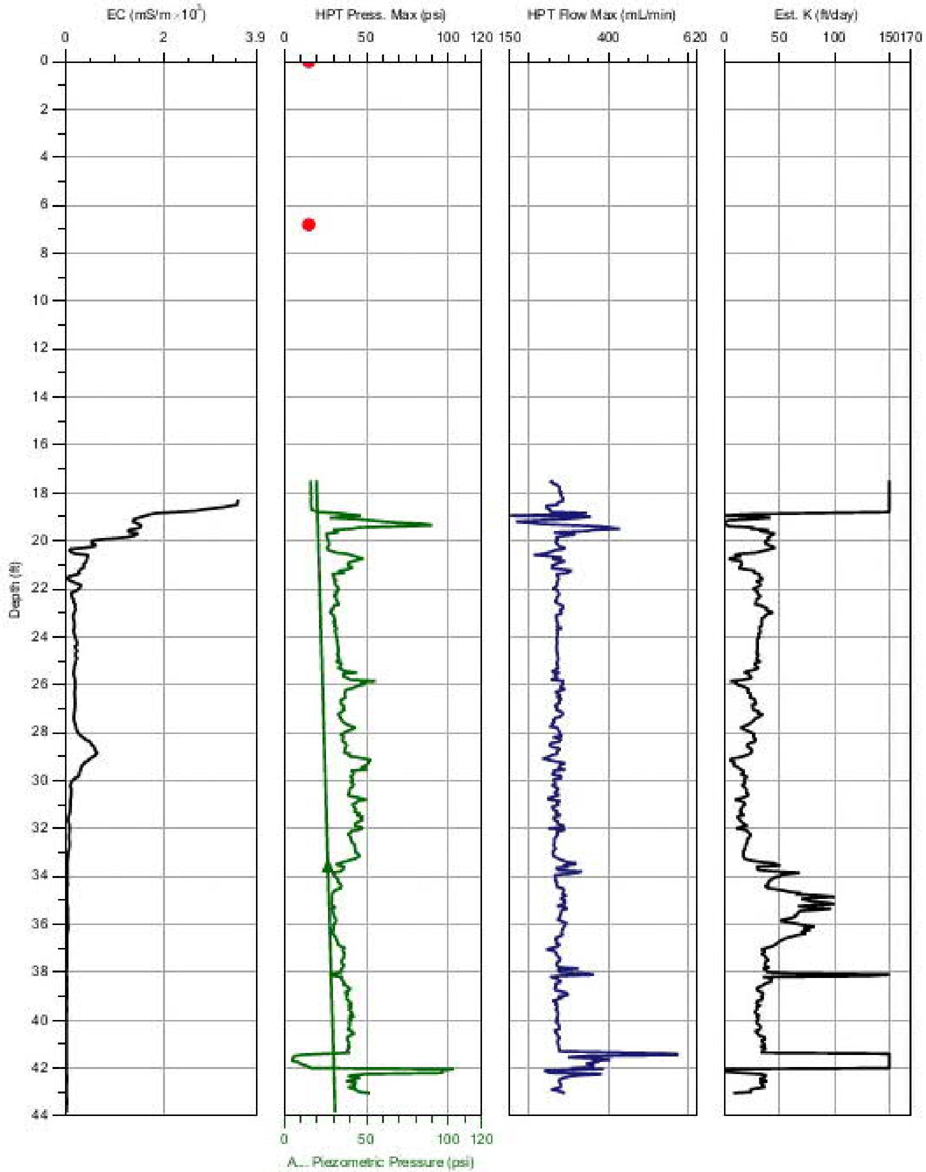
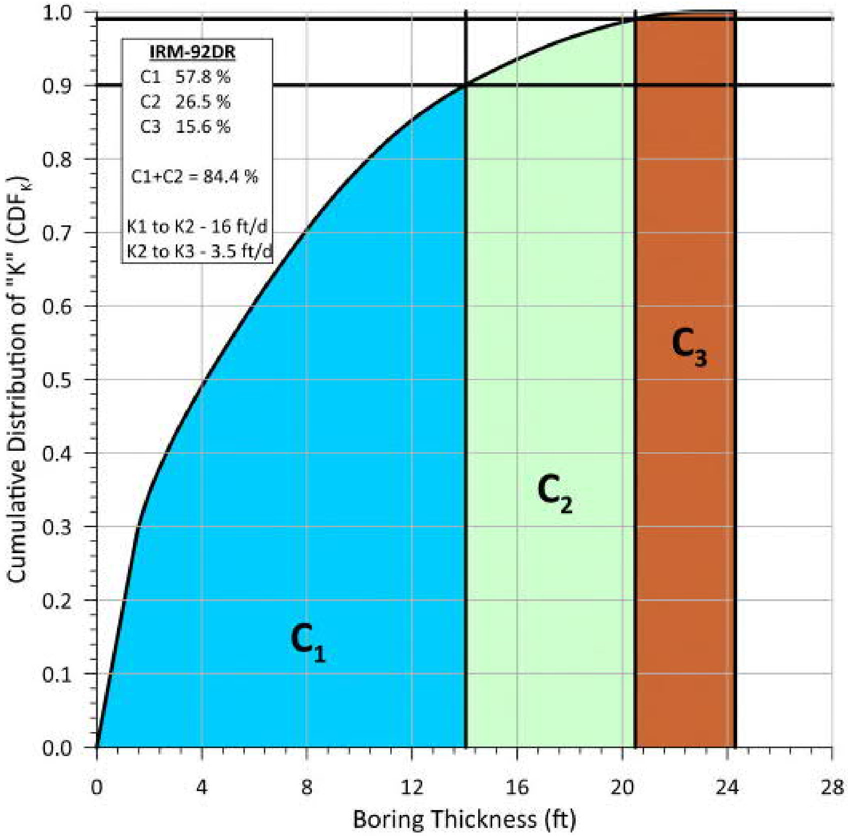
114-P2-IRM-89D

ARCADIS Design & Consultancy for natural and built assets

FIGURE
E28





Notes:
C1 – most permeable soils, dominated by advective transport
C2 – moderately permeable soils, dominated by slow advection
C3 – low permeability soils, dominated by diffusion

PPG INDUSTRIES
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JERSEY CITY, NEW JERSEY

114-P2-IRM-92DR

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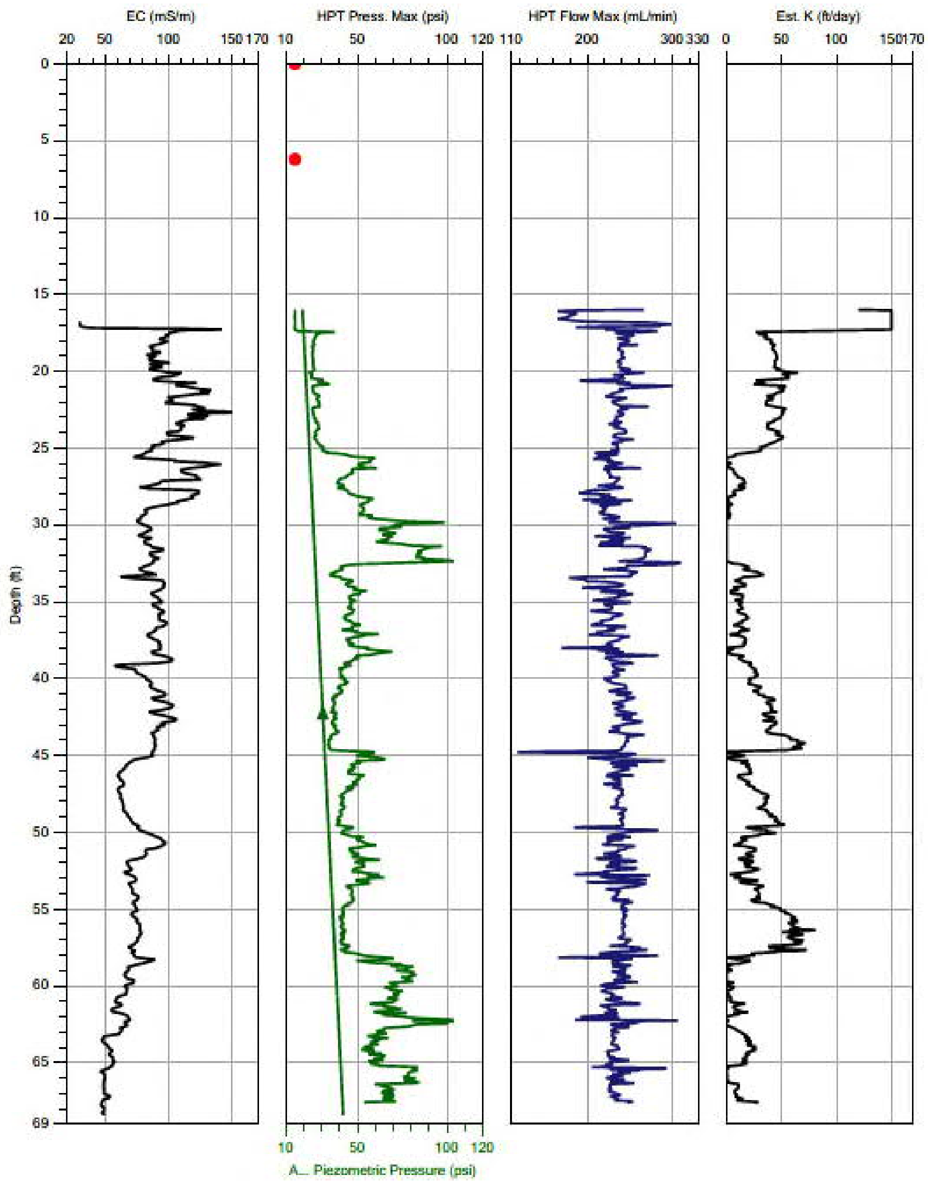
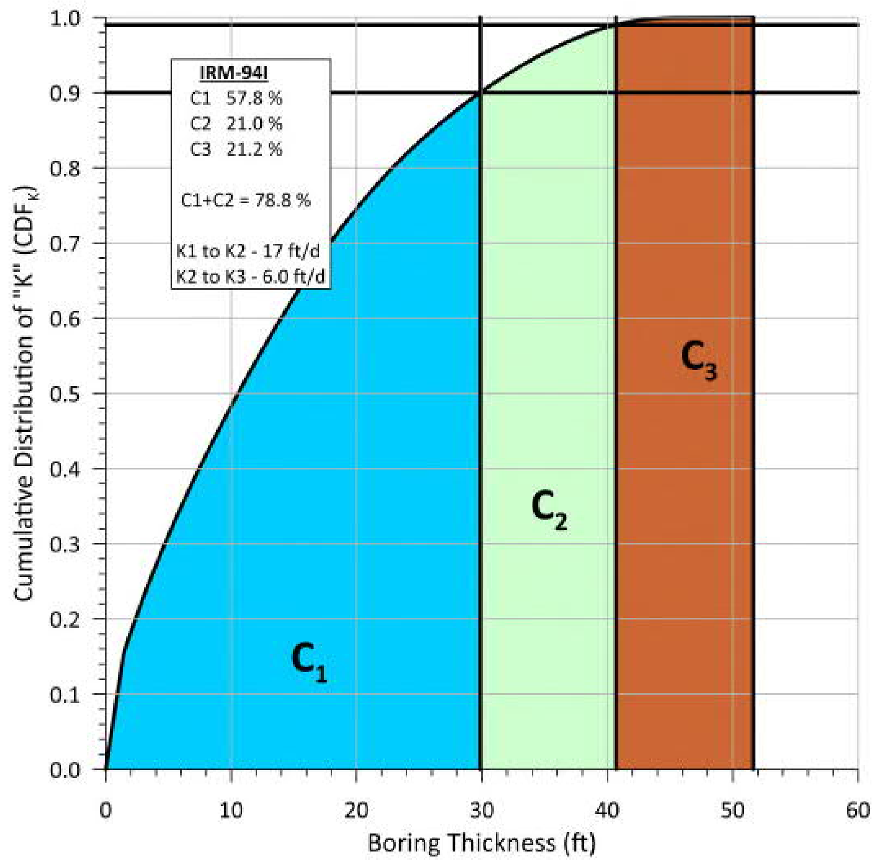
FIGURE
E29





Notes:
C1 – most permeable soils, dominated by advective transport
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C3 – low permeability soils, dominated by diffusion

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114-P2-IRM-94I

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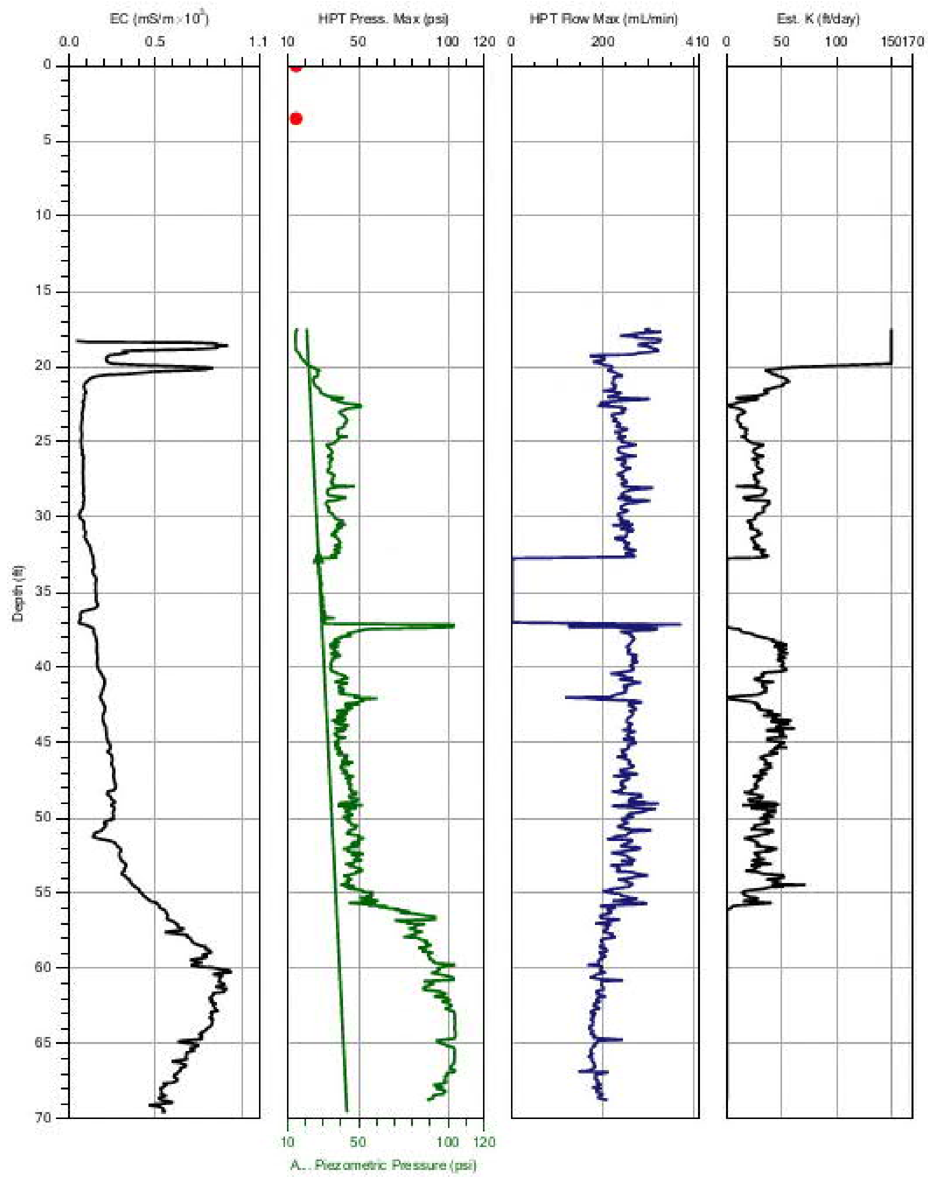
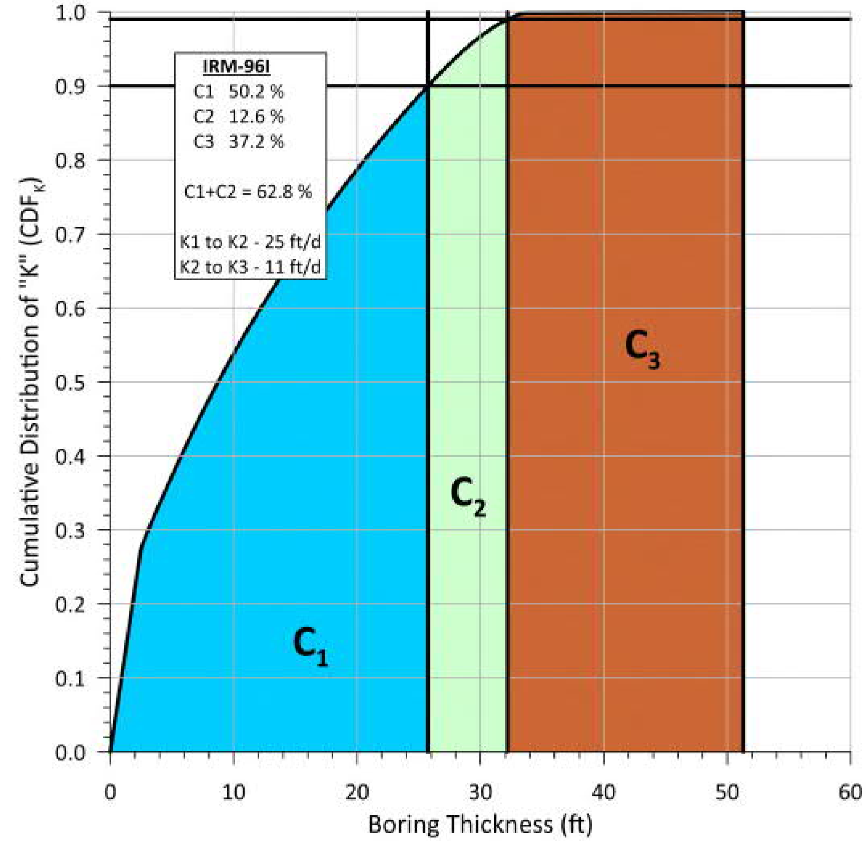
FIGURE
E30





Notes:
C1 – most permeable soils, dominated by advective transport
C2 – moderately permeable soils, dominated by slow advection
C3 – low permeability soils, dominated by diffusion

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114-P2-IRM-96I

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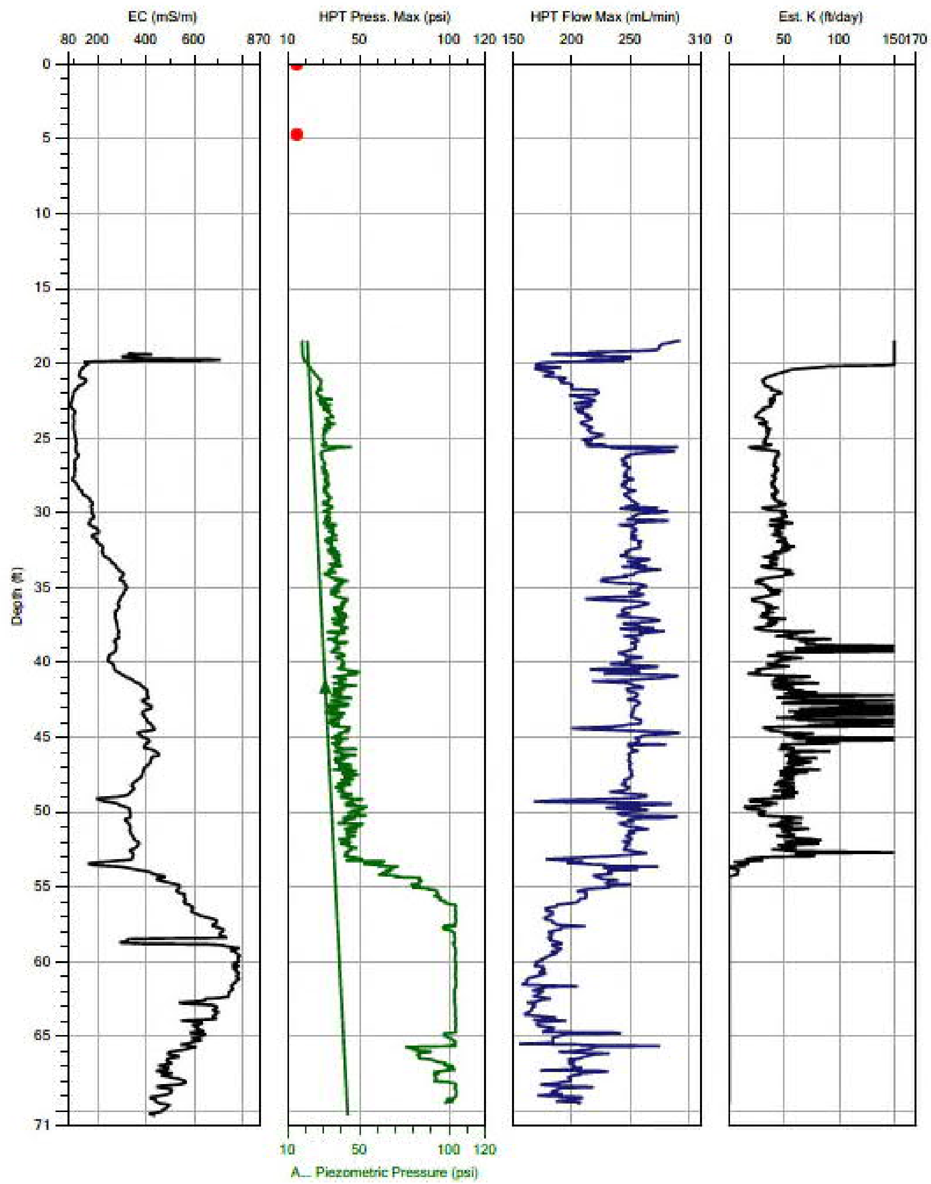
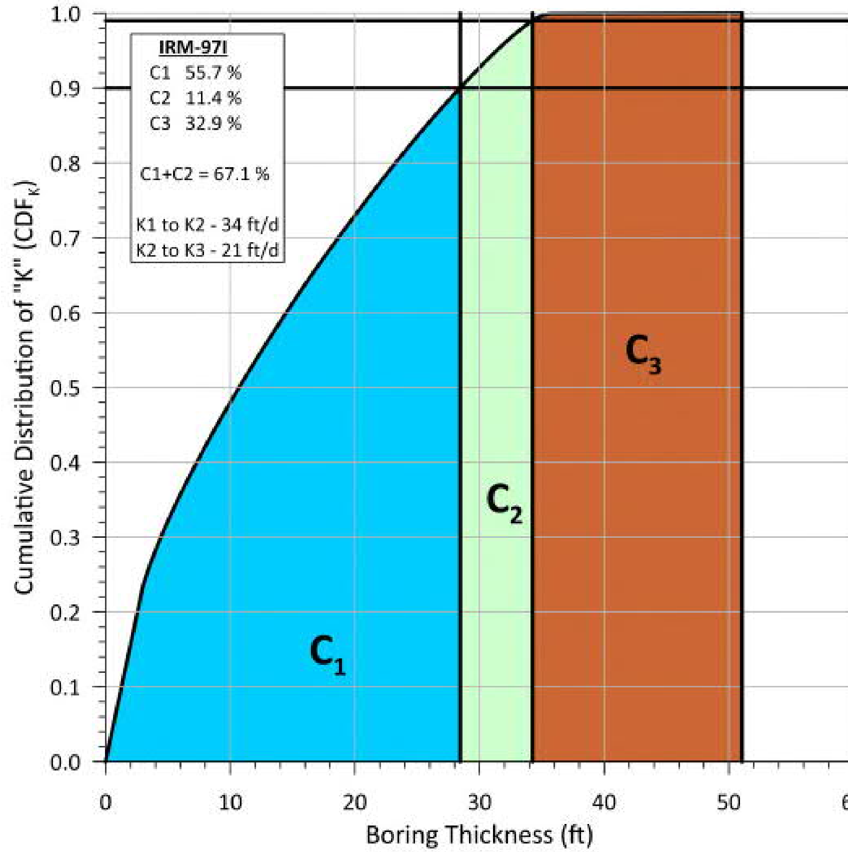
FIGURE
E31





Notes:
C1 – most permeable soils, dominated by advective transport
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C3 – low permeability soils, dominated by diffusion

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114-P2-IRM-97I

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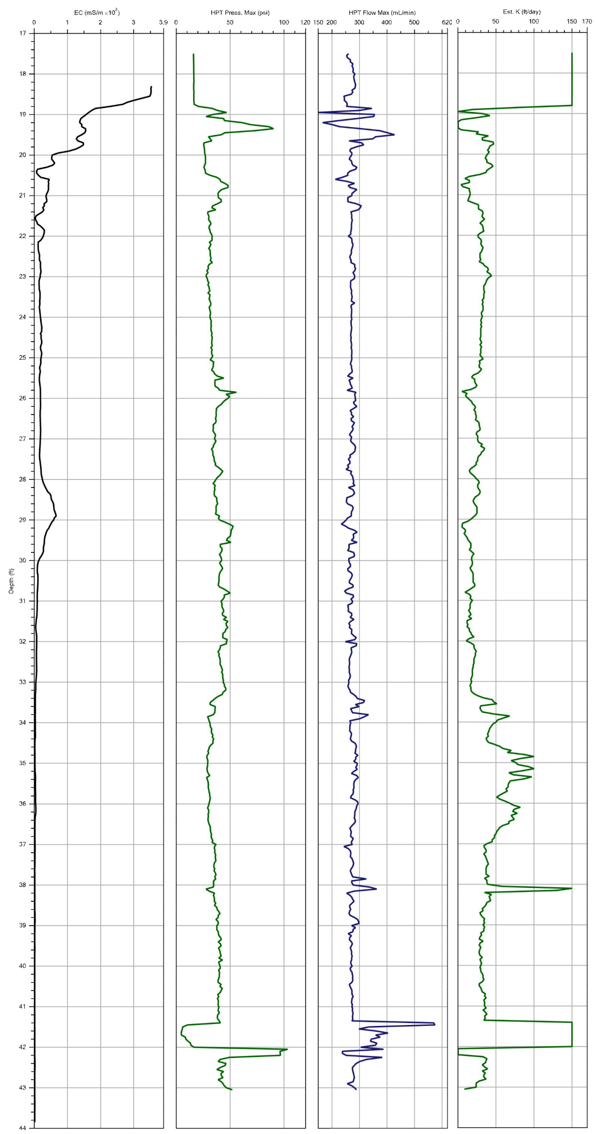
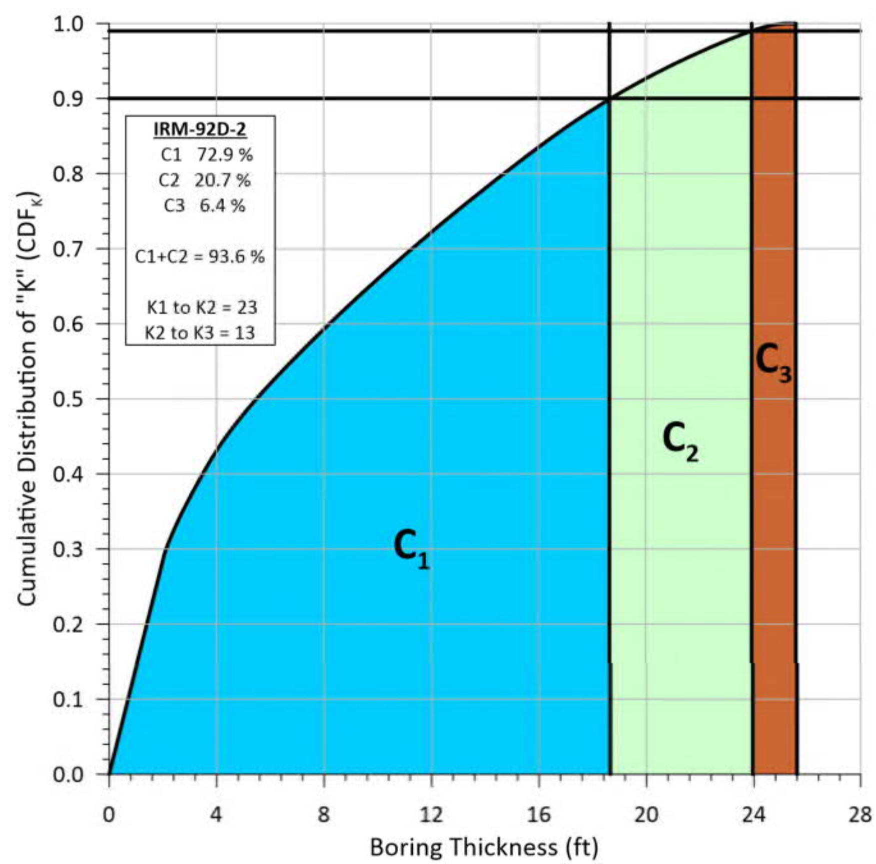
FIGURE
E32





Notes:

C1 - most permeable soils, dominated by advective transport

C2 - moderately permeable soils, dominated by slow advection

C3 - low permeability soils, dominated by diffusion

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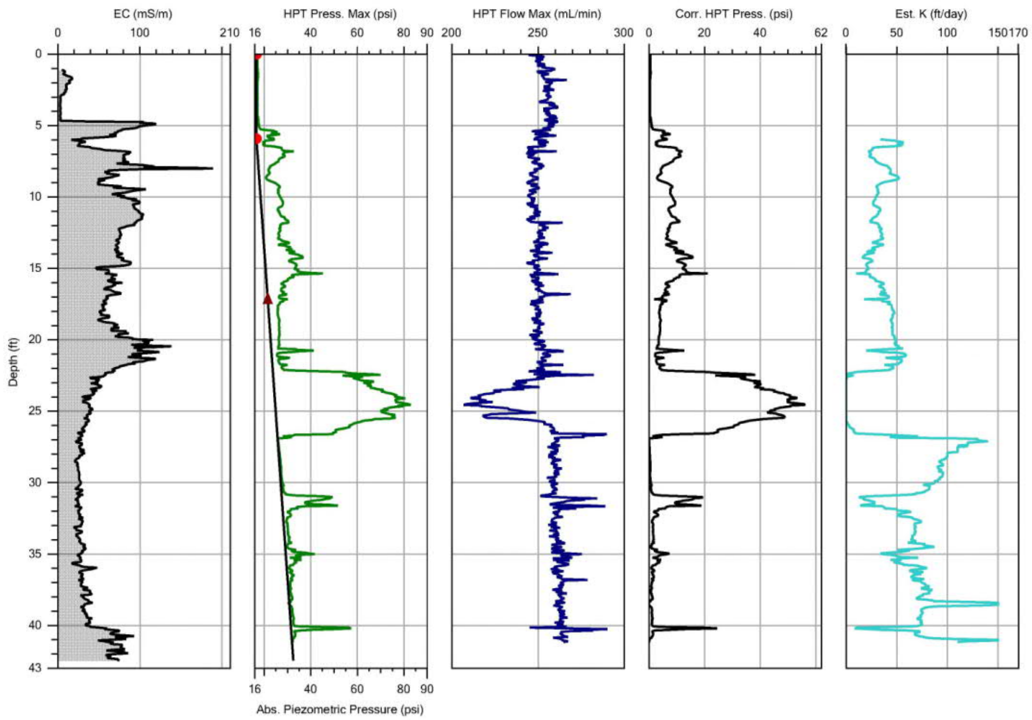
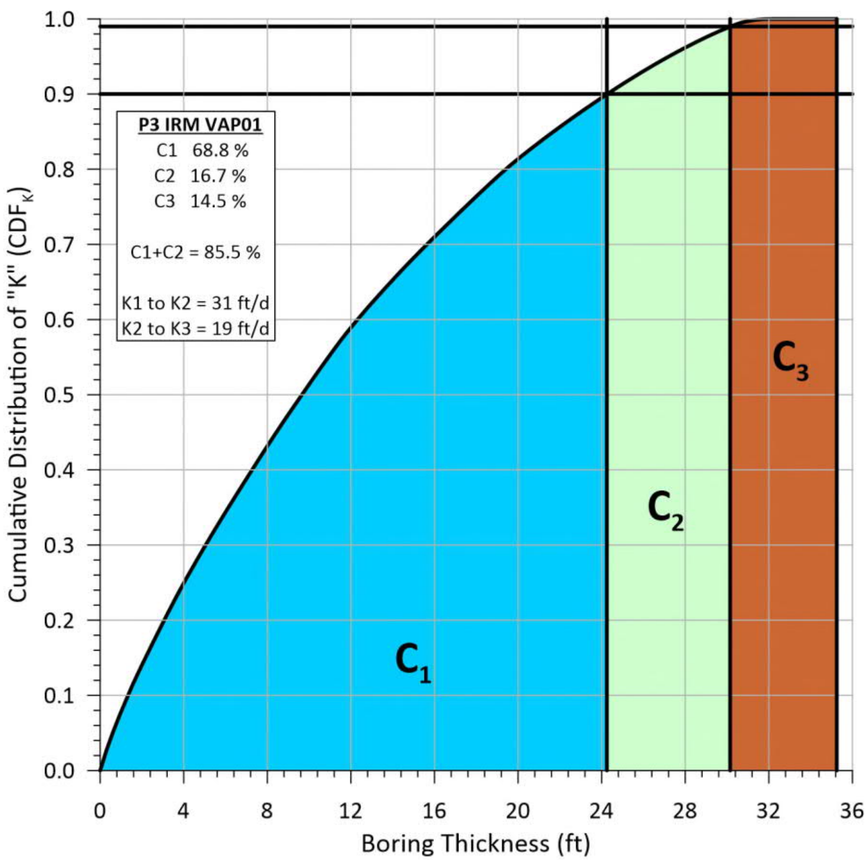
GARFIELD AVENUE GROUP SITES
JERSEY CITY, NEW JERSEY

114-P2-IRM-92D-2

ARCADIS Design & Consultancy for natural and built assets

FIGURE
E33





Notes:

C1 - most permeable soils, dominated by advective transport

C2 - moderately permeable soils, dominated by slow advection

C3 - low permeability soils, dominated by diffusion

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P3-IRM-VAP01

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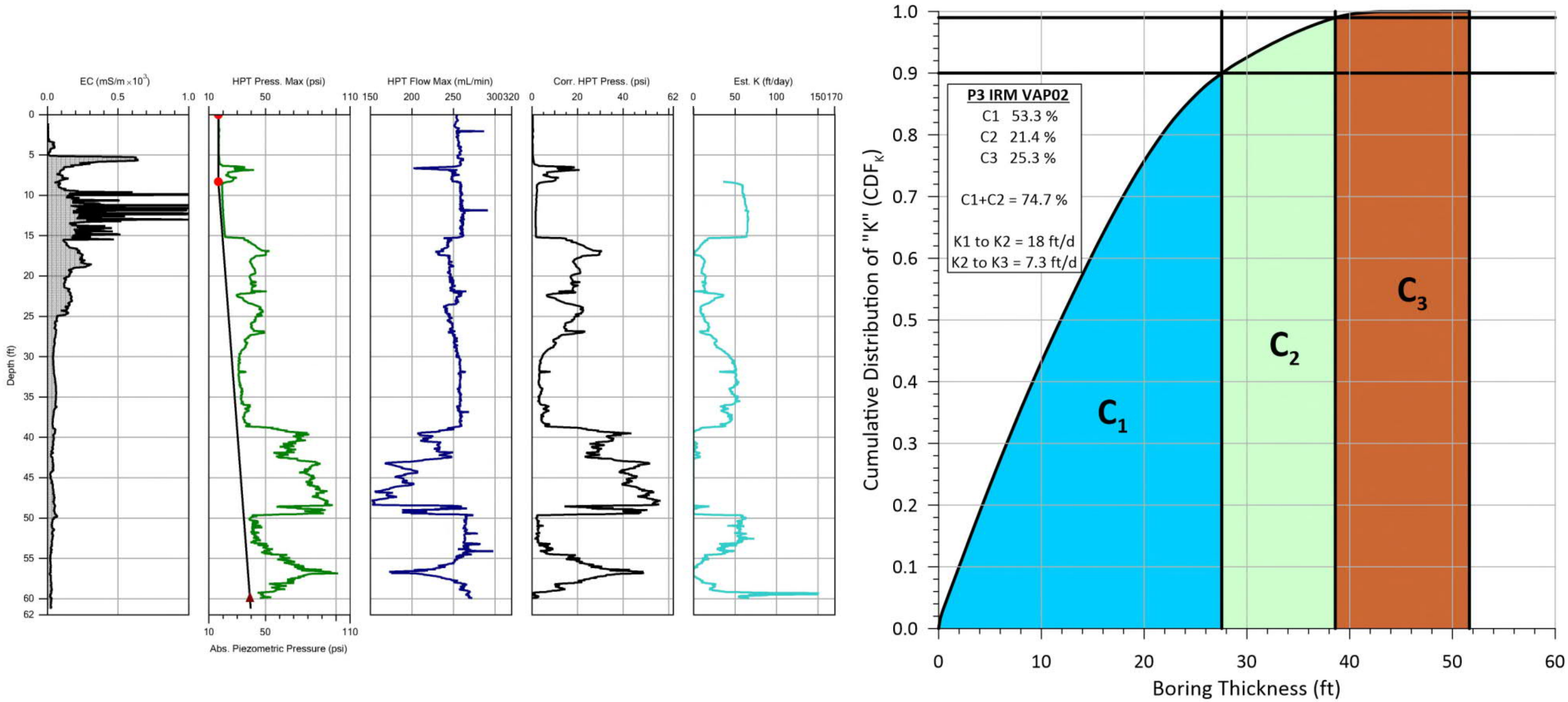
FIGURE

E34



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P3-IRM-VAP02

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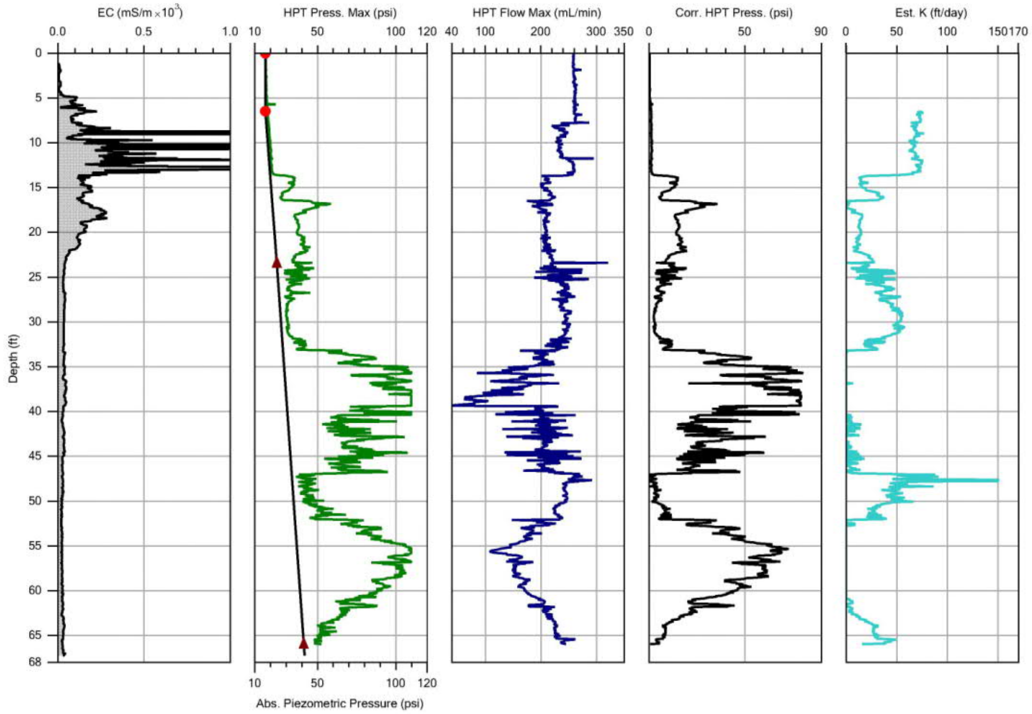
FIGURE
E35

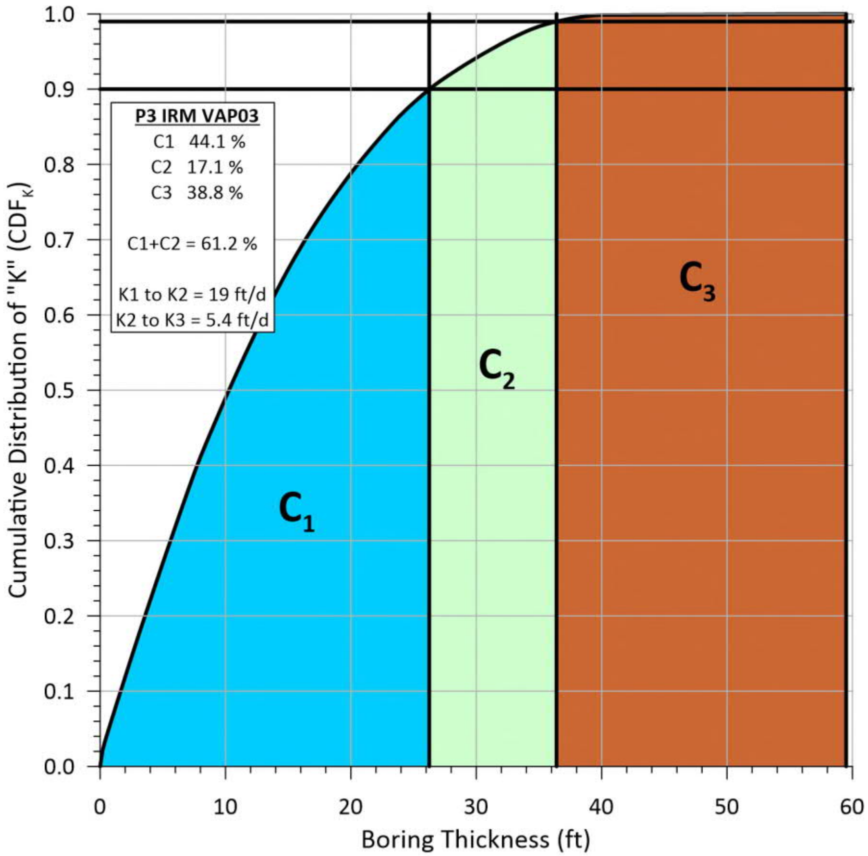
Notes:

C1 - most permeable soils, dominated by advective transport

C2 - moderately permeable soils, dominated by slow advection

C3 - low permeability soils, dominated by diffusion





Notes:

C1 - most permeable soils, dominated by advective transport

C2 - moderately permeable soils, dominated by slow advection

C3 - low permeability soils, dominated by diffusion

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GARFIELD AVENUE GROUP SITES
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P3-IRM-VAP03

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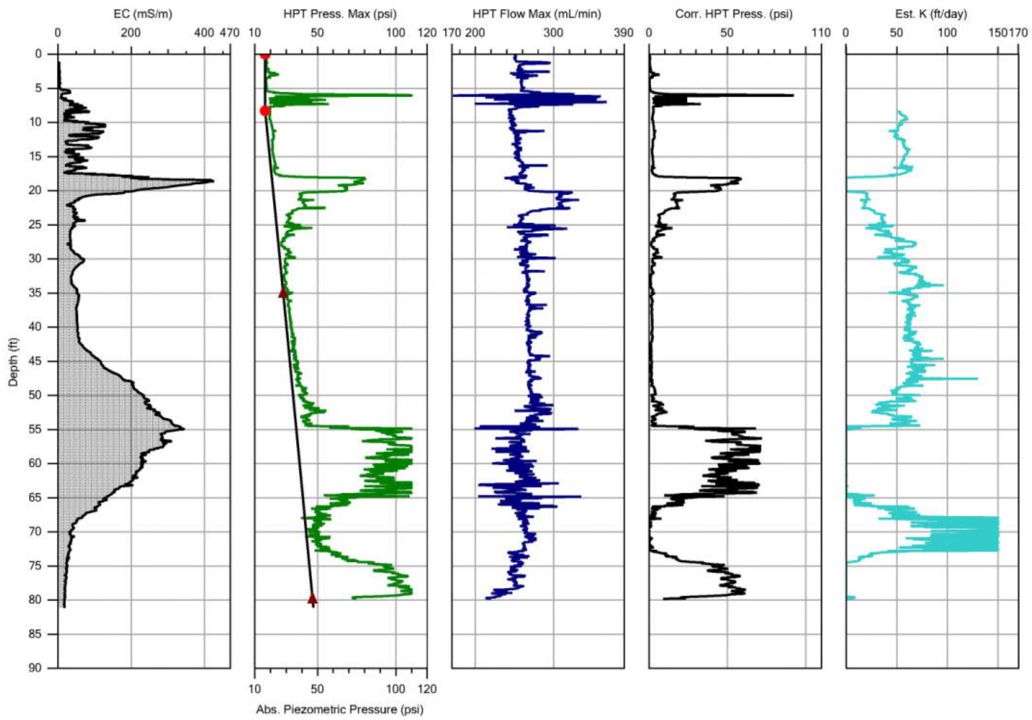
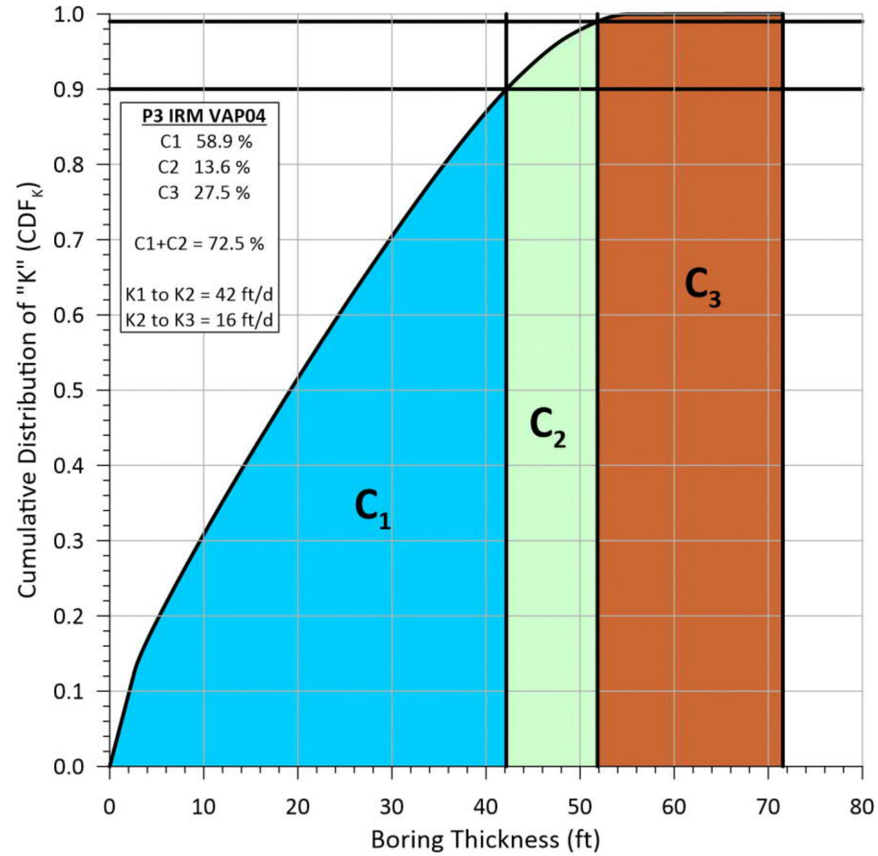
FIGURE
E36





Notes:

C1 - most permeable soils, dominated by advective transport

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C3 - low permeability soils, dominated by diffusion

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P3-IRM-VAP04

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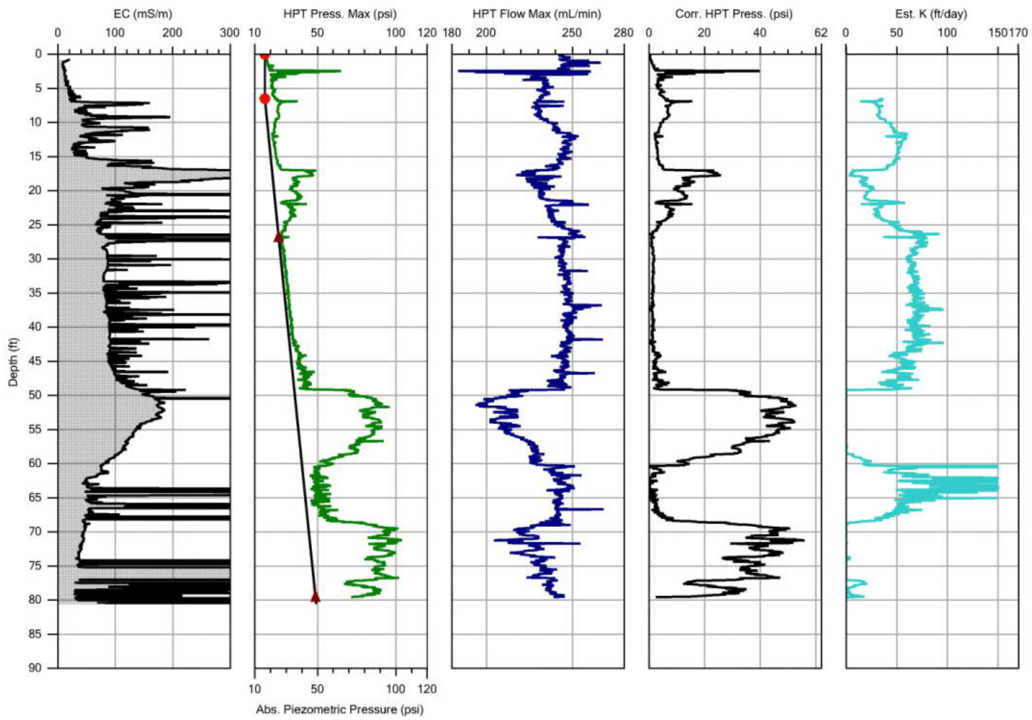
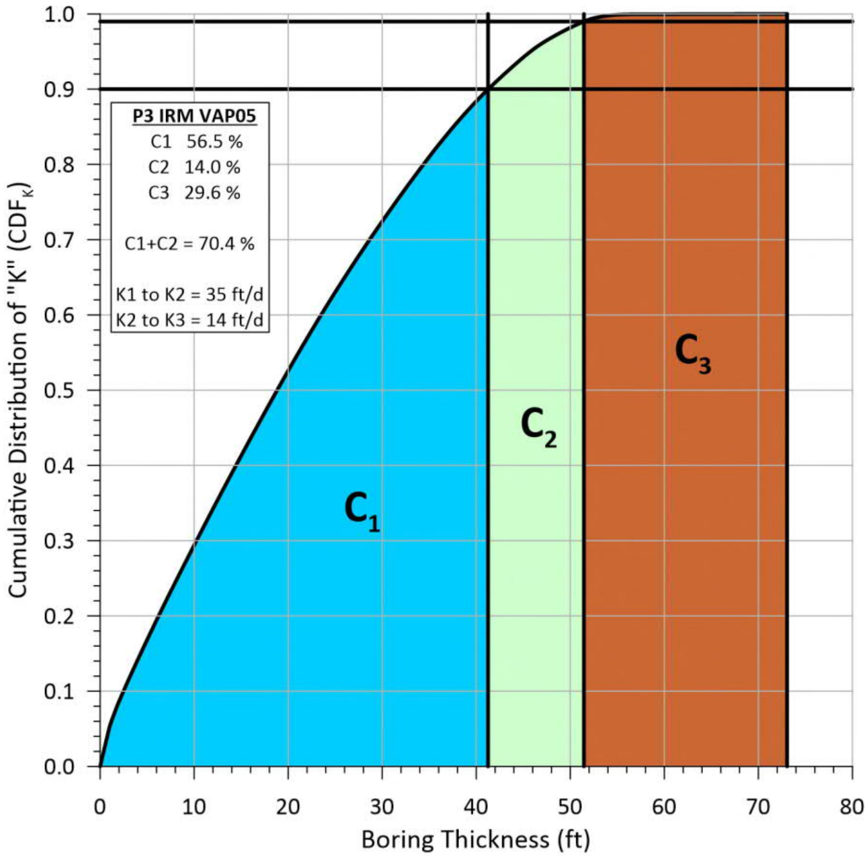
FIGURE
E37





Notes:

C1 - most permeable soils, dominated by advective transport

C2 - moderately permeable soils, dominated by slow advection

C3 - low permeability soils, dominated by diffusion

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P3-IRM-VAP05

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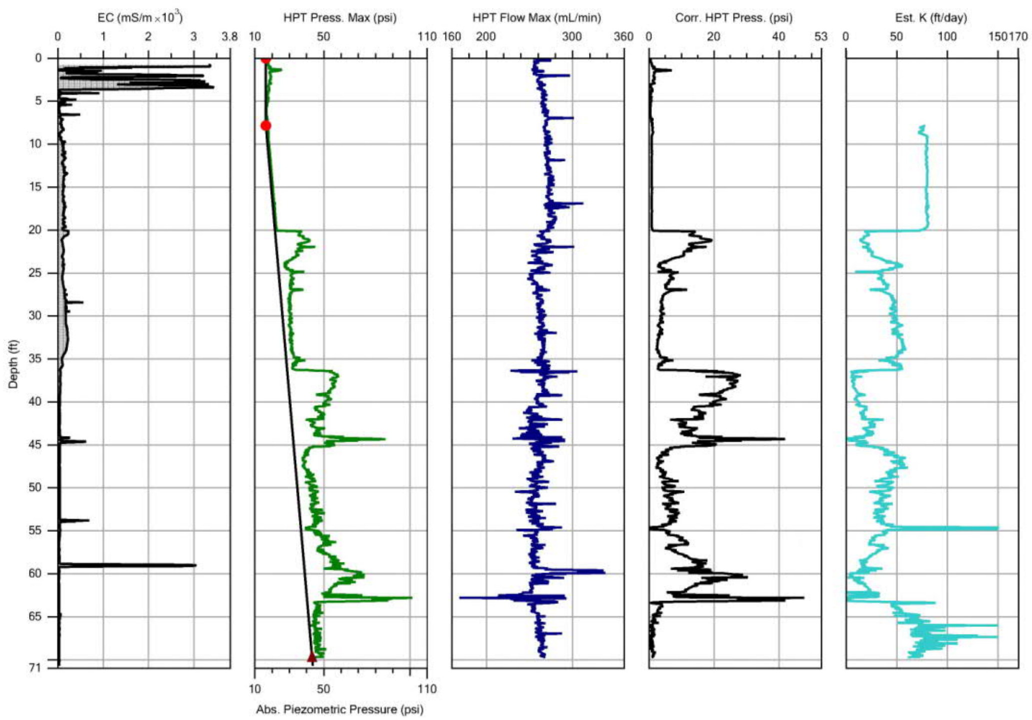
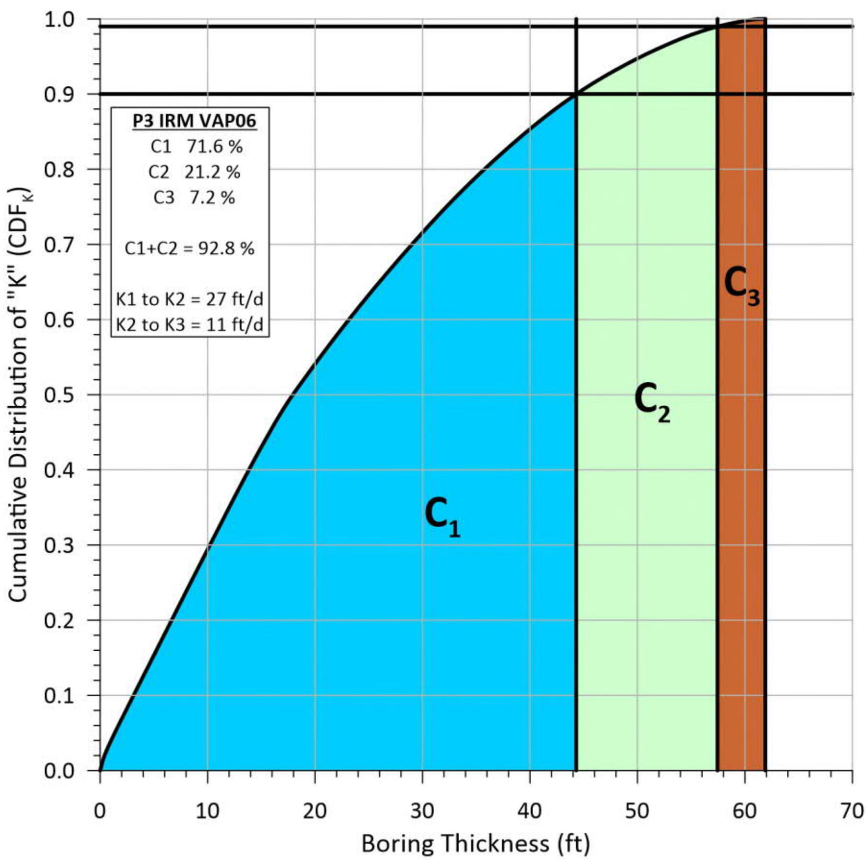
FIGURE
E38





Notes:

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P3-IRM-VAP06

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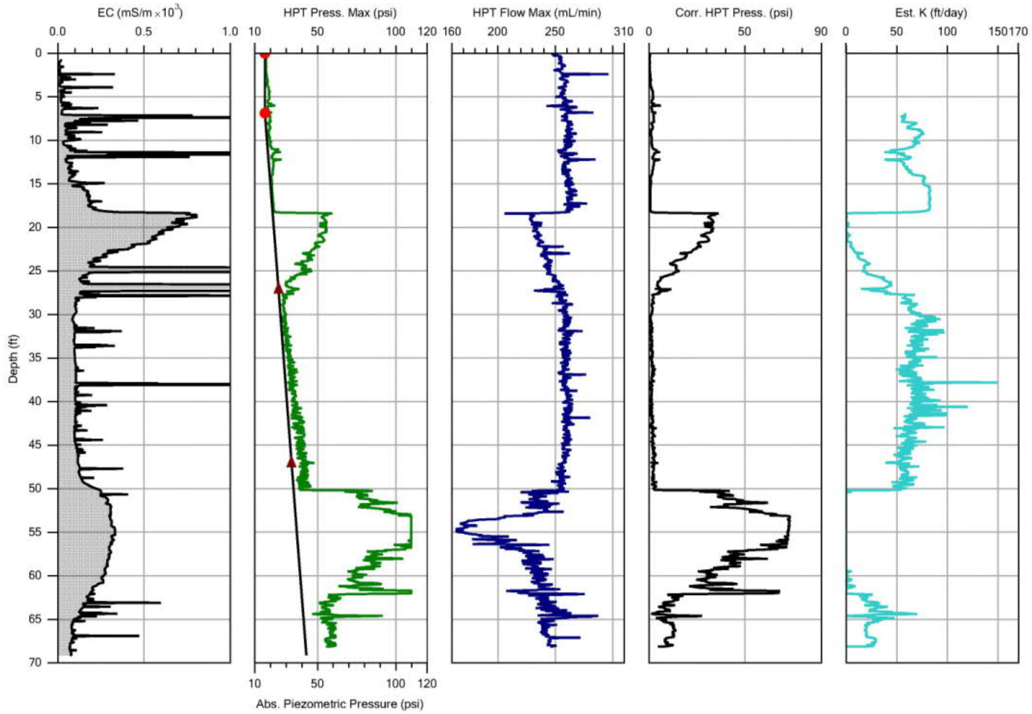
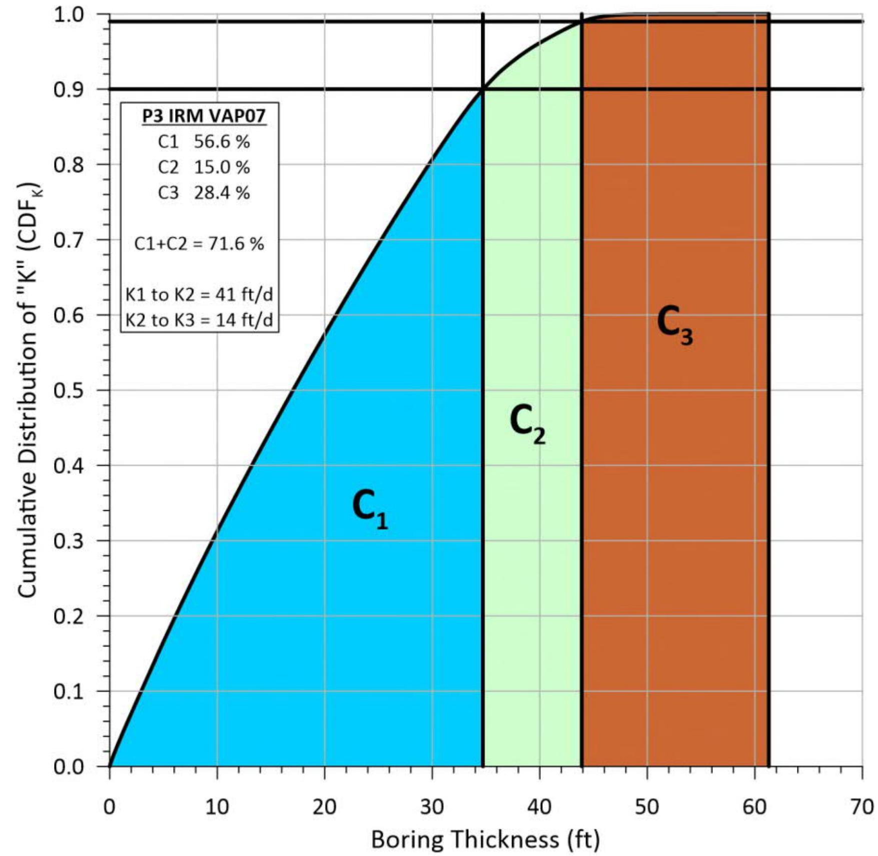
FIGURE
E39





Notes:

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P3-IRM-VAP07

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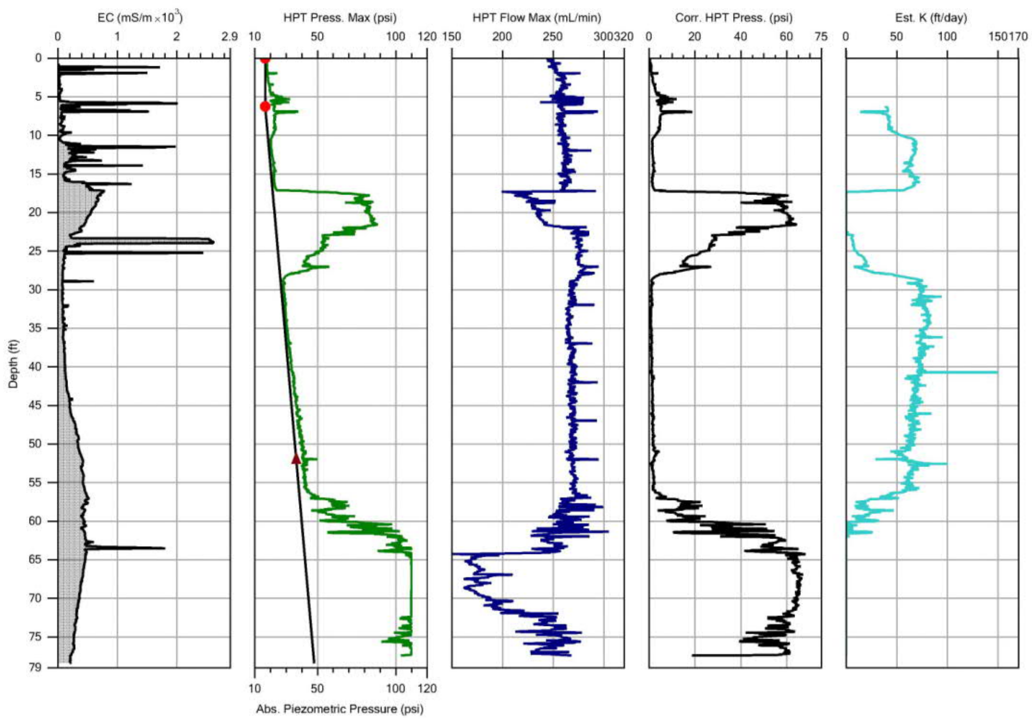
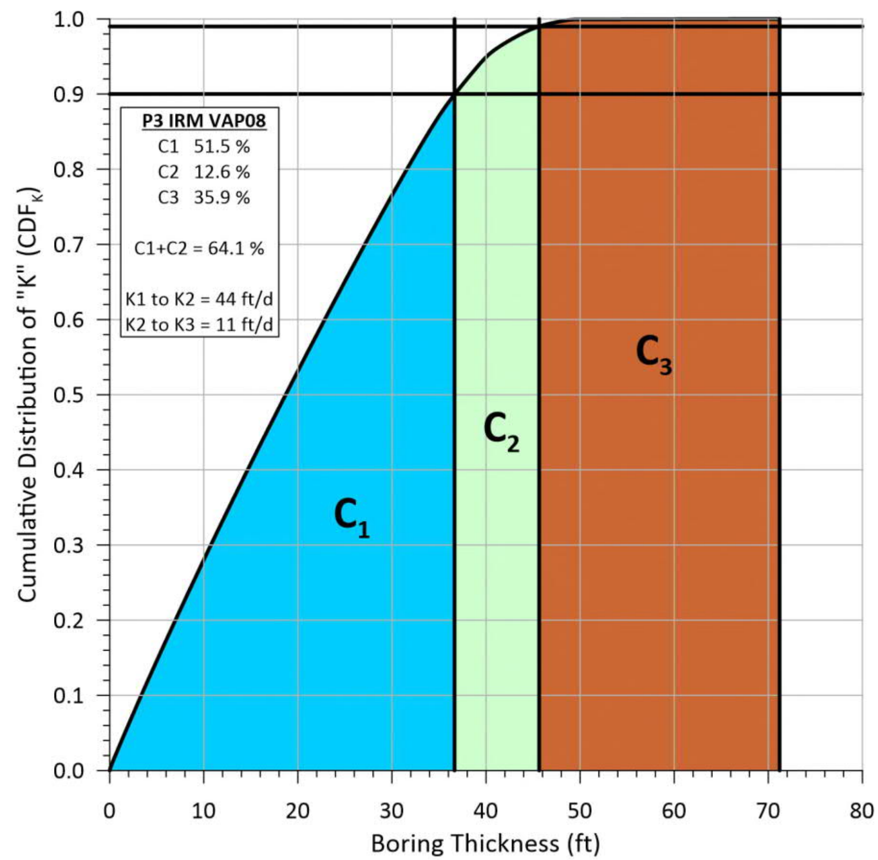
FIGURE
E40





Notes:

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P3-IRM-VAP08

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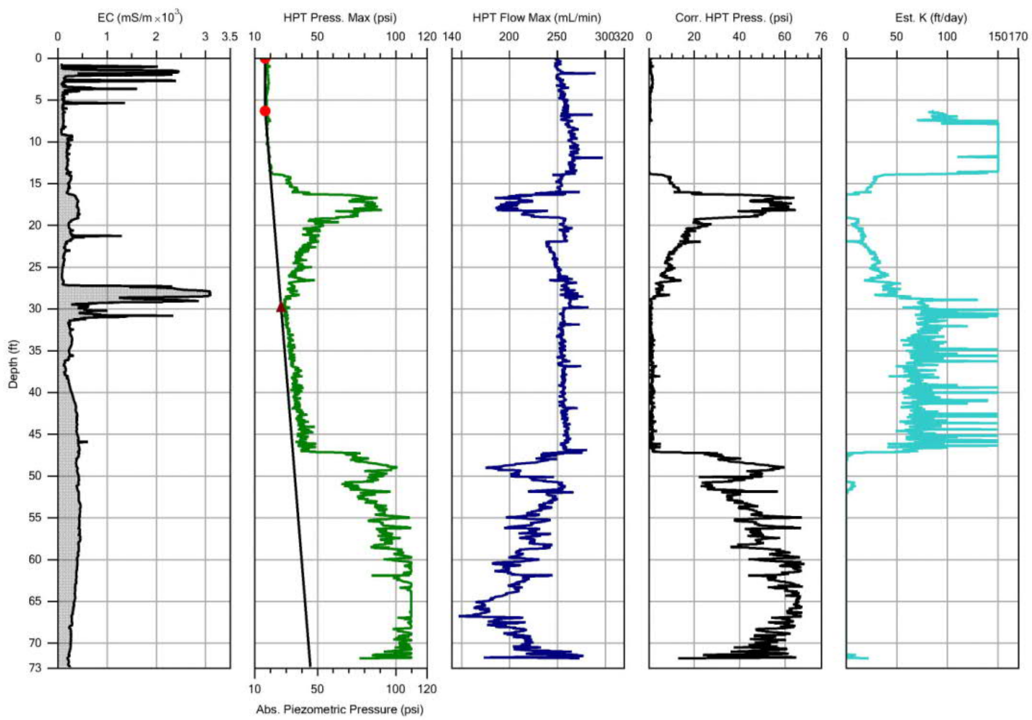
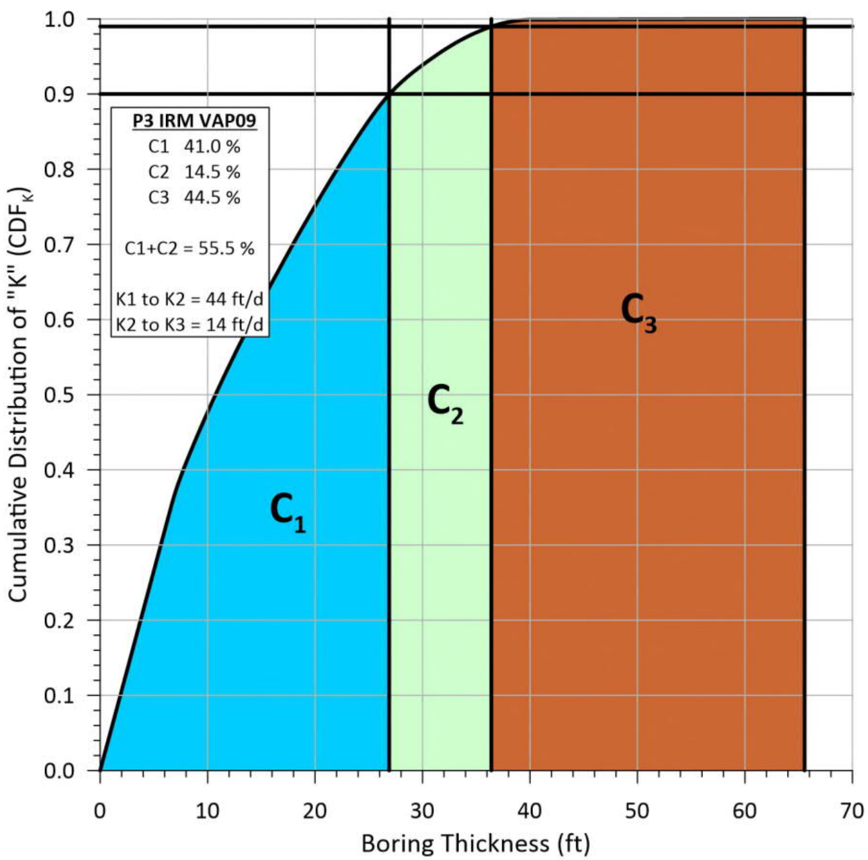
FIGURE
E41





Notes:

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P3-IRM-VAP09

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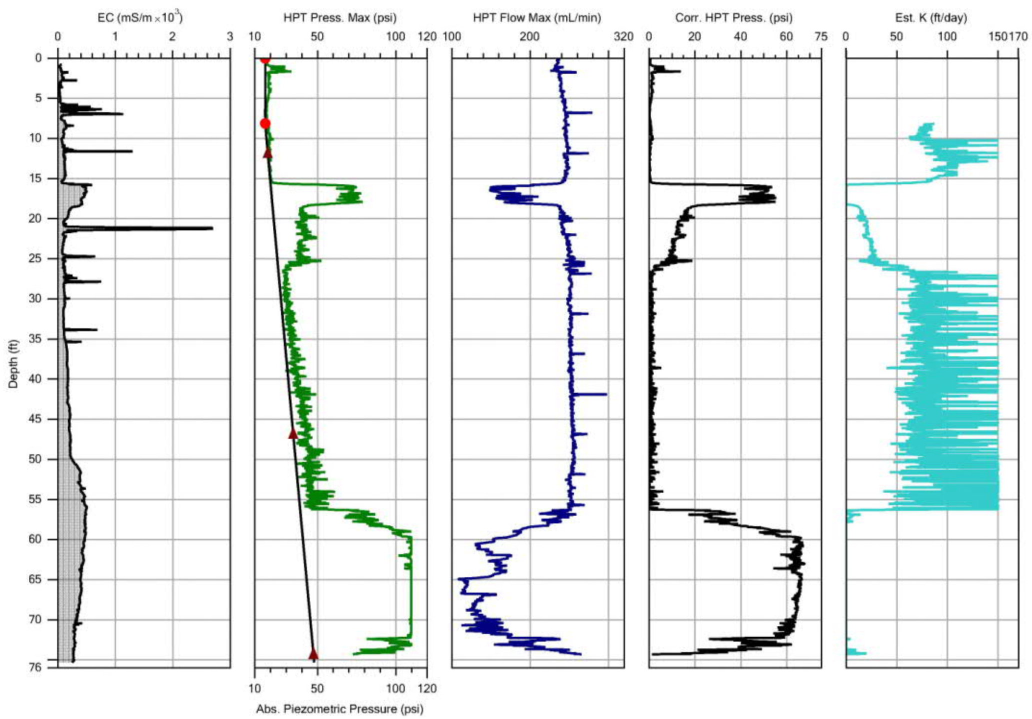
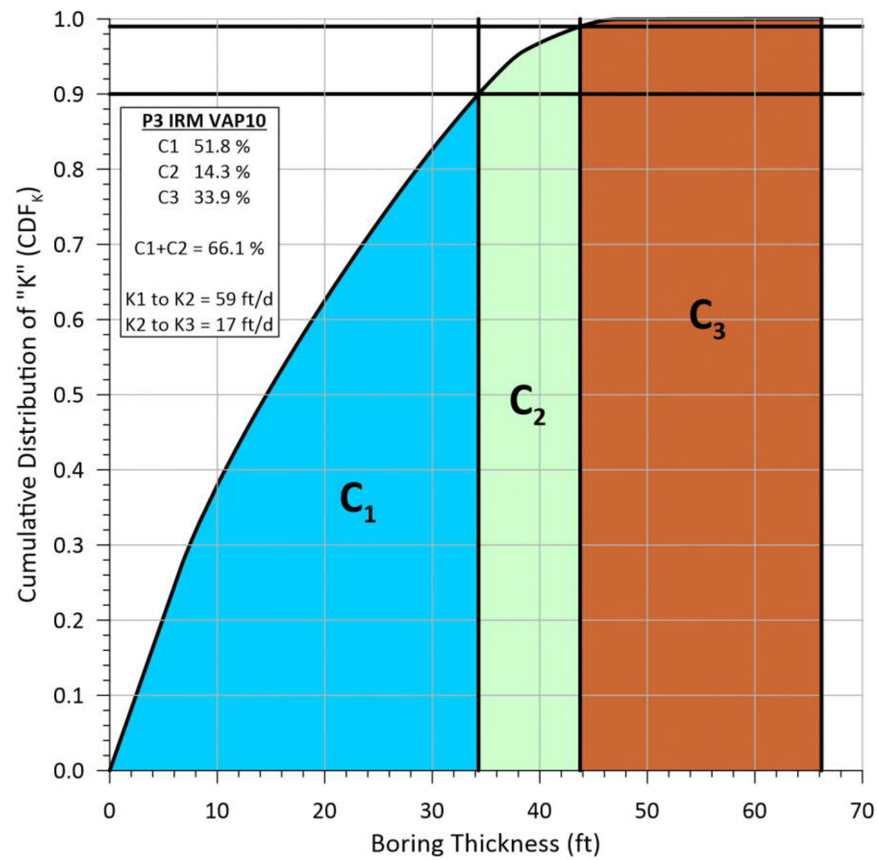
FIGURE
E42





Notes:

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P3-IRM-VAP10

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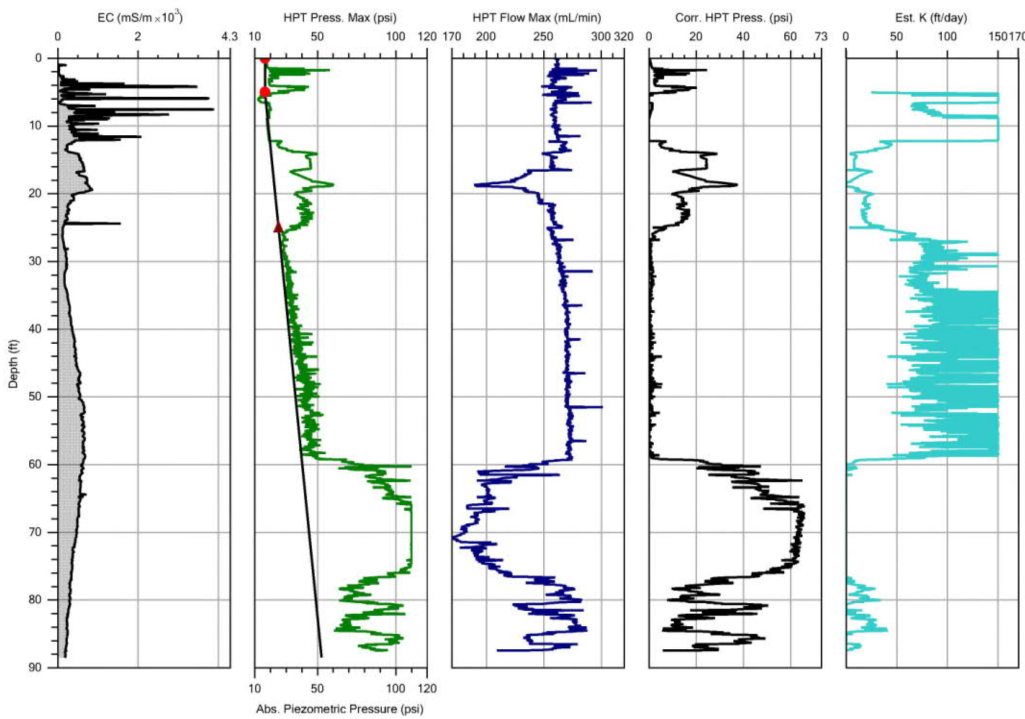
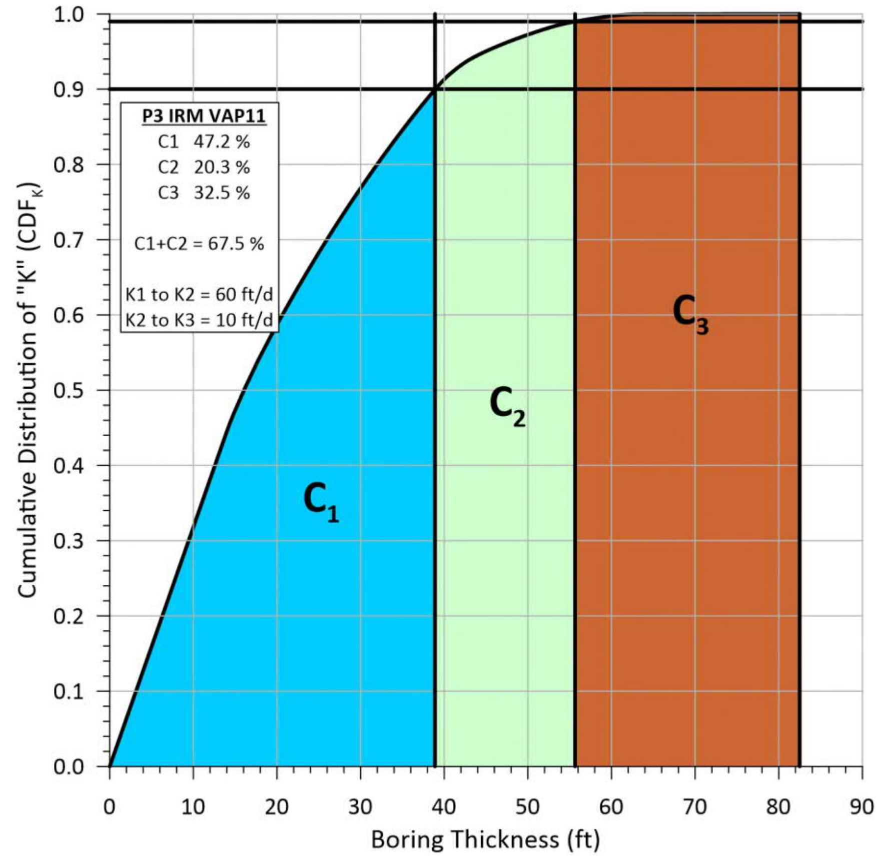
FIGURE
E43





Notes:

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P3-IRM-VAP11

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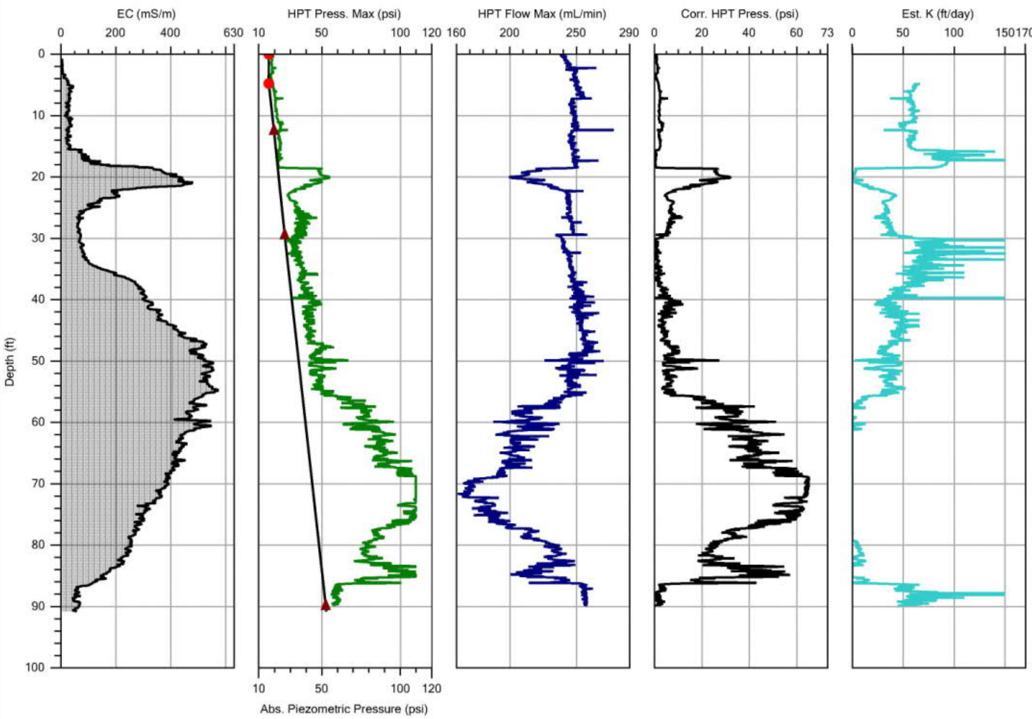
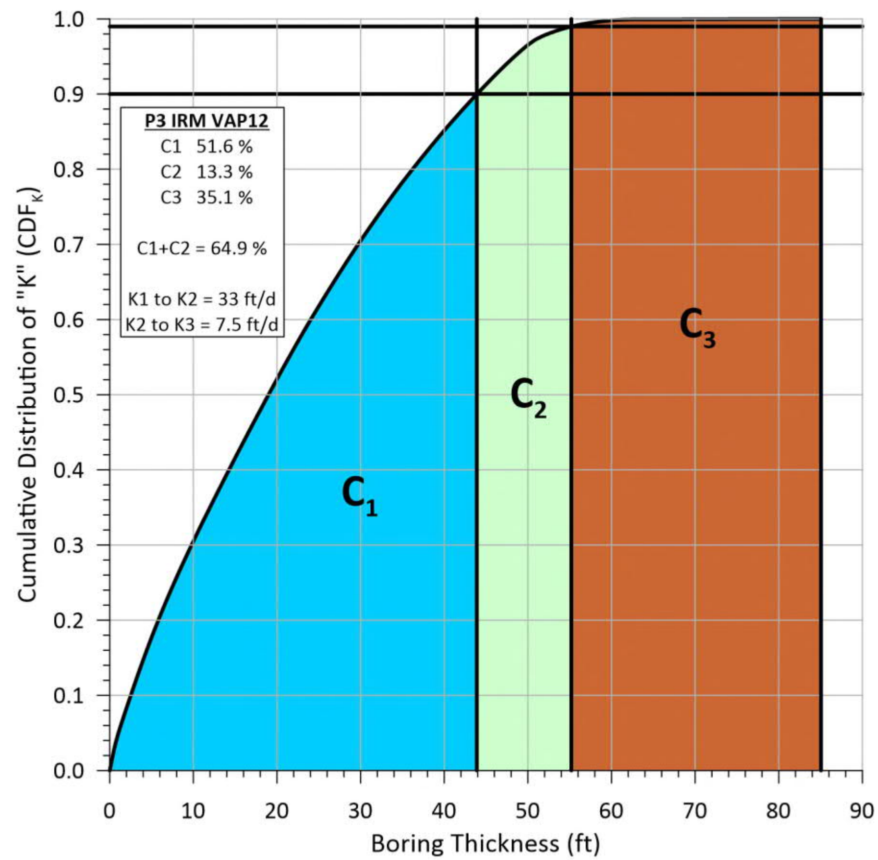
FIGURE

E44





Notes:

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P3-IRM-VAP12

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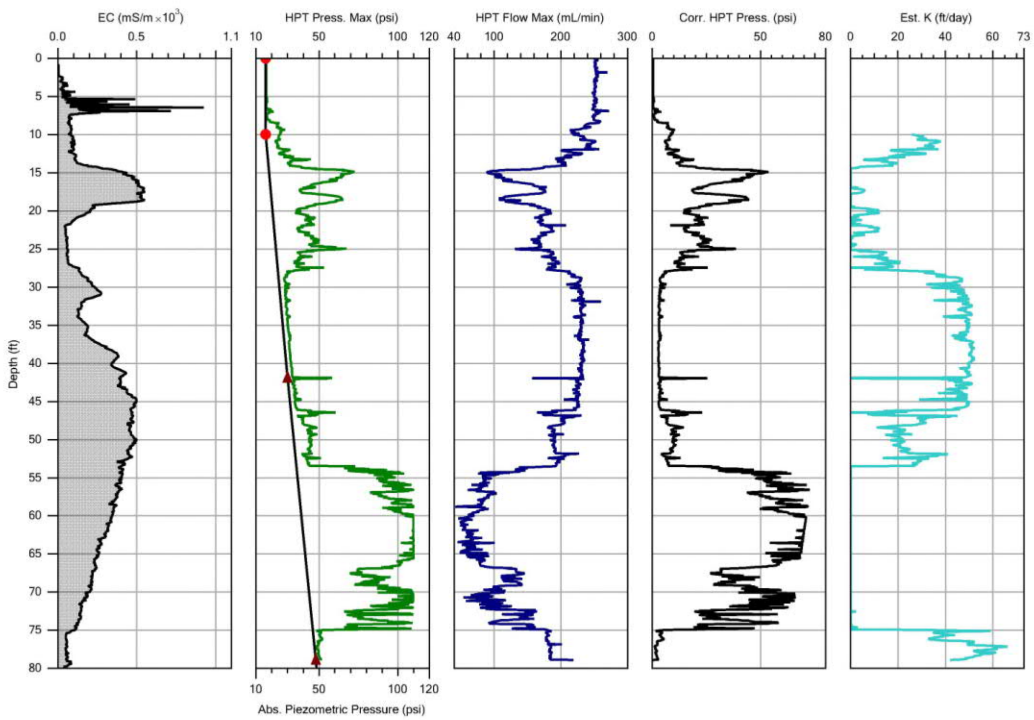
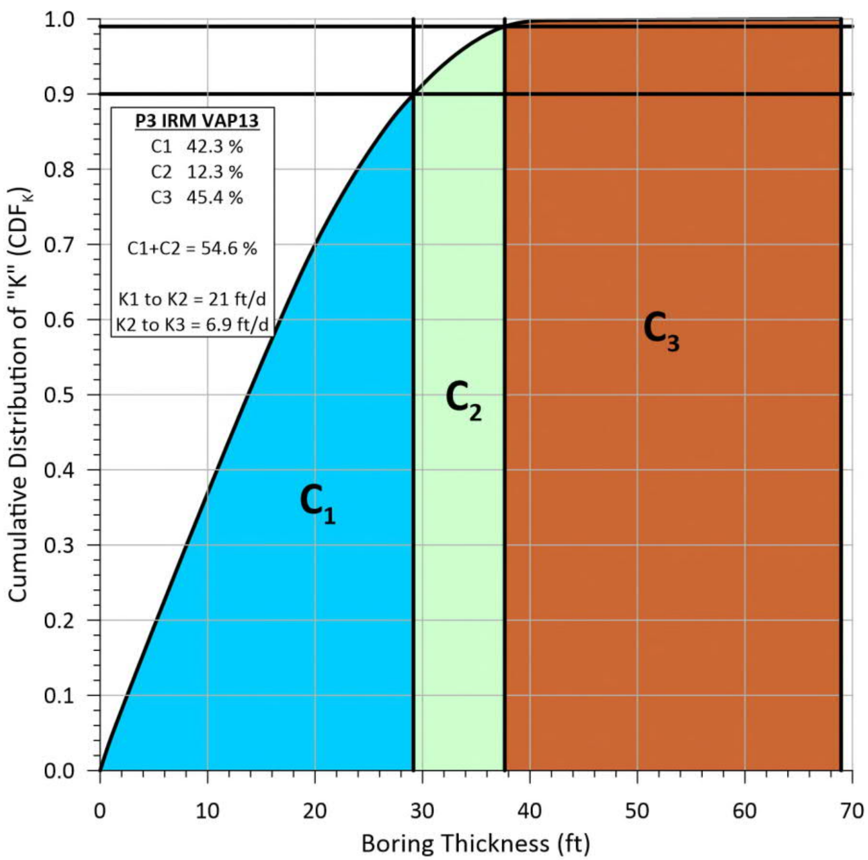
FIGURE

E45





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P3-IRM-VAP13

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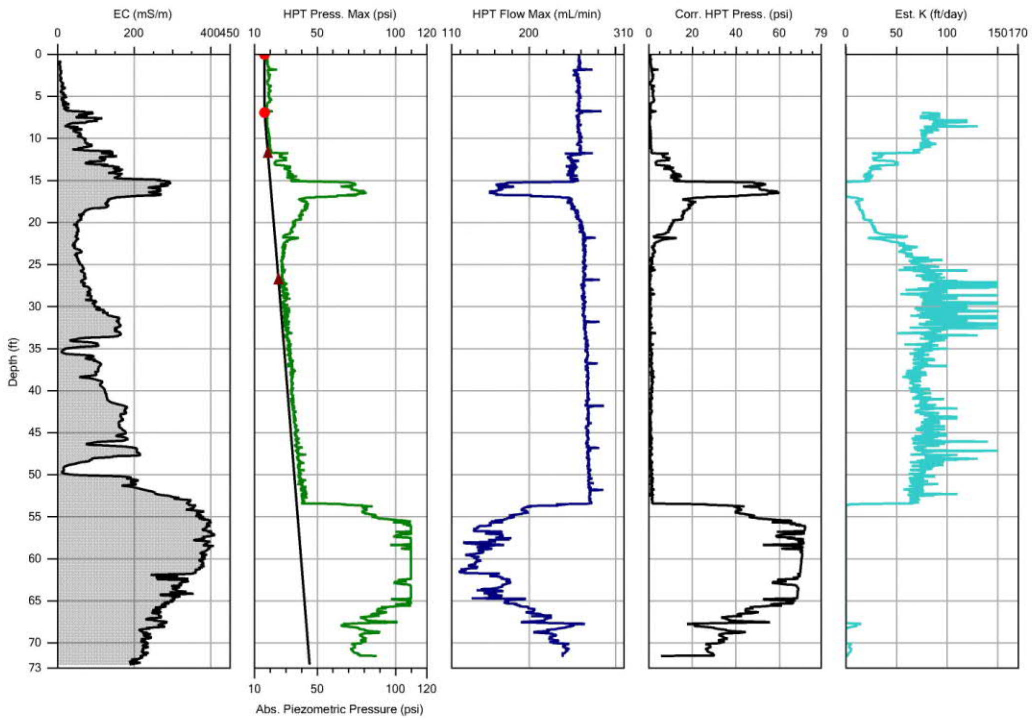
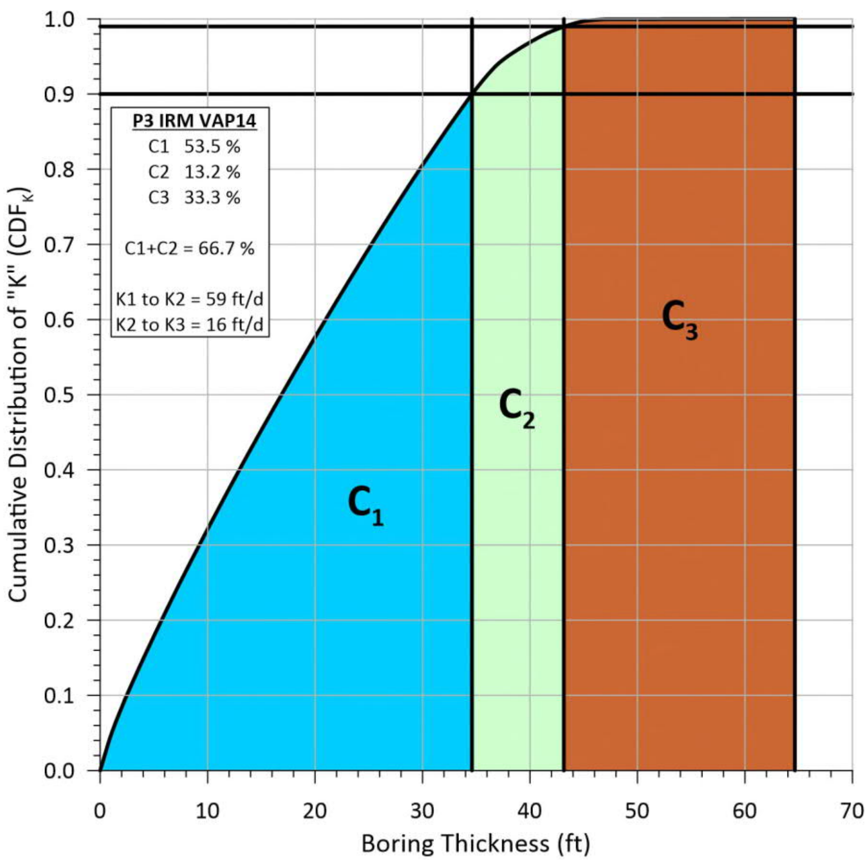
FIGURE

E46





Notes:

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GARFIELD AVENUE GROUP SITES
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P3-IRM-VAP14

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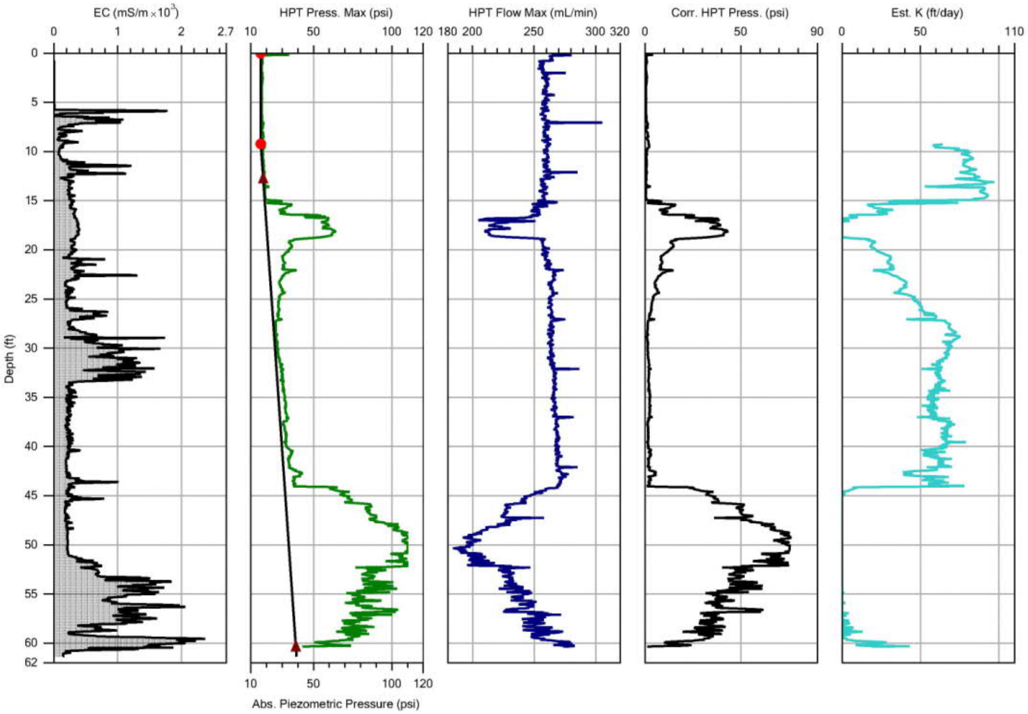
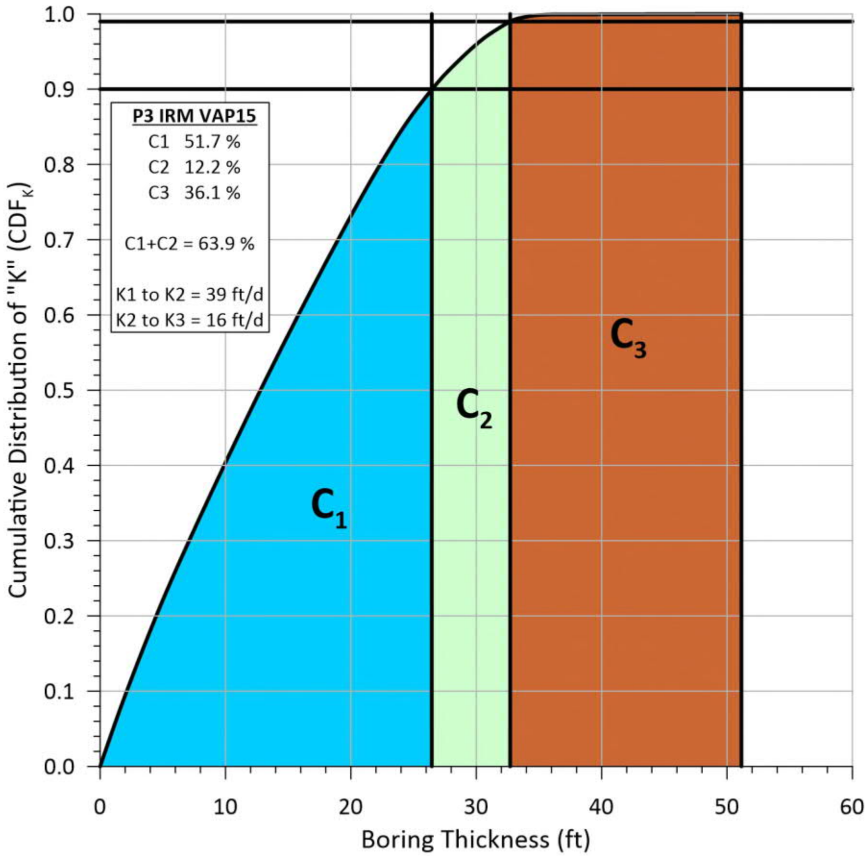
FIGURE

E47





Notes:

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GARFIELD AVENUE GROUP SITES
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P3-IRM-VAP15

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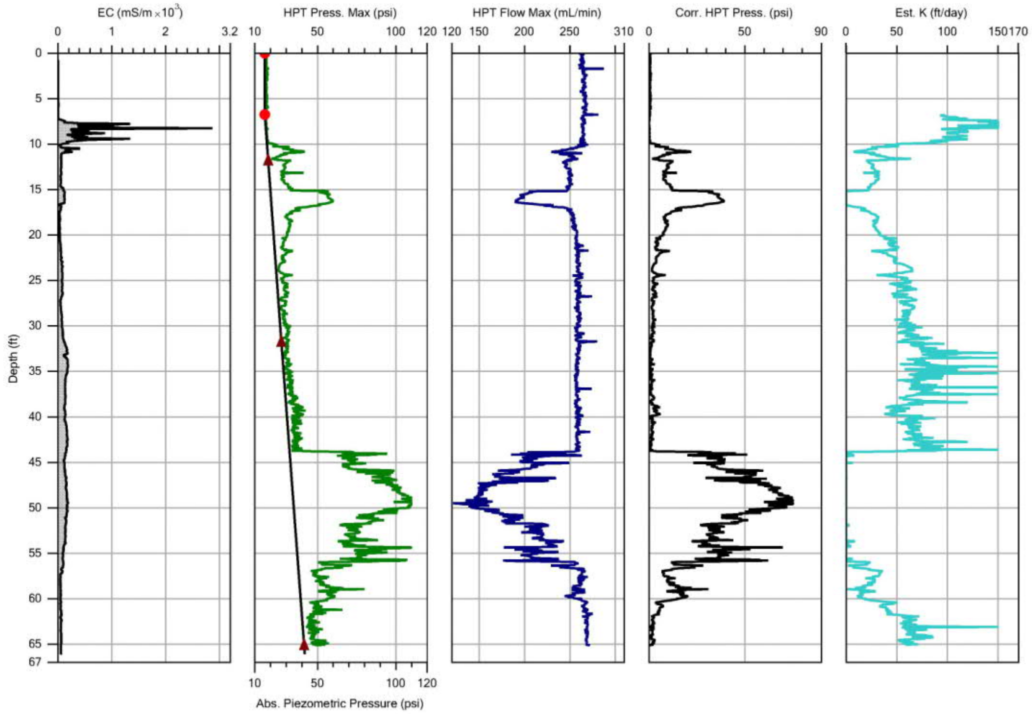
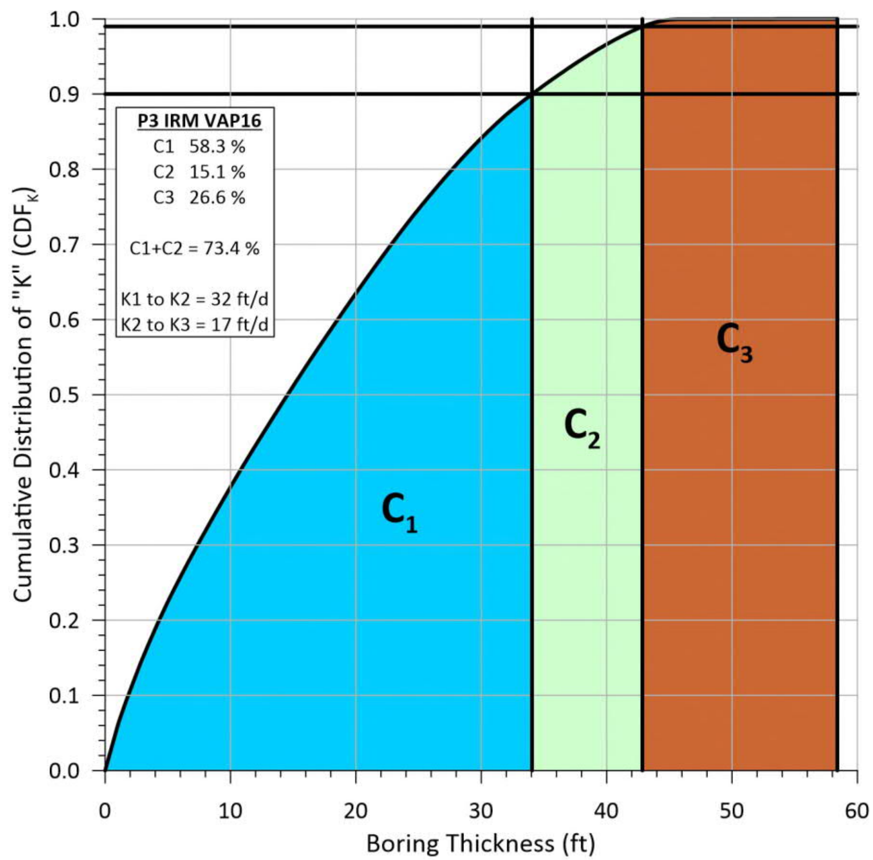
FIGURE E48





Notes:

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GARFIELD AVENUE GROUP SITES
JERSEY CITY, NEW JERSEY

P3-IRM-VAP16

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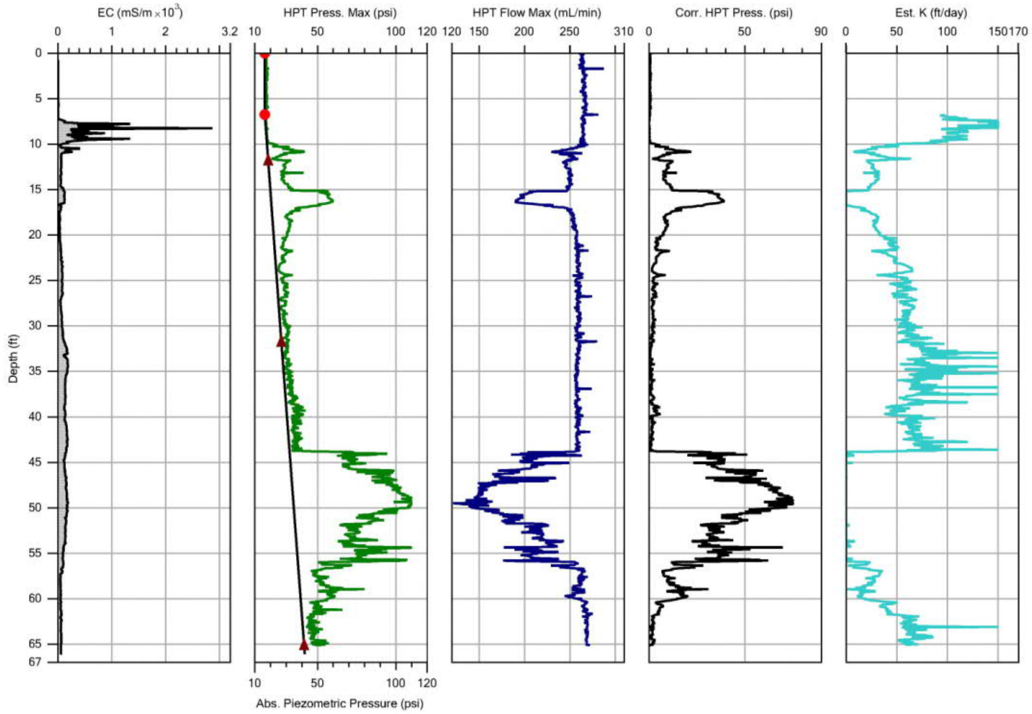
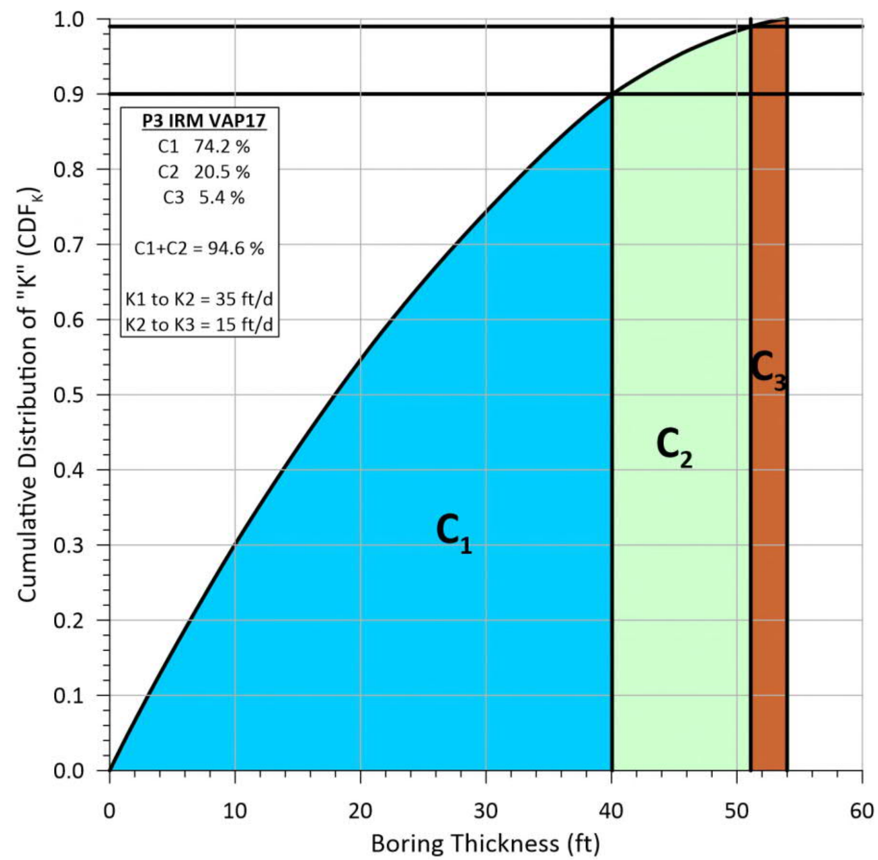
FIGURE
E49





Notes:

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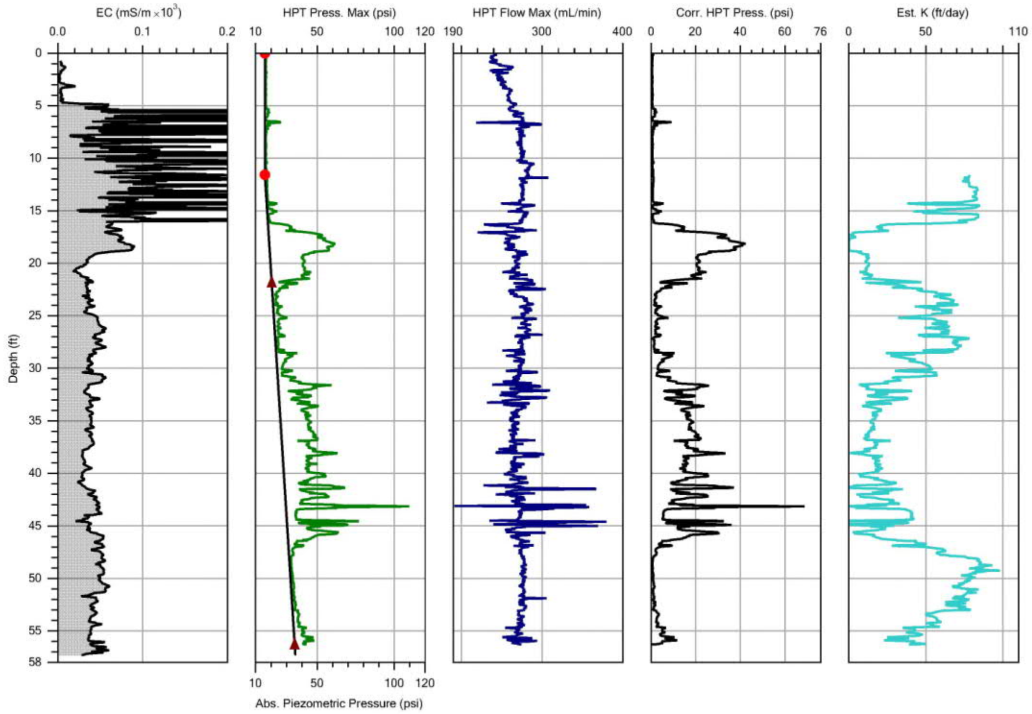
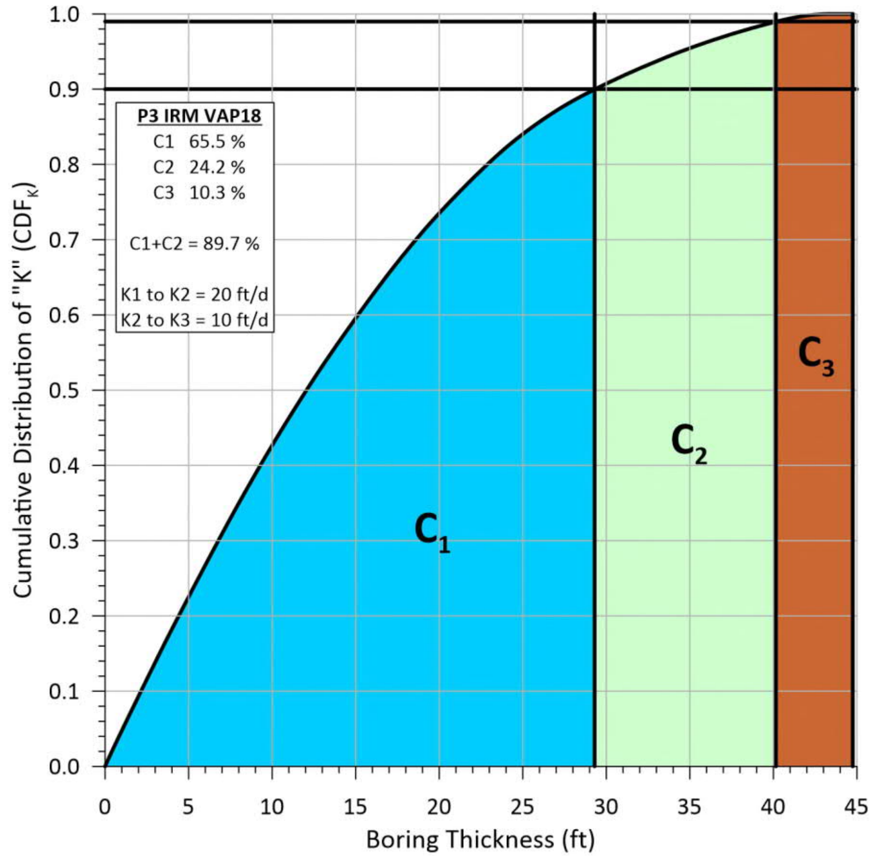
PPG INDUSTRIES GARFIELD AVENUE GROUP SITES JERSEY CITY, NEW JERSEY	
P3-IRM-VAP17	
ARCADIS Design & Consultancy for natural and built assets	FIGURE E50





Notes:

C1 - most permeable soils, dominated by advective transport

C2 - moderately permeable soils, dominated by slow advection

C3 - low permeability soils, dominated by diffusion

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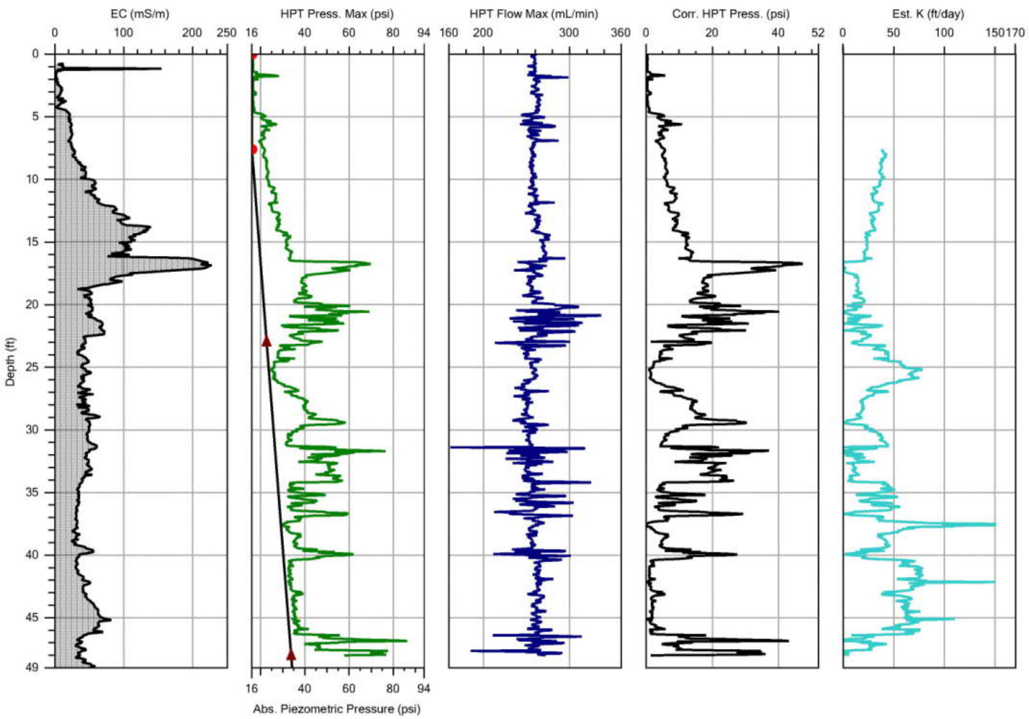
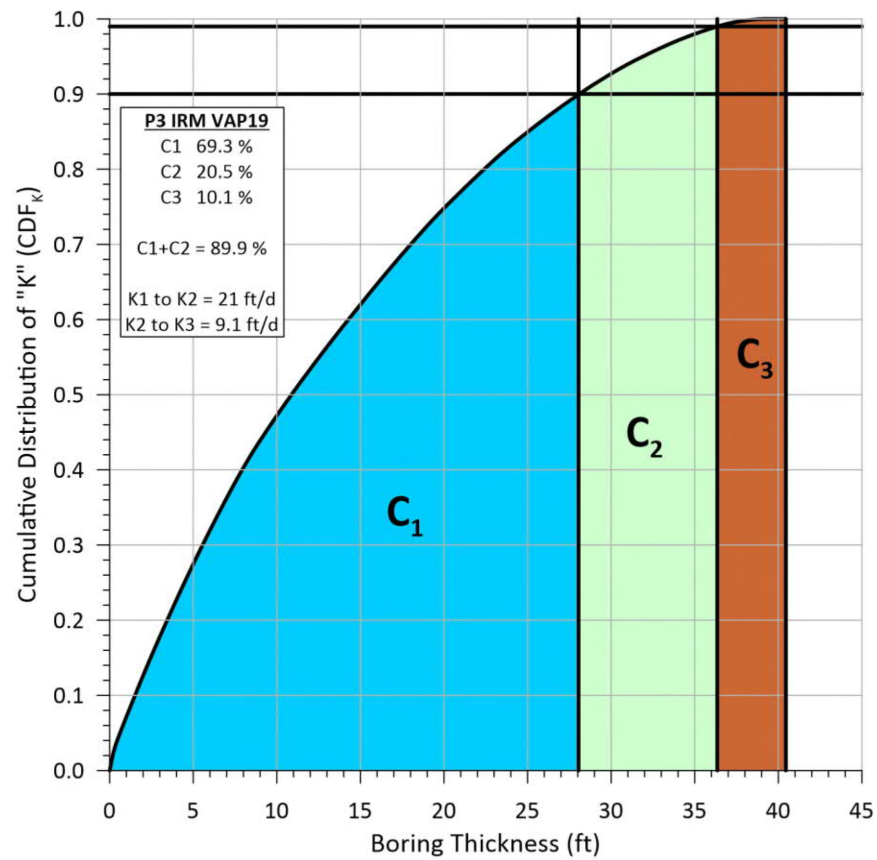
FIGURE
E51





Notes:

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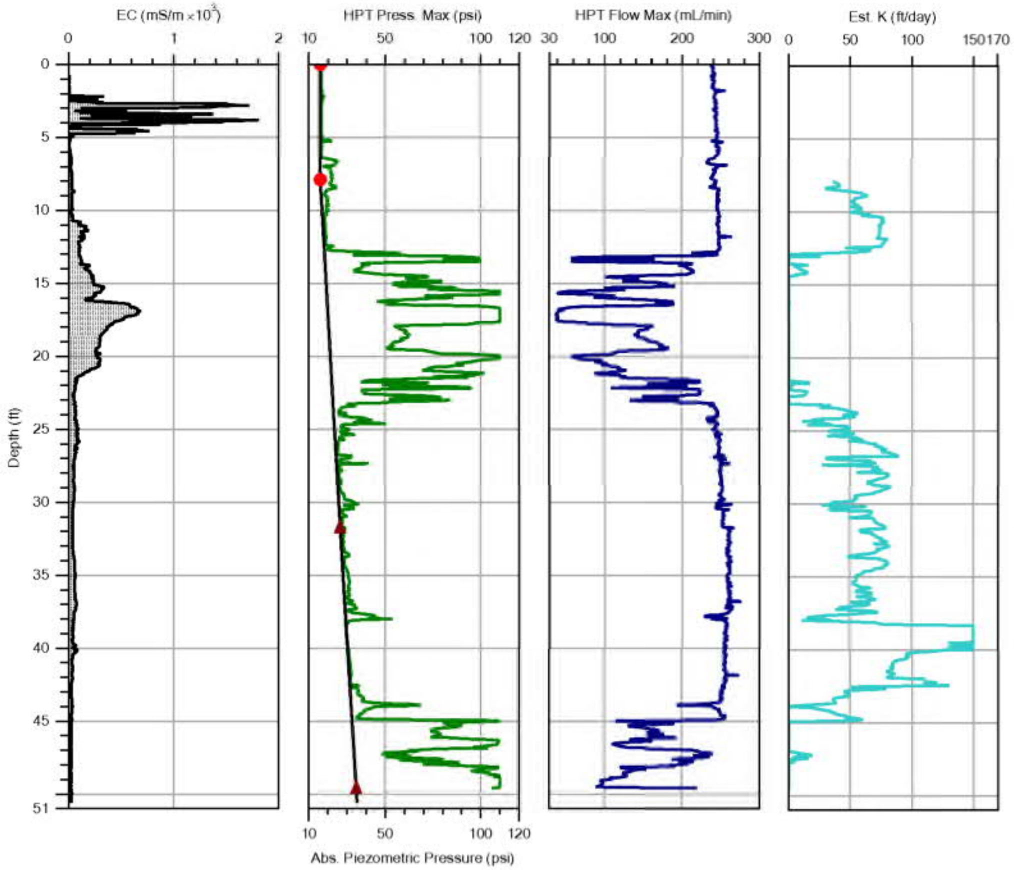
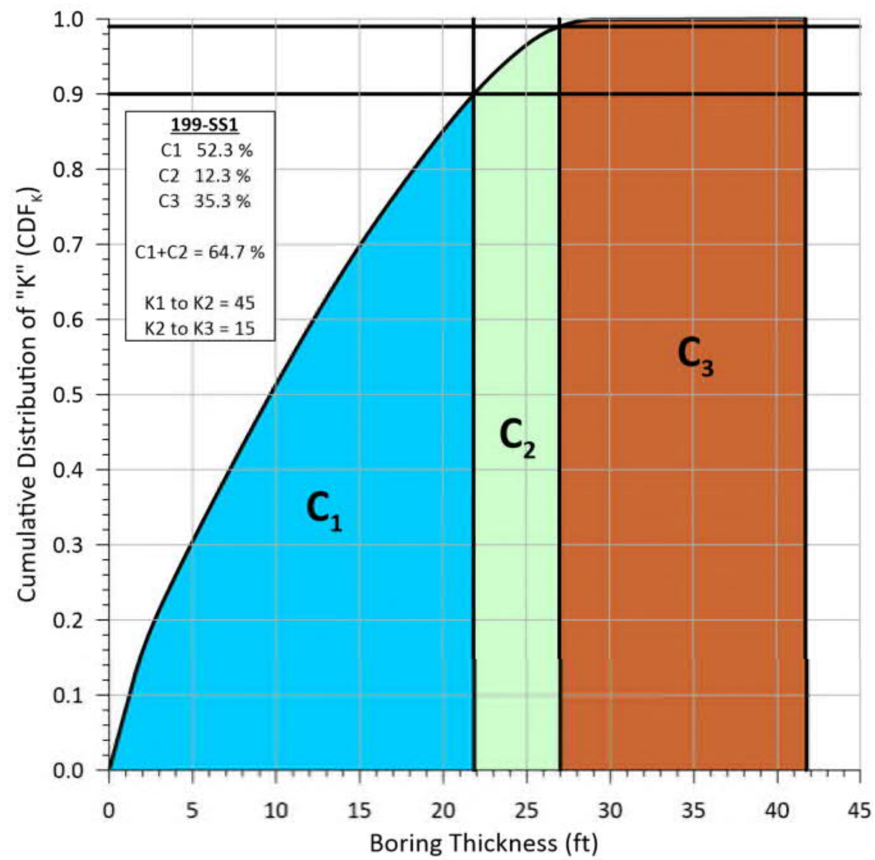
FIGURE
E52





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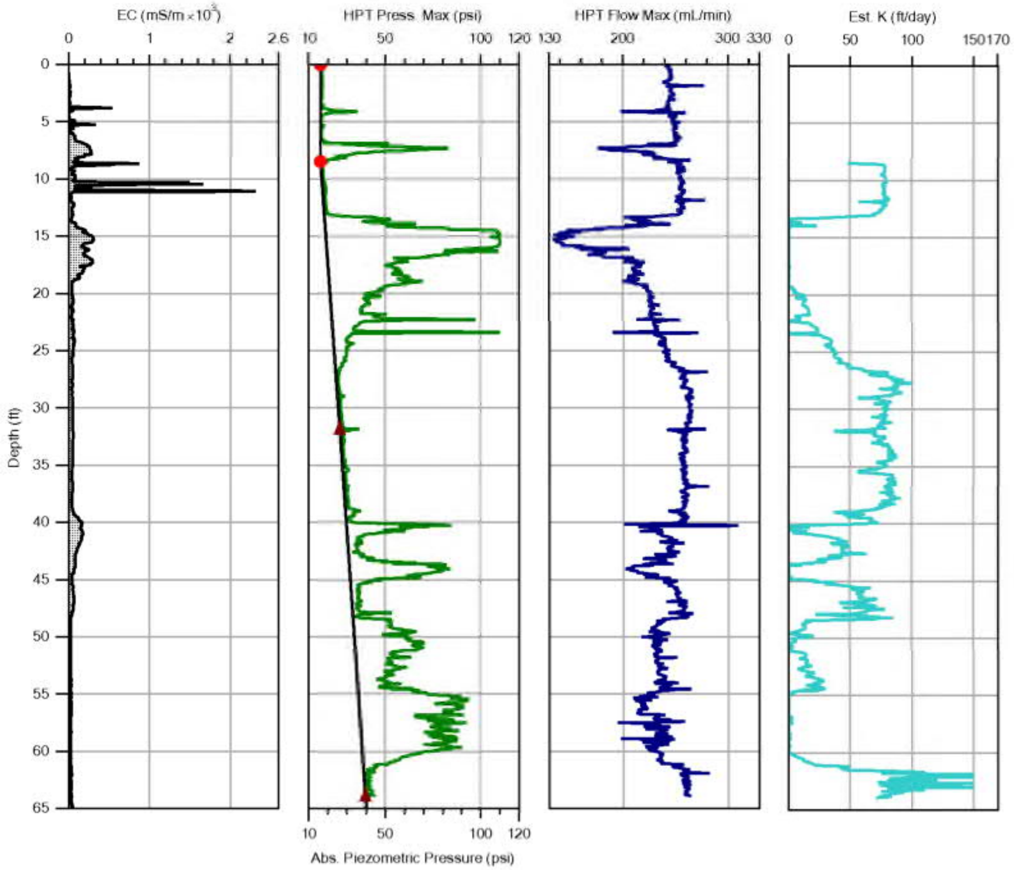
199-SS1	
ARCADIS Design & Consultancy for natural and built assets	FIGURE E53



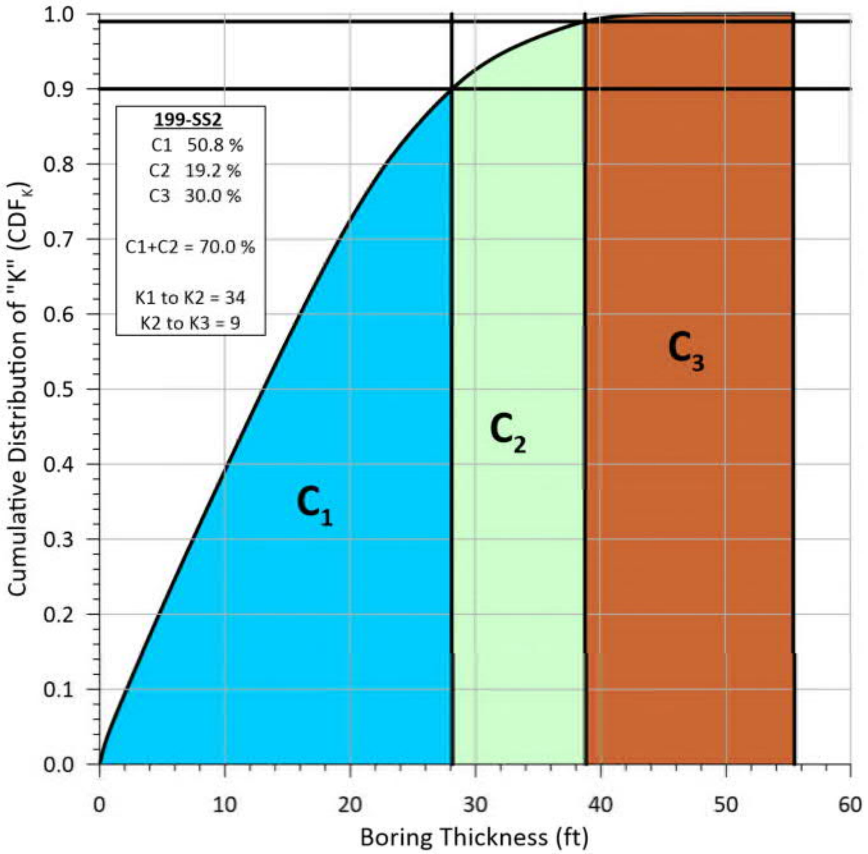


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FIGURE
E54