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Tech Guide for Calculation of Estimated Hydraulic Conductivity (Est. K) Log from HPT Data

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FAQ: How can I use the HPT pressure and flow data to calculate a log of estimated hydraulic conductivity for the formation?

Answer: You can use the latest version of DI Viewer to estimate hydraulic conductivity from HPT logs.

Introduction

This technical guide will provide information on how to use the DI Viewer Software and hydraulic profiling tool (HPT) log data to calculate a log of estimated hydraulic conductivity (K). For more information about HPT logging review the system operating procedure (Geoprobe 2007) or visit the Direct Image web site (www.geoprobe-di.com). The estimated K value is calculated using the HPT pressure and flow data. This estimate is only applicable to the saturated portion of the formation. It also is necessary to have at least one response test performed immediately before or after the log was run. Having both a response test before and after the log provides higher confidence in the data and resulting K calculations. Additionally, it is necessary to have at least one pressure dissipation test performed during the logging operation, below the local water level. If there is a possibility of changing vertical gradients between sand layers isolated by clay layers (or similar) it is best to have a dissipation test in each isolated sand zone. This will provide more representative results for the corrected pressures and estimated K value. Dissipation tests should be run in sandy (coarse grained) formation materials to minimize run time and assure good data quality for the test and subsequent calculations.

A typical HPT log (Figure 1) displays the electrical conductivity (EC) (mS/m) on the left, HPT pressure (psi or kPa) in the center and flow (ml/min) on the right. Depth is provided along the vertical axis at left. HPT logs are viewed and printed from the DI Viewer software package. The software is available for free download at www.geoprobe-di.com.

When an HPT log is opened in the DI Viewer software there are several steps required to calculate and view the estimated K log. These are:

- Review the information file to verify that at least one reference test was conducted during the log and it passed the QA test.
- View the dissipation test(s).
- Verify the dissipation test(s) had reached stabilized pressure.
- Select the stabilized pressure in the dissipation log file(s).

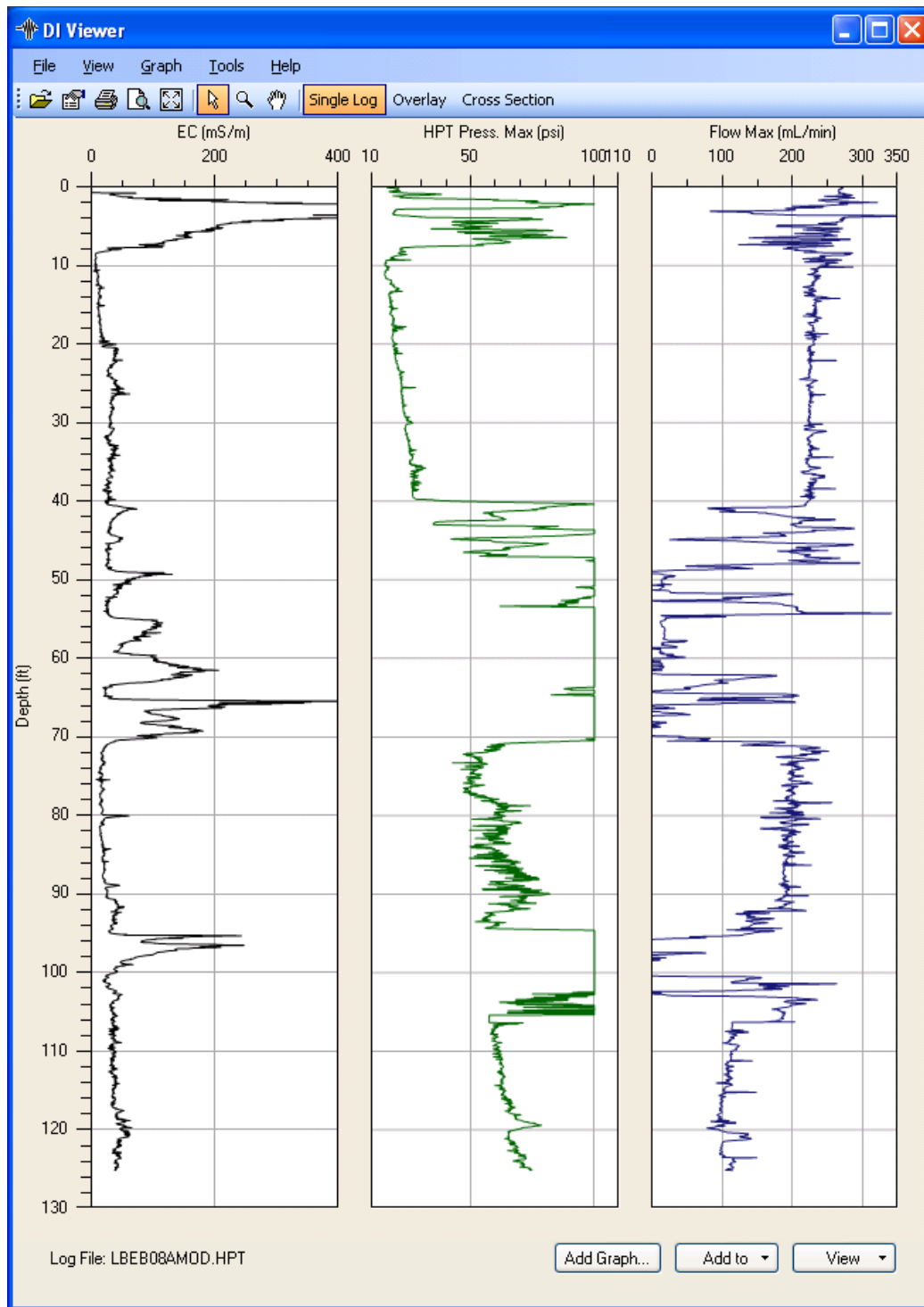


Figure 1: Typical HPT log with electrical conductivity reported in milliSiemens/meter (mS/m), pressure in pounds per square inch (psi) and flow in milliliters per minute (mL/min) versus depth (feet). Alternatively, pressure may be plotted in units of kiloPascal (kPa) and depth in meters (m).

- Use the DI Viewer to calculate and plot the “absolute hydrostatic pressure” line.
- Display the HPT corrected pressure graph for review/reporting.
- Use the DI Viewer to calculate and plot the estimated K value log below the water table.
- Print or export the graphs to an image file (*.png) for later reporting, presentation or review.

Details of the required steps are reviewed in the following sections.

Reviewing Log QA Data

Once the file is opened in the DI Viewer Software (the Viewer) it is recommended that you first review the information file to verify that a pre-log or post log reference test was completed (better if both were conducted).

To review the information file click on the “View” button on the lower right corner of the DI Viewer screen to activate the pop-up menu (Figure 2). This will allow you to access and view the information file for a log or the dissipation test(s) performed during a log. Click on “INF File” to observe the information file of an HPT log. Check to verify the transducer passed the reference tests (PASS) with a NO FLOW pressure difference of $0.21\text{psi} \pm 10\%$ ($1.5\text{kPa} \pm 10\%$) between the top and bottom levels of the reference test.

Dissipation Tests and Hydrostatic Pressure

To view any dissipation test results click on the “View” button at the lower right side of the screen (Figure 2) and select the “Dissipation” option. To set the hydrostatic pressure for a dissipation test (Figure 3) move the cursor over the graph and right click on the desired point along the pressure curve after the baseline has been stable for some time. A pop-up menu will appear, select the option “Set as hydrostatic pressure for this test ...” from this menu. If more than one dissipation test was performed during a log you may view the other tests by clicking on the drop down arrow next to the “Depth” box. This will allow you to select the dissipation tests run at other depth intervals. Repeat the procedure above to select the stabilized hydrostatic pressure for each dissipation test.

Remember, dissipation tests should be run in sandy formation materials to minimize run time and assure good data quality for the test. Dissipation tests in fine grained materials can take several hours to dissipate the excess pore pressure.

WARNING If not allowed to fully dissipate to ambient formation pressure a dissipation test will yield incorrect water level data. This could lead to erroneous HPT corrected pressure data and incorrect estimated hydraulic conductivity data. An example of the effects caused by use of unstabilized dissipation tests is provided in Appendix I.

NOTE: *HPT dissipation tests may not be used to calculate a point estimate of hydraulic conductivity as done for CPT dissipation tests. This is due to the water in the trunk line above the HPT port and pressure sensor.*

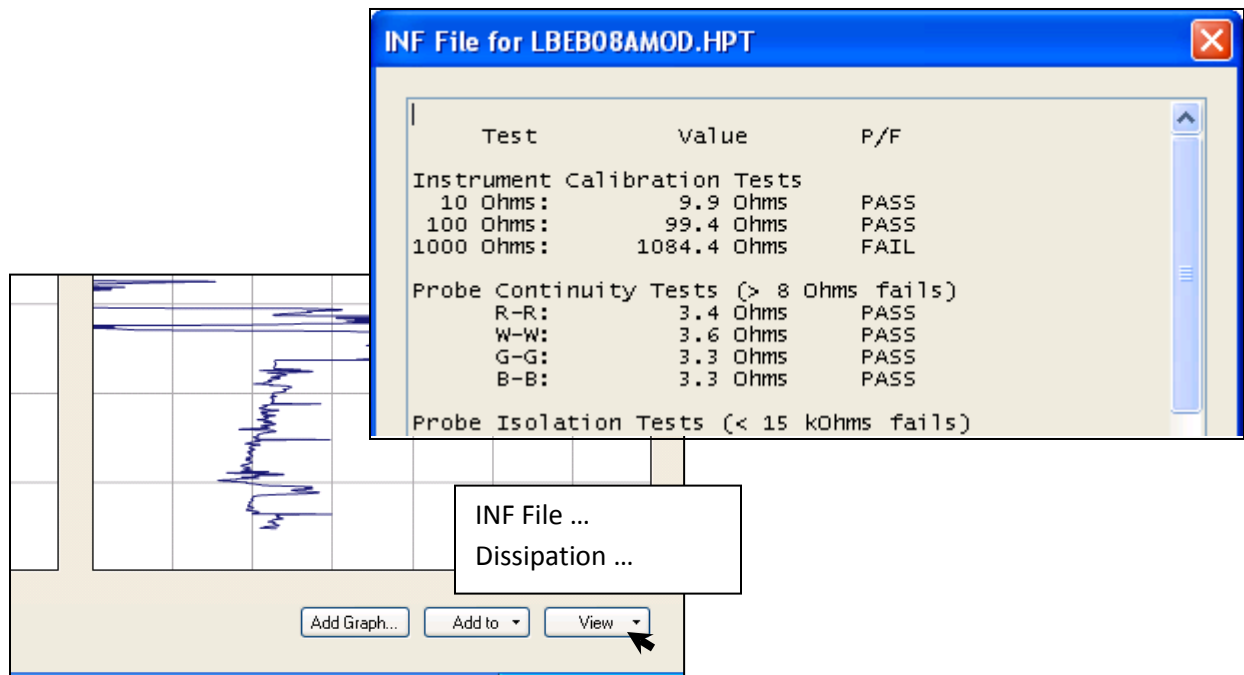


Figure 2: Accessing the information file for review in the software. Only a small portion of the HPT information file is shown here. The file includes data for HPT reference tests run before and after the log is obtained as well as information about the electrical conductivity system and Wenner array QA tests.

Command Tree for this action:

```

View
  INF File ...
    (Scroll down to review QA data in the file)
  
```

Once the hydrostatic pressure for a dissipation test has been set, the HPT Hydrostatic Pressure graph pops up on the screen (Figure 4). The absolute static pressure value selected from each dissipation test is plotted on the graph at the depth where the test was conducted. Both the dissipation graph and hydrostatic pressure graphs may be printed or exported to an image file (*.png) for later review and reporting. See the last section of this bulletin for information on printing and exporting graphs.

Occasionally, a good dissipation test may not be obtained as a log is run. This may be the case when the entire formation penetrated is finer grained material, or thin sandy layers were accidentally bypassed as a log was run. If a monitoring well or temporary piezometer is installed near the HPT log location at the same ground elevation the stabilized water level may be measured and recorded. Based

on this information the data analyst may enter hydrostatic pressure information for the log (Appendix II) and generate corrected pressure and estimated K information, if desired.

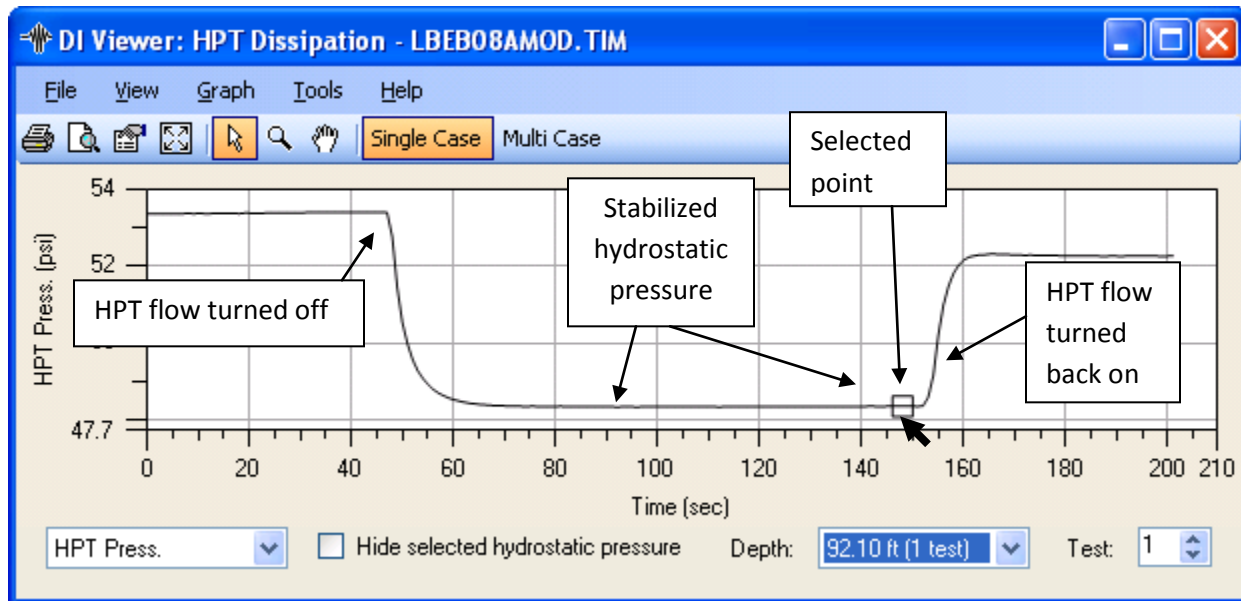


Figure 3 : This is the time file showing a dissipation test performed at a depth of 92.1 ft when this log was obtained. This is a typical dissipation test for sandy materials. The stabilized pressure observed during a dissipation test reflects the absolute hydrostatic pressure in the local formation. Click on the down arrow next to the depth box to select and view dissipation tests run at different depths as the log was obtained.

Command Tree for this action:

View

Dissipation...

(Right click desired point on curve to select stabilized pressure and access popup menu)

Select "Set as hydrostatic pressure for this point..."

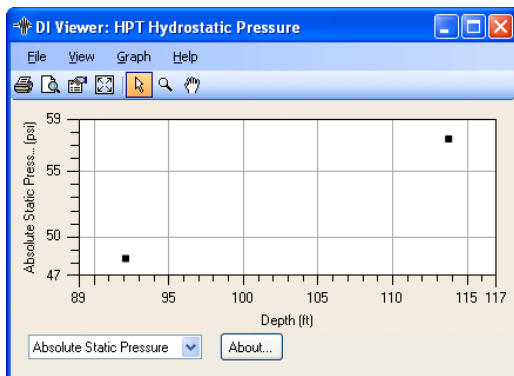


Figure 4: An HPT hydrostatic pressure graph. This figure displays a hydrostatic pressure of 48.37psi for the dissipation test conducted at the depth of 92.1 ft and a hydrostatic pressure of 57.53psi for the dissipation test conducted at the depth of 113.75ft. Click the down arrow and select "Static Water Level" to view the water level determined for the pressure measured at each depth interval.

After the hydrostatic pressure is defined for each of the dissipation tests (Figures 3 and 4) the graph of Absolute Hydrostatic Pressure may be determined with the Viewer. Simply right click on the pressure graph to open the pop-up menu. Then select the “Secondary Series” option followed by the “Absolute Hydrostatic Pressure” option. The software will then use data from the pre- and/or post log reference tests and the absolute hydrostatic pressure data from the dissipation test(s) to calculate and plot the absolute hydrostatic pressure line for the log (Figure 5).

HPT Corrected Pressure (P_{corr}) and Log of Estimated Hydraulic Conductivity (Est. K)

Next, a log of the corrected HPT pressure (Figure 6) may be plotted with the Viewer. This is done by clicking on the “Add Graph” button at the lower right. When the pop-up menu opens, select “Primary Series” and then scroll down the drop-down menu that opens and select the “Corr. HPT Press.” option. The corrected pressure is calculated by subtracting the absolute hydrostatic pressure from the Average HPT pressure at each depth increment of the log.

The corrected pressure and HPT average flow rate (Figure 6) may be used to calculate and plot an estimated hydraulic conductivity (Est. K) log for the saturated formation penetrated as a log was run. To plot the Est. K log (Figure 7) click on the “Add Graph” button and select “Primary Series” from the popup menu. Next, scroll down the drop-down menu and select the “Est. K” option. The Est. K log will be plotted onscreen.

An empirical model to estimate formation hydraulic conductivity (K) for HPT average flow (Q_{avg}) and corrected pressure (P_{corr}) data was developed by Geoprobe (McCall & Christy 2010, Geoprobe 2010). One field site was used to develop the basic empirical model utilizing several HPT logs and co-located slug tests. The slug tests were conducted in temporary groundwater sampling tools and DP wells at targeted depths (ASTM 2007a, ASTM 2007b, ASTM D 2007c, Geoprobe 2005, 2006a, 2006b). The resulting model was found to generally fit paired HPT log and slug test data from several field sites in the central United States (Figure 8). This general model to estimate K from the HPT Q and P data is included in the DI Viewer software. Once the corrected pressure for a log is determined using log specific dissipation test(s) and response test(s) the software can be used to calculate and plot the estimated K value versus depth as discussed above (Figure 7). The estimated-K value is provided at inch-scale resolution and should prove useful for risk assessment and transport modeling as well as remediation design. Under appropriate conditions applying the general model for estimation of K can provide reasonable estimates of hydraulic conductivity. The lower K boundary for the general model is at approximately 0.1ft/day (0.03m/day) and the upper boundary is near 75ft/day (25m/day). To provide greater confidence in the estimated K value a site specific model could be developed.

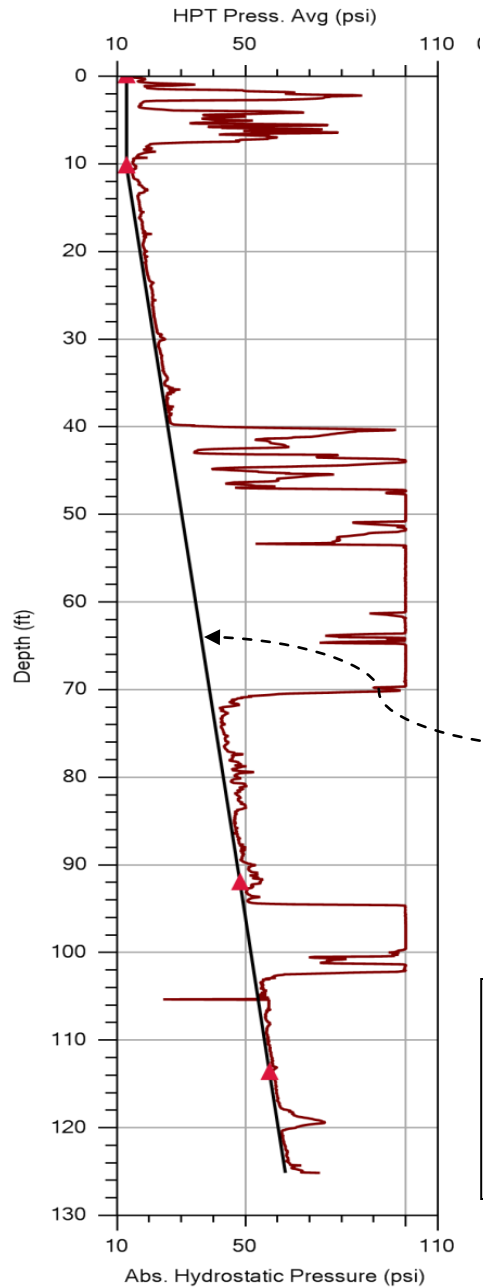


Figure 5: The absolute hydrostatic pressure line is plotted along with the average HPT pressure for this log. Triangles on the line indicate depths where dissipation tests were run and the absolute hydrostatic pressure at that depth. The upper most triangle indicates where the absolute hydrostatic pressure intersects atmospheric pressure (the water table in unconfined systems). The absolute hydrostatic pressure line may not be straight if hydrostatic pressures vary with depth. This may be most apparent when confined layers are penetrated during a log or if a pumping or injection well is located nearby.

Hydrostatic Pressure Line

Command Tree for this action:

(Right click on pressure graph to open pop-up menu)
 Secondary Series
 Absolute Hydrostatic Pressure

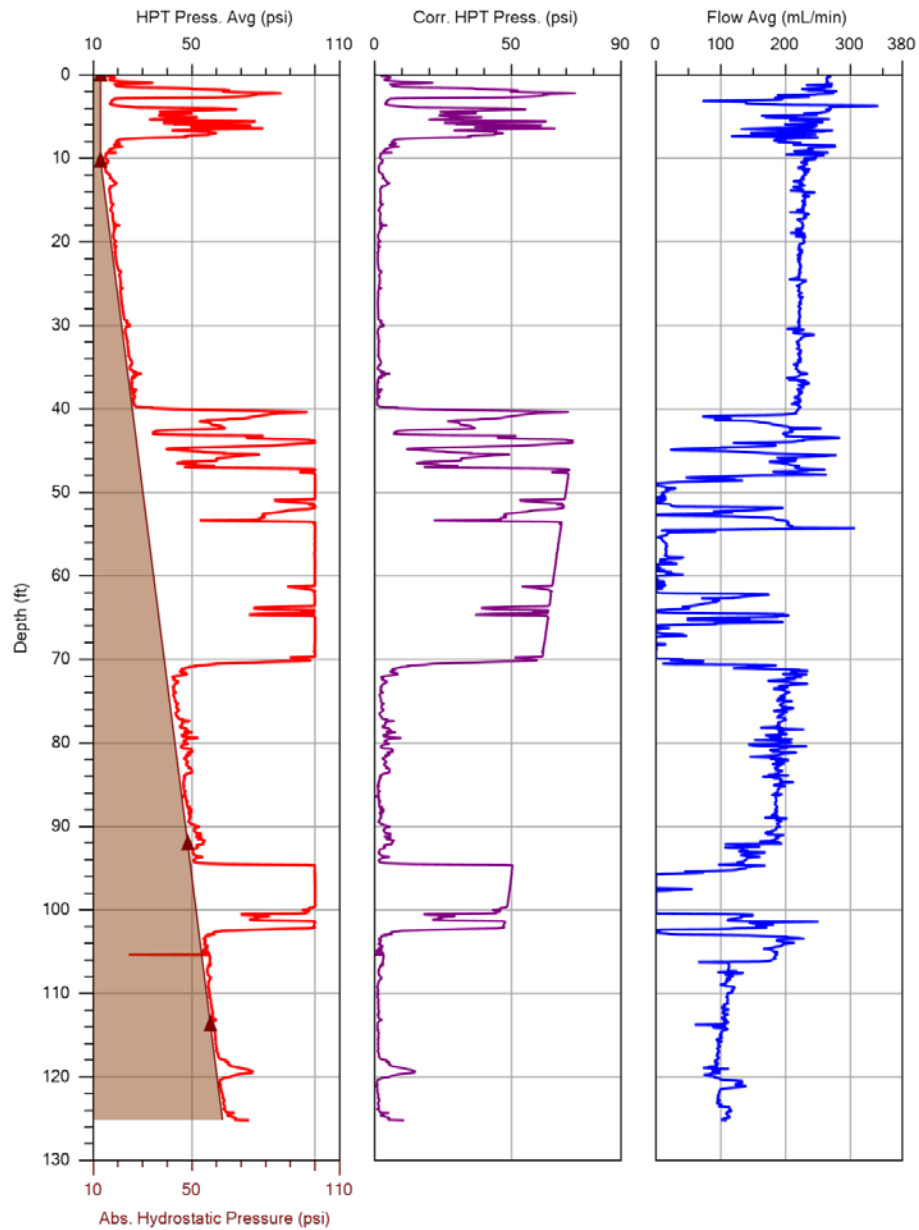


Figure 6: The corrected HPT pressure is plotted in the middle graph of this log. This is calculated by subtracting the absolute hydrostatic pressure (shaded) from the average HPT pressure (left graph) at each depth increment. The corrected pressure is used in the calculation of the estimated hydraulic conductivity.

Command Tree for this action:

Add Graph
 Primary Series
 (click on drop down menu)
 Corrected Pressure

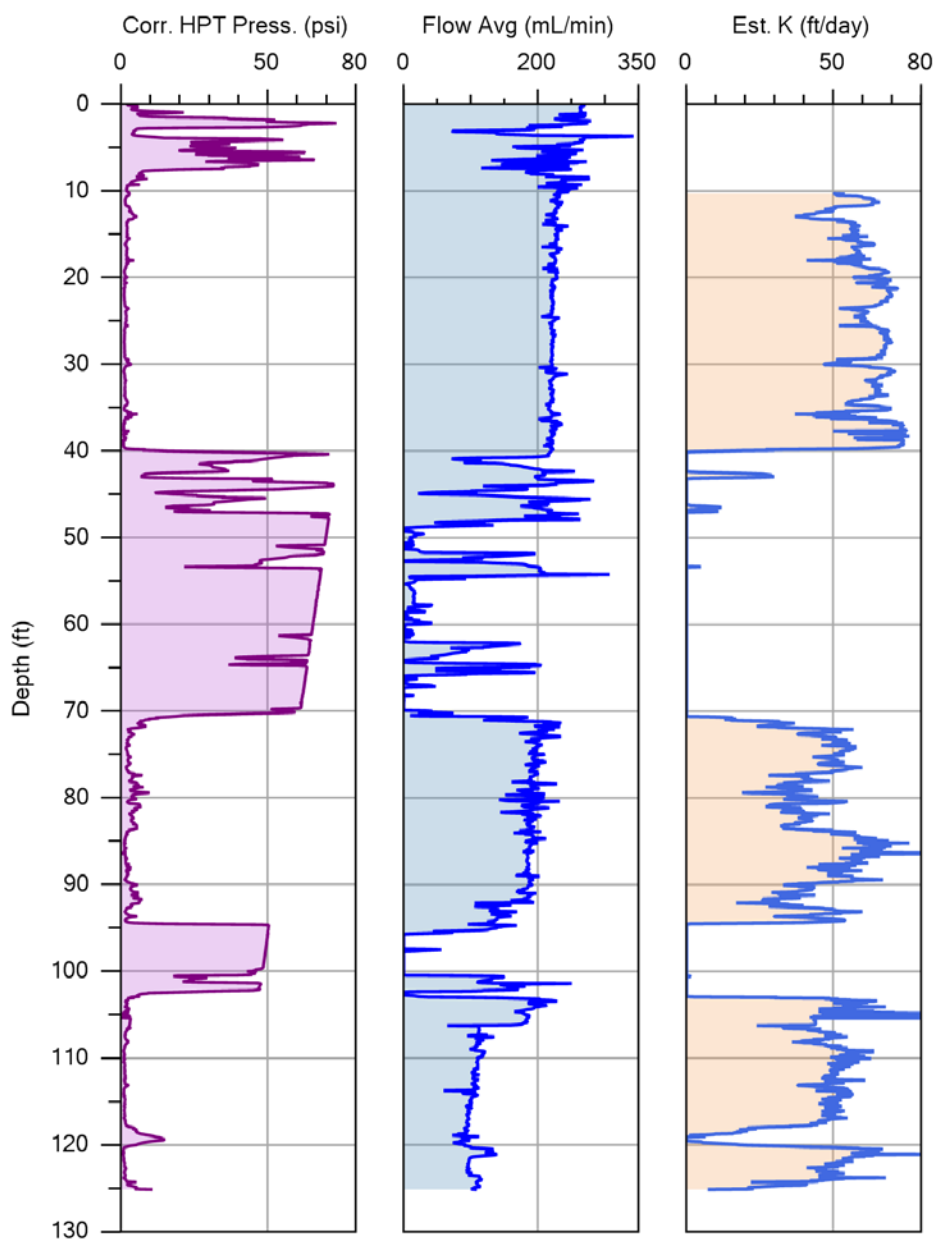


Figure 7: The HPT corrected pressure, average flow rate and estimated hydraulic conductivity (ft/day) are plotted in this log. The ratio of the flow to corrected pressure (Q/P^*) is used to calculate the estimated hydraulic conductivity. The estimated K is plotted only below the static water level (here approximately 10ft) determined by one or more HPT dissipation tests obtained as the log was run.

Command Tree for this action:

Add Graph
Primary Series
Est. K

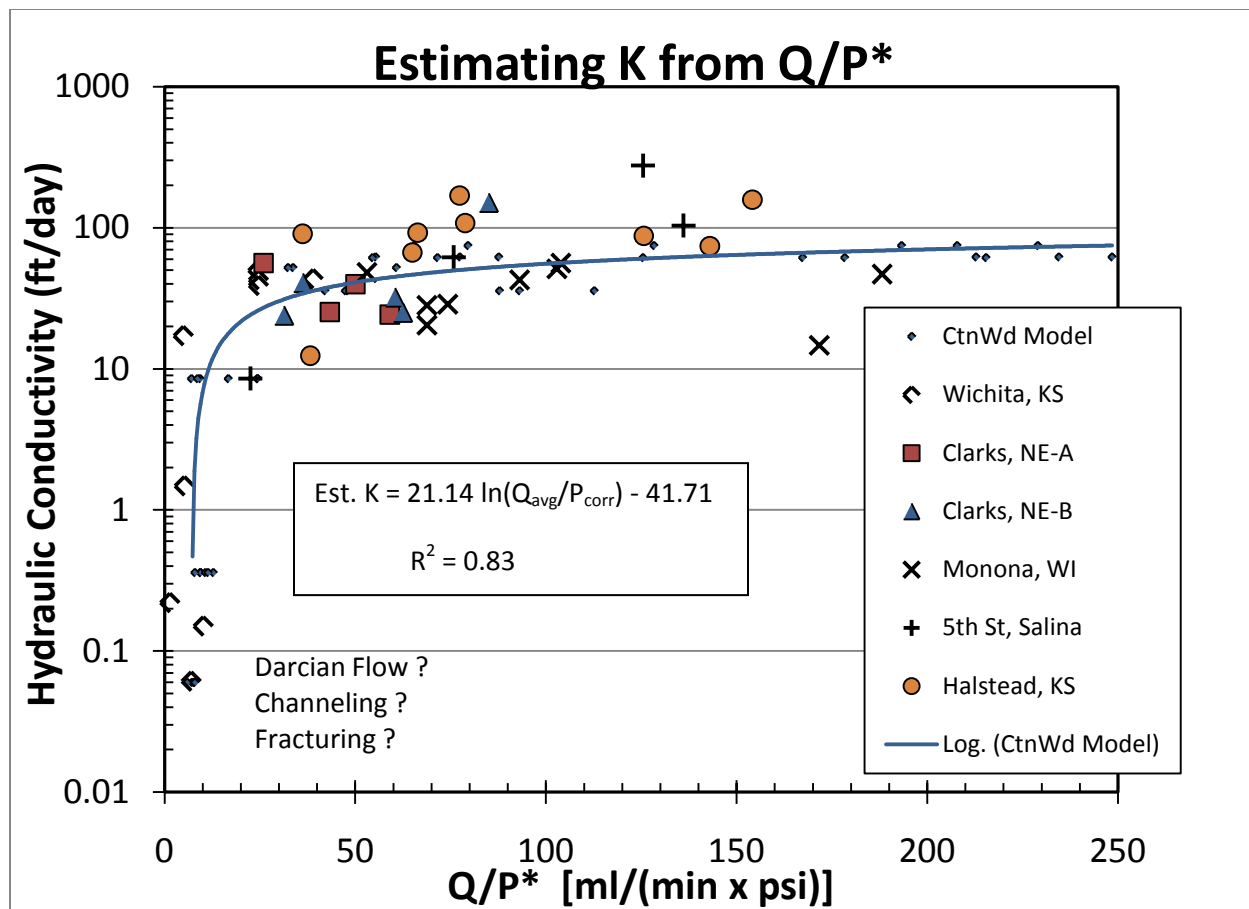


Figure 8: A model relating HPT average flow and corrected pressure (Q/P^*) to hydraulic conductivity (K) is used in the DI Viewer software to calculate an estimated value of the formation hydraulic conductivity for the saturated formation. This general model provides a good approximation of K based on data from multiple field sites in the central U.S. (After McCall and Christy, 2010). Hydraulic conductivity was measured by slug testing wells or piezometers installed near the HPT log locations. Screen intervals ranged from 1 to 5ft in length for the wells and piezometers.

Printing Logs and Exporting Graphs and Data

To print the HPT graph simply click on “File” in the command bar of the open Window, then click on “Print” and proceed with the normal Windows print command sequence. To Export the HPT log or other graphs from the DI Viewer to an image (*.png) file proceed with the following steps from the command bar of the open Window:

Command Tree for graph export:

```

File
  Export Graph
    (adjust size as needed in the “Graph Export Options Window”
    Click “OK”
      (enter desired filename)
      (browse to desired folder)
    SAVE
  
```

The HPT data user also may need to export HPT data to spreadsheet software for other calculations or to modeling software to allow for more detailed modeling and presentation in 2D and 3D formats. The HPT data can be exported from the main DI Viewer window by following these steps (see also Figure 9):

Command Tree for data export:

File

Export Log Data ...

(In the Export Log Data window click on the desired data series and move it to the Export Columns with the ">>" icon. Move undesired data columns back to the left with the "<<" icon.)

Select OK

Enter desired filename

Browse to desired folder and SAVE

The HPT data is exported as a comma separated text (*.dat) file. These files may be imported into spreadsheet software and graphical modeling software packages.

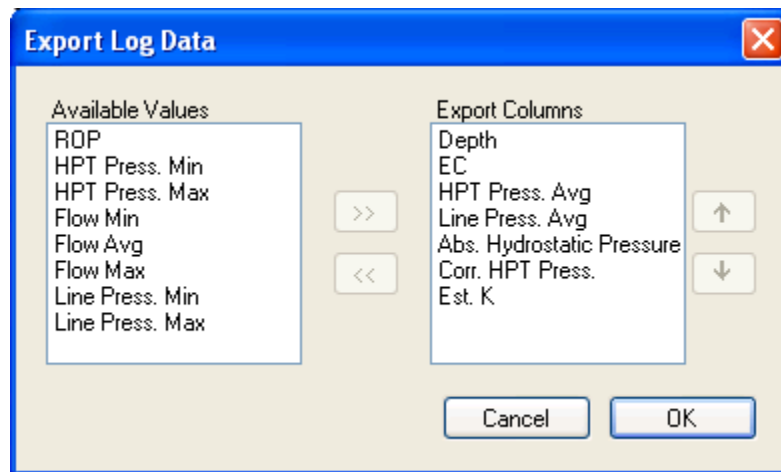


Figure 9: Selection of HPT data columns for export to a comma separated (*.DAT) file. Simply click on "File" and then select "Export Log Data" from the drop down menu to access this window. The exported data can be imported into spreadsheets for calculations or graphical modeling software for 2D and 3D modeling.

References

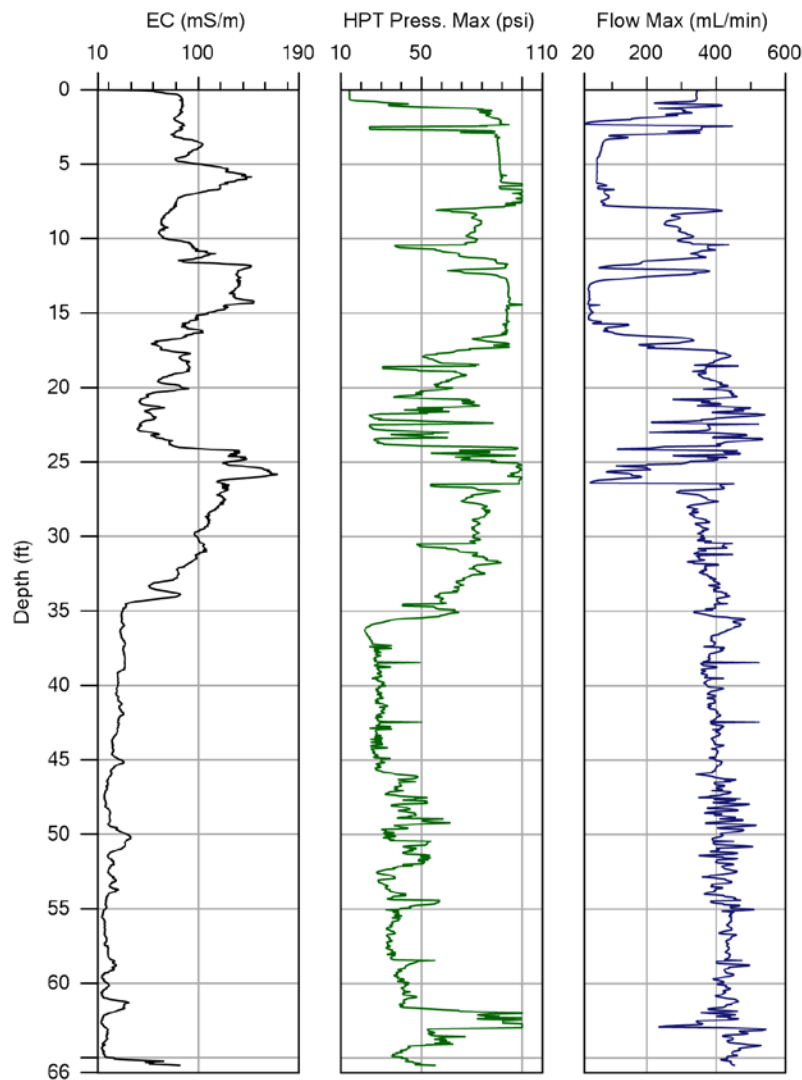
- American Society of Testing and Materials (ASTM), 2007a. D 6001 Standard Guide for Direct-Push Ground Water Sampling for Environmental Site Characterization. ASTM International, West Conshohocken, PA. www.astm.org
- American Society of Testing and Materials (ASTM), 2007b. D 6725 Standard Practice for Direct Push Installation of Prepacked Screen Monitoring Wells in Unconsolidated Aquifers. ASTM International, West Conshohocken, PA. www.astm.org
- American Society of Testing and Materials (ASTM), 2007c. D 7242 Standard Practice for Field Pneumatic Slug (Instantaneous Change in Head) Tests to Determine Hydraulic Properties of Aquifers with Direct Push Ground Water Samplers. ASTM International, West Conshohocken, PA. www.astm.org
- Geoprobe 2005. Geoprobe®Pneumatic Slug Test Kit, Standard Operating Procedure. Technical Bulletin No. 19344. Kejr Inc., Salina, KS. December.
- Geoprobe 2006a. Geoprobe® Screen Point 16 Groundwater Sampler, Standard Operating Procedure. Technical Bulletin No. MK3142. Kejr Inc., Salina, KS. December.
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- Geoprobe 2010 (In Press). Application of the HPT logging System for Geo-Environmental Investigations. Technical Bulletin in press. Kejr Inc., Salina, KS. In Press.*
- McCall, Wesley and Thomas Christy, 2010. Development of a Hydraulic Conductivity Estimate for the Hydraulic Profiling Tool (HPT). Abstract and Presentation, *The 2010 North American Environmental Field Conference & Exposition*. The Nielsen Environmental Field School, Las Cruces, NM. January.

Appendix I

Evaluating HPT Dissipation Test Stability

Dissipation tests that are not given sufficient time to return to true absolute hydrostatic pressure and equilibrium with the natural formation conditions will result in the calculation of an inaccurate absolute hydrostatic pressure line in the DI Viewer. This will further result in erroneous HPT corrected pressure calculations and incorrect Est-K results if they are based on the inaccurate absolute hydrostatic pressure line. The following example provides information on determining if a dissipation test has fully dissipated and is stable. Tests that do not fully dissipate may cause errors in water level calculations and subsequent HPT corrected pressure calculations.

Figure AI-1: The base HPT log data from the cottonwood03 location.



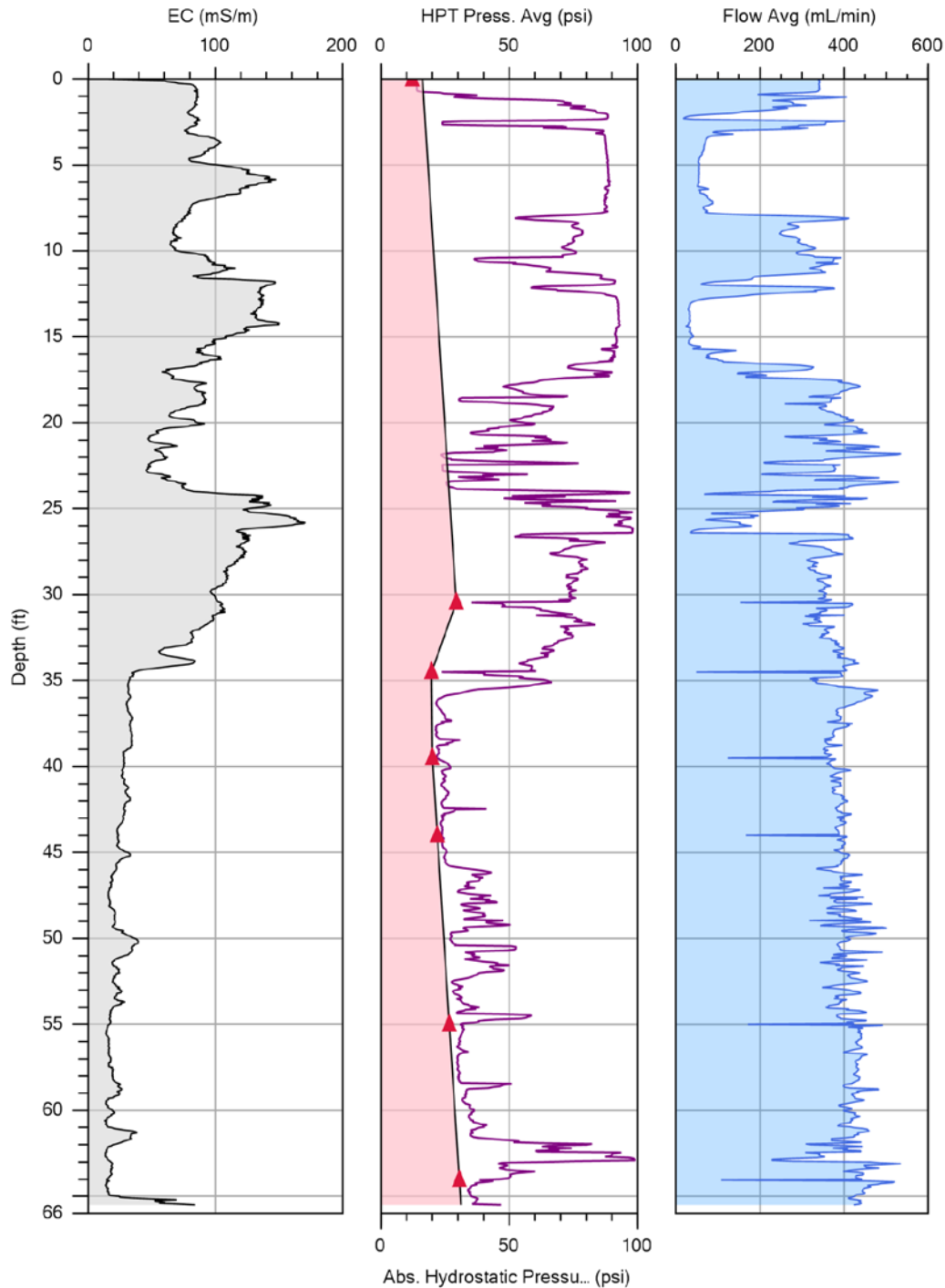
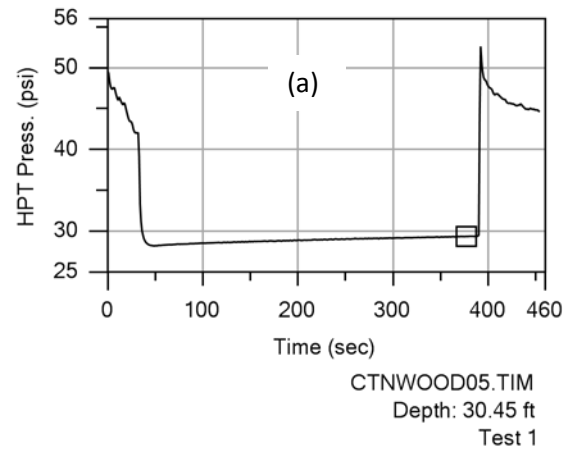


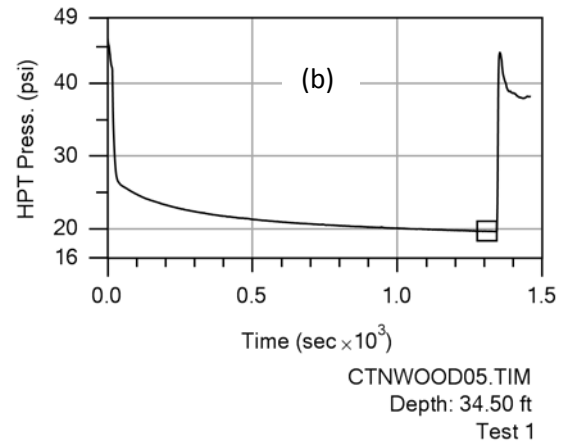
Figure AI-2: The center graph displays the HPT average pressure plotted along with the absolute hydrostatic pressure line when all six of the dissipation tests for this log are included. Depths where dissipation tests were conducted and the observed pressures are denoted by solid triangles on the absolute hydrostatic pressure line. Note significant inflection in the absolute hydrostatic pressure line caused by the dissipation test at 30.45ft depth. The Abs. Hydrostatic pressure line of this graph suggests that the water level is above ground surface by several feet (artesian conditions). Wells at this location actually exhibited water levels at about 21.5ft below grade. This fact suggests that a review of the dissipation tests is needed to evaluate the discrepancy between observed and calculated water levels.

Figures AI-3a, b and c: Dissipation tests at 30.45ft, 34.5ft and 39.5ft in this log.

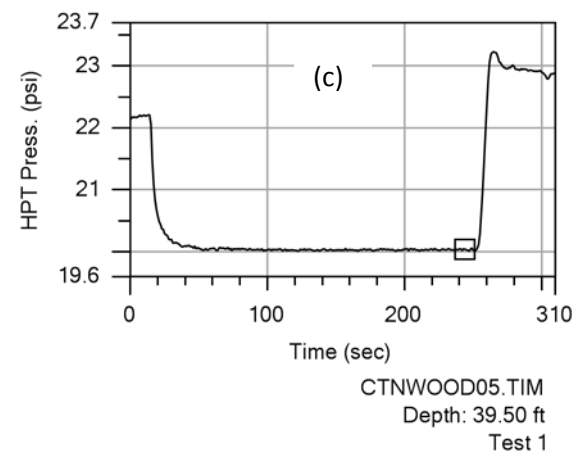
1st Dissipation Test: Run at 30.45ft depth where decrease in HPT pressure and EC suggests a possible increase in sand/silt (Figure AI-1 and AI-2). Note that pressure is still increasing even 300+ seconds after flow was turned off. This clearly indicates that excess pore pressure induced by insertion of the probe and injection of water is still rising. Could potentially take hours for this test to fully dissipate in this silty-clay material. Stopped test and continued logging.



2nd Dissipation Test: Run at 34.5ft depth where decrease in HPT pressure and EC on the log suggests a possible increase in sand/silt (Figure AI-1 and AI-2). Note that pressure is still slowly dropping even 1200+ seconds after flow was turned off. This clearly indicates that excess pore pressure induced by insertion of the probe and injection of water is dissipating slowly. Could potentially require 30+ minutes more for this test to fully dissipate. Stopped test and continued logging.



3rd Dissipation Test: Run at 39.5ft depth where decrease in HPT pressure and EC on the log clearly suggests an increase in sand (Figure AI-1 and AI-2). Note that pressure drops quickly and stabilizes at less than 100 seconds after the flow was turned off. Good stability of the HPT pressure here for over 100 seconds indicates pressure observed is in equilibrium with the formation hydrostatic pressure.



Figures AI-4a, b and c: Dissipation tests at 44.0, 55.0 and 64.05ft depths for this log.

4th to 6th Dissipation Tests: Run at depths of 44ft, 55ft, and 64.05ft. At each of these depth intervals the log reveals relatively low HPT pressure and low EC suggesting coarser grained materials. (Figure AI-1 and AI-2). Note that pressure drops quickly and stabilizes fairly quickly after the flow was turned off. Good stability of the HPT pressure on each graph for over 100 seconds indicates pressure observed is in equilibrium with the formation hydrostatic pressure at the depths tested.

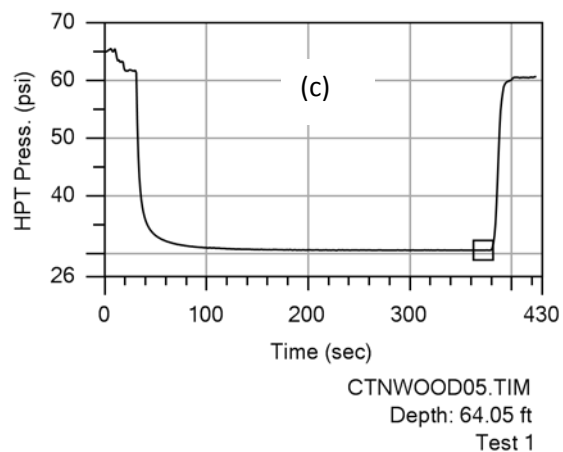
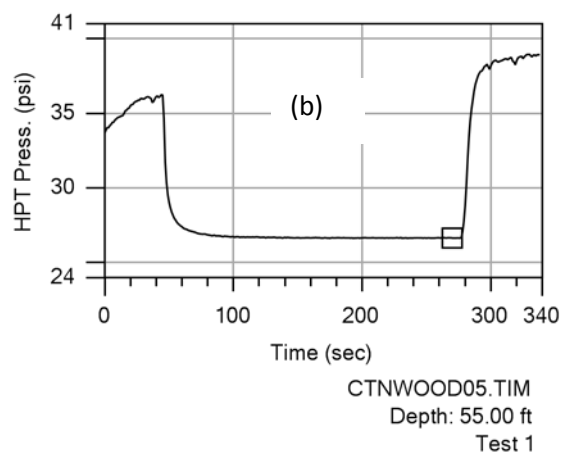
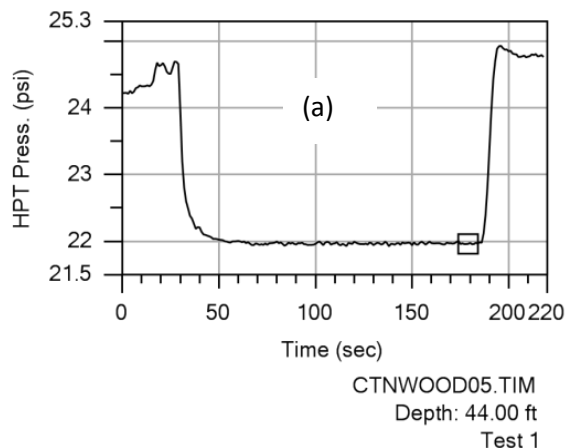
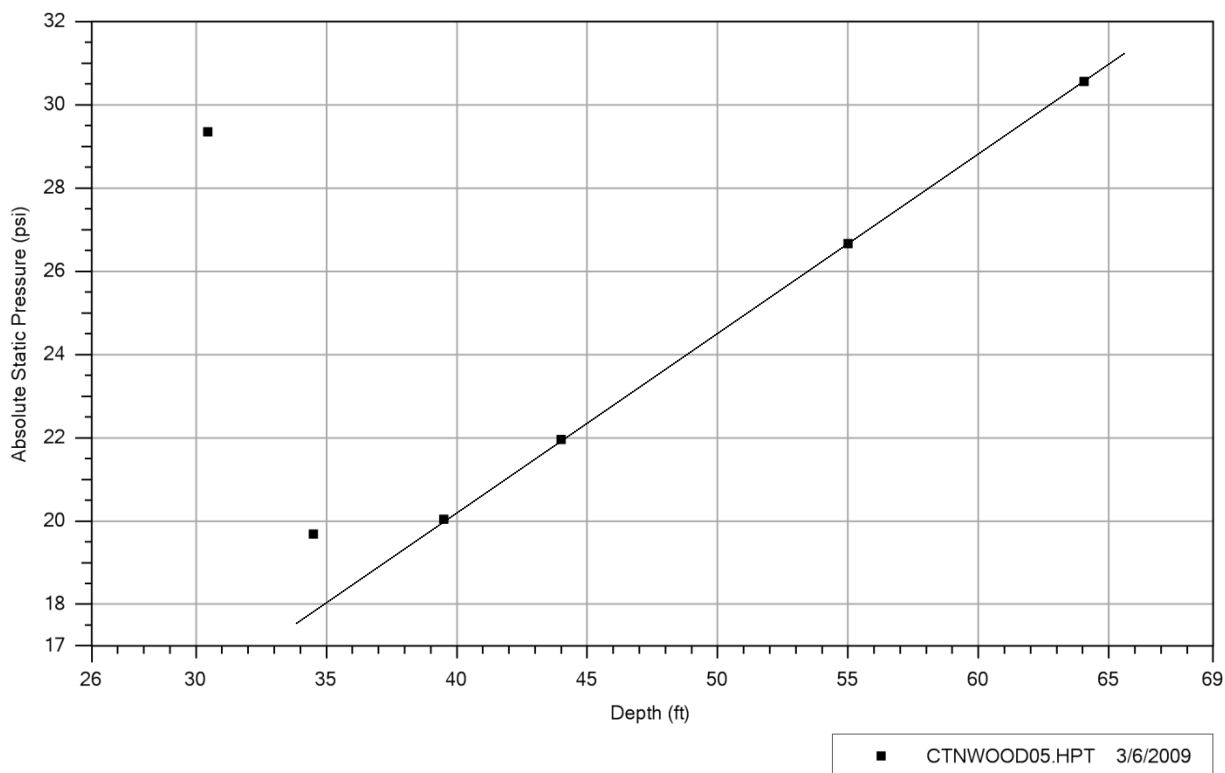


Figure AI-5: Below is the graph of the observed static pressure versus depth for the six dissipation tests obtained for this log as plotted in the DI Viewer. Note that the lower four dissipation tests (below 39ft depth) provide a straight line for pressure versus depth over the lower part of the log. This along with the dissipation test plots above (Figures AI-3c and AI-4a to AI-4c) indicates pressure dissipated to equilibrium with the formation during each of these dissipation tests.

Conversely, the two shallow dissipation tests (Figures AI-3a and AI-3b) did not fully dissipate the excess pore pressure (induced by insertion of the HPT probe and water injection) in the time allowed and so did not achieve equilibrium with the natural formation pressure. To obtain an accurate plot of the absolute hydrostatic pressure on the HPT log the two shallow dissipation tests performed for this log must not be used to define the absolute hydrostatic pressure line.



NOTE: Artesian conditions have been observed and documented with the HPT system and dissipation tests. Full dissipation of the excess pore pressure during a dissipation test will result in a flat, stable pressure readout (e.g. Figures AI-4a-c). As observed above (Figures AI-3a and 3b), the fine grained matrix of the formation where the two shallow dissipation tests were performed would require a long wait for full dissipation to occur. It is generally not time- or cost-efficient to wait an hour or several hours for a test to fully dissipate. Again targeting coarse grained zones for dissipation tests is more time efficient and provides good quality data.

Some project objectives may require dissipation tests in finer grained formations. Be sure to build in extra field time if this is required. Remember, HPT dissipation tests cannot be used to calculate a point estimate for hydraulic conductivity as done for CPT dissipation tests.

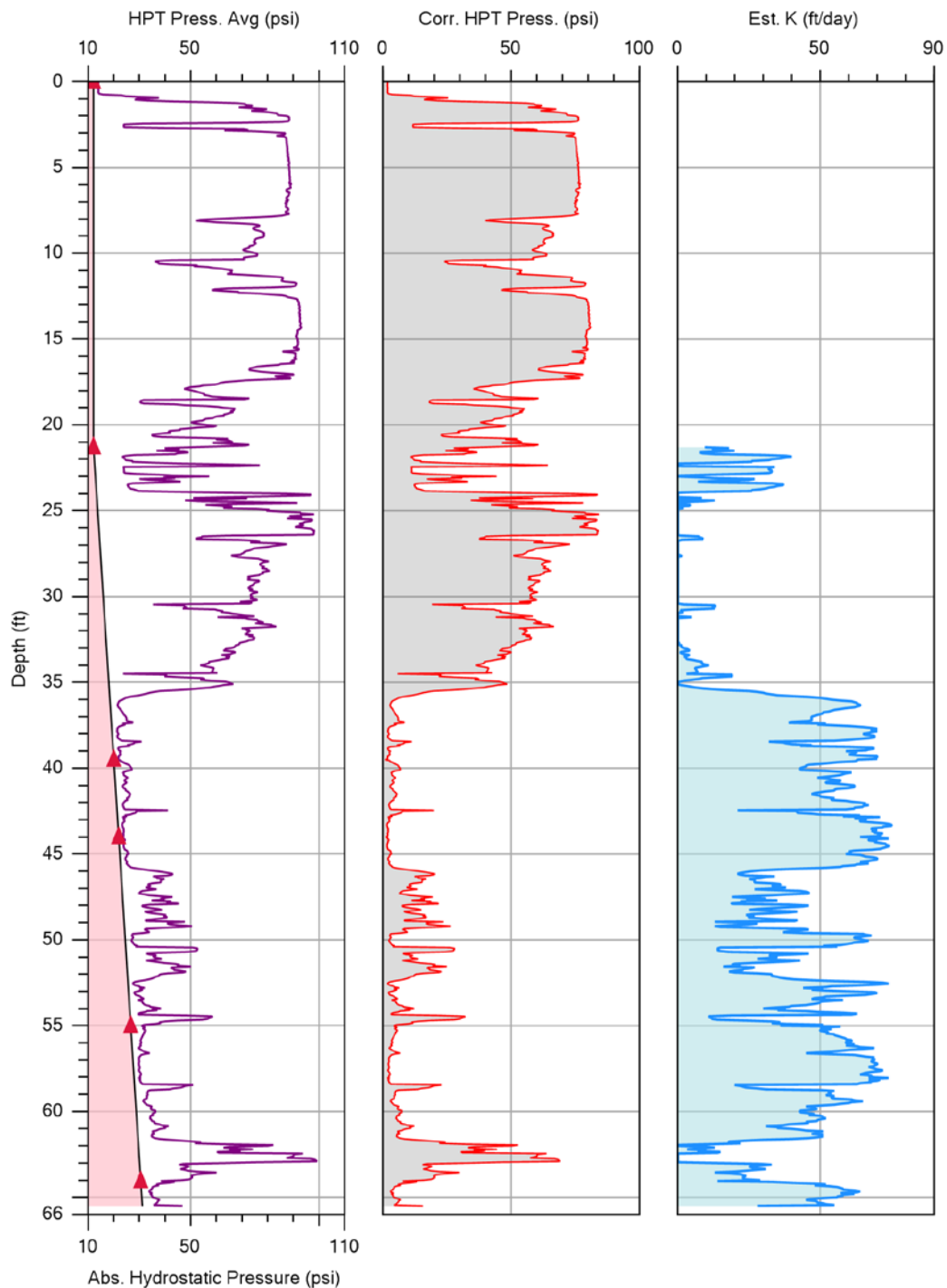


Figure AI-6: HPT log with plot of good dissipation tests used to calculate and plot the correct absolute hydrostatic pressure line (left graph, shaded). Middle graph gives the corrected HPT pressure. The right graph provides a log of the estimated K values calculated based on the corrected pressure and average flow data.

Appendix II

User Defined Hydrostatic Pressures

If a dissipation test was not obtained during an HPT log the data analyst may use other available water level data or hydrostatic pressure data to create an Absolute Hydrostatic Pressure line for the log. This will make it possible to calculate HPT corrected pressures and the Estimated K log.

One source of ambient hydrostatic pressure data is from a well or temporary piezometer installed near the HPT log, at the same ground elevation. The static water level measured in the well may be used to determine the hydrostatic pressure in the formation at the screened interval. As an example a piezometer was installed about 1 meter from HPT log obtained at the cottonwood03 location and screened over an interval of 43-45ft below grade (Figure All-1 below). The equilibrium water level was measured at 21.5ft below grade. Knowing this and the fact that water exerts a pressure of 0.432psi/ft the hydrostatic pressure at the center of the screen interval (44ft) can be calculated.

$44\text{ft} - 21.5\text{ft} = 22.5\text{ft}$ of water column

$22.5\text{ft} \times 0.432\text{psi/ft} = 9.72\text{psi}$ of water pressure at 44ft in the formation.

Local atmospheric pressure determined by the reference test for this log was 12.065psi

Therefore the total pressure that would be observed at 44ft in the formation is:

$12.065\text{psi} + 9.72\text{psi} = 21.785\text{psi}$

To enter user-defined hydrostatic pressure nodes follow these steps (see Figure All-1 below):

Command Tree for This Action:

- Right click on the pressure graph to access the pop-up menu.
- Mouse over "Secondary Series" to open the drop down menu for this option
- Select "Abs. Hydrostatic Pressure ..."

At this point a straight vertical line is plotted on the pressure graph (Figure All-1) at the atmospheric pressure measured by the reference test(s) done with this log.

- Right click anywhere in the pressure graph again to open the pop-up menu.
- Select "Edit Static Pressures" option

At this point the "User-Edited Static Pressure Nodes" window opens

- Double click on the depth box and enter 44ft
- Double click on the pressure box and enter 21.785psi
- (more depth and pressure points may be added if available)
- Click OK

The Absolute Hydrostatic Pressure line is updated and the user entered points are shown as open triangles along the revised Absolute Hydrostatic pressure line.

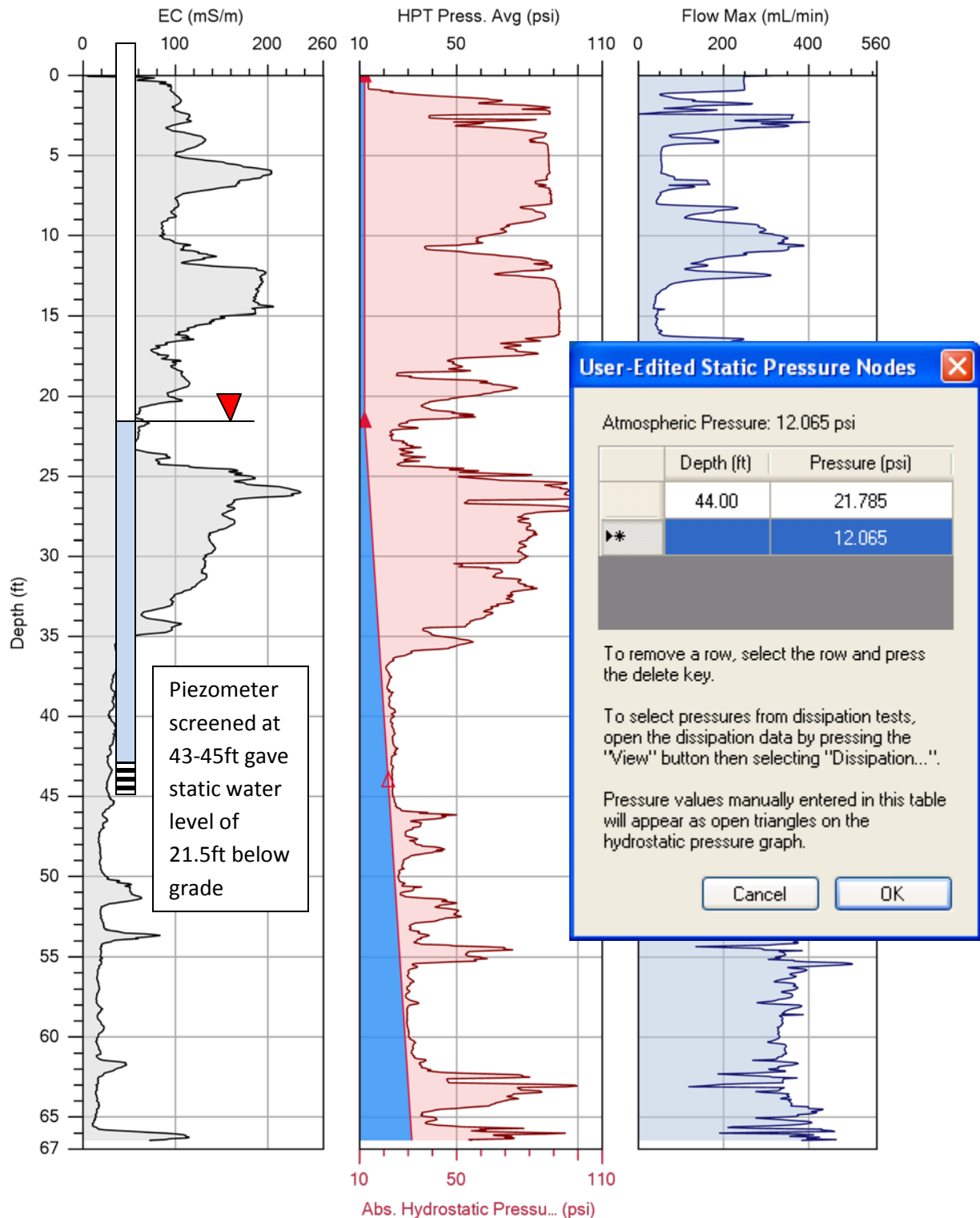


Figure AII-1: A dissipation test was not obtained for this log. However, a temporary piezometer near the log locations provided a static water level of 21.5ft below grade. This information can be used to edit in a static pressure node (open triangle) and then plot the absolute hydrostatic pressure line. This can subsequently be used to calculate and plot the HPT corrected pressure and estimated K logs.