Geoprobe® Pneumatic Slug Test Kit
(GW1600)

Installation and Operation Instructions for USB System
Instructional Bulletin No. MK3195

Prepared: February, 2014
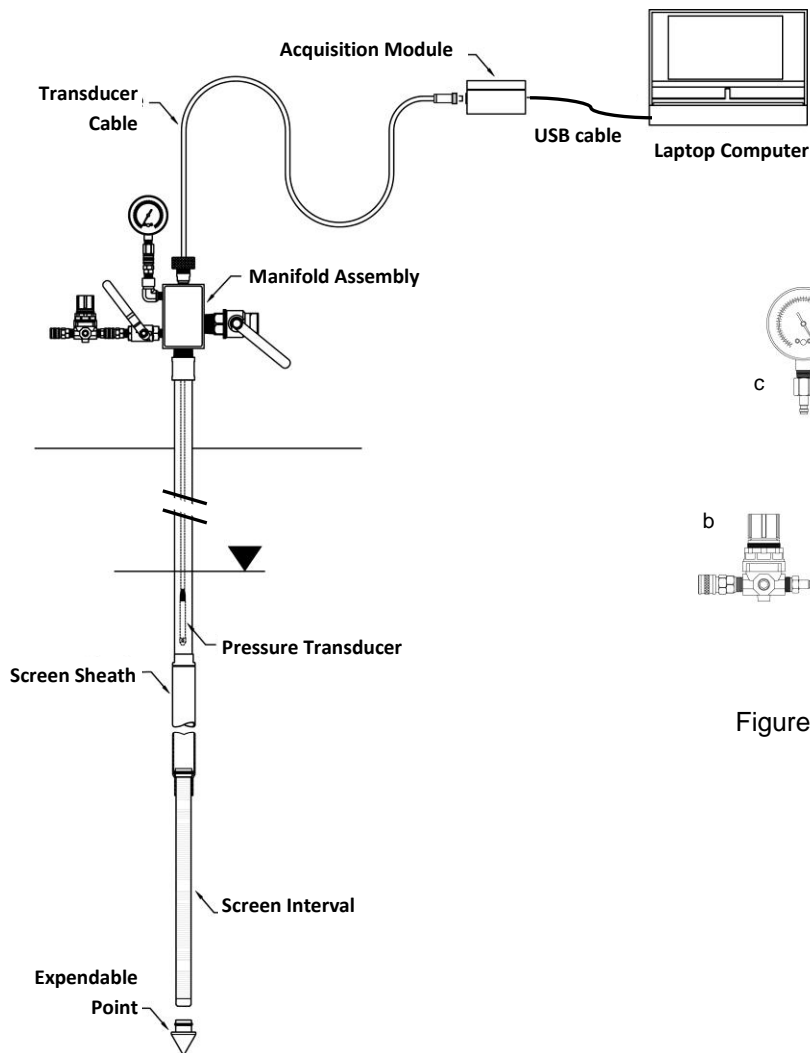
Figure A: Typical field setup with SP15/16 groundwater sampler
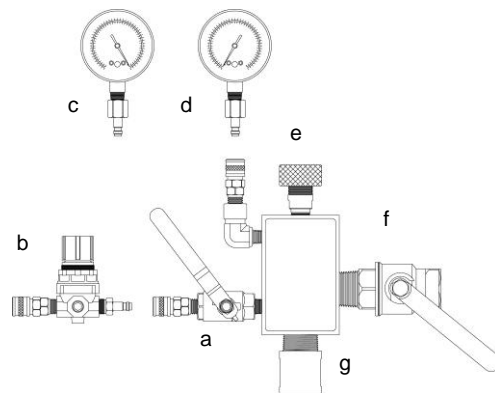
Figure B: Manifold Assembly with:

(a) inlet valve

(b) regulator

(c) vacuum gauge

(d) pressure gauge

(e) transducer port

(f) release valve

(g) 1.25" rod adapter

Operating the Pneumatic Slug Test Kit

1.0 Objective

The Geoprobe® Pneumatic Slug Test Kit is used in conjunction with direct push (DP) groundwater sampling tools (SP16, SP22, etc.) or monitoring wells to perform slug tests. The slug test responses are modeled and used to determine the hydraulic conductivity (K) of the screened aquifer (Butler 1997, Butler and Garnett 2000, Butler et al. 2002, McCall et al. 2002). This bulletin identifies the tools and basic techniques required to successfully operate the Pneumatic Slug Test Kit. The DP groundwater samplers or wells (Geoprobe® 2006a,b,c, 2009a,2010) may be installed at multiple depths (profiling) and locations across a site to define the spatial variations in K and contaminant distribution (McCall et al. 2002, 2006, 2009). The procedures outlined below conform to the ASTM Standard Practice D 7242 (ASTM 2013a) for performing pneumatic slug tests with DP methods.

2.0 Required Equipment

All the components of the Pneumatic Slug Test kit are provided in a carrying case for ease of transportation. The major components of the kit (Figure 1) include the pneumatic head assembly, pressure transducer, data logger and accessories needed to complete the slug testing process.   When slug testing PVC wells additional PVC adapters will be required (214039 for sch. 40 PVC wells ≤1-inch, 207304 for sch. 40, 2-inch PVC wells). Pneumatic slug testing of larger diameter wells may be performed with custom adapters.

3.0 Preparation Before Slug Testing

The groundwater sampling tools (Figure A, cover; Geoprobe® 2006, 2010, ASTM 2013b) or monitoring wells (Geoprobe® 2006b, 2006c, 2009a, ASTM 2013c) must be installed properly before slug testing can be performed. For both wells and DP groundwater samplers O-rings (or equivalent) must be used on each casing or rod joint respectively, to provide for an airtight system needed for pneumatic testing. Once installed the groundwater samplers or wells must be adequately developed (ASTM 2013d, Geoprobe® 2002a) to obtain representative slug test results. When installed in sandy formations many groundwater samplers and wells may be adequately developed (Figure 2) with a simple check valve (GW4210, GW4220 or GW4230) to assure that representative slug tests and K-values are obtained. Water quality sampling usually requires more stringent methods for well development (Geoprobe® 2002a, ASTM 2013d).

For short screen groundwater samplers and wells purging as little as 1 to 5 gallons (4 to 20 liters) is often sufficient for development. Be sure to document well construction parameters (screen length, boring diameter, casing radius, etc.) so that K may be correctly calculated. Information about aquifer thickness and whether the aquifer is confined or unconfined will need to be determined to enable correct K calculation. In order for pneumatic slug tests to be successfully performed the static water level must be above the screened interval of the well, prior to and during the pneumatic slug test. If this is not the case mechanical slug tests may be performed on the well using the transducer, acquisition module and software included with the kit. A mechanical slug is not included with the GW1600 kit.
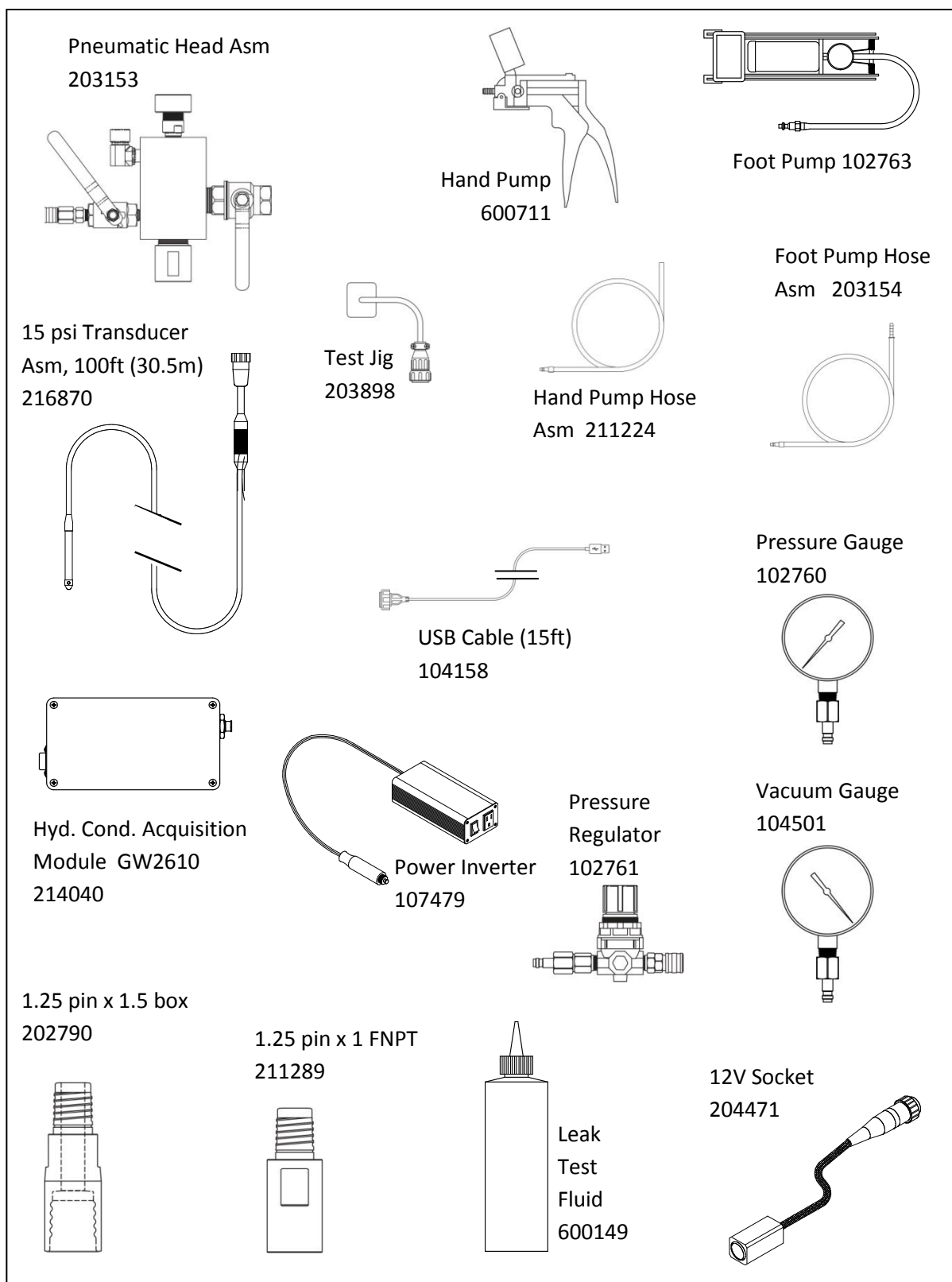
Pneumatic Head Asm 203153

Hand Pump 600711

Foot Pump 102763

15 psi Transducer Asm, 100ft (30.5m) 216870

Test Jig 203898

Hand Pump Hose Asm 211224

Foot Pump Hose Asm 203154

USB Cable (15ft) 104158

Pressure Gauge 102760

Hyd. Cond. Acquisition Module GW2610 214040

Power Inverter 107479

Pressure Regulator 102761

Vacuum Gauge 104501

1.25 pin x 1.5 box 202790

1.25 pin x 1 FNPT 211289

Leak Test Fluid 600149

12V Socket 204471

Figure 1: Major components of the GW1600 Pneumatic Slug Test Kit (not to scale).

4.0 Installation of the Pneumatic Head and Transducer

The pneumatic head is installed on the probe rod using the appropriate adapter (Figure 3). When slug testing PVC wells additional PVC adapters will be required to attach the pneumatic head to the well casing (Geoprobe® 2002b). Use appropriate O-rings, plumbers tape or bushing to obtain an air tight seal between the pneumatic head and probe rod or PVC casing. When the pneumatic head is installed unthread the knurled fitting from the transducer port and remove the copper washer and split bushing (Figure 4). Replace the copper washer and knurled fitting on top of the transducer port. Next lower the transducer down through the well until it is submerged about 6 feet (2 m) below the static water level. Allow the transducer to cool to the ambient groundwater temperature (usually 3 to 5 minutes) before zeroing or slug testing is started. Reinstall the split bushing (Figure 4) to complete the seal after the transducer is zeroed at atmospheric pressure (see below) and installed at the desired depth.

Please review the following notes to be sure you obtain valid data and to minimize potential damage to kit components:

NOTE: The inside diameter of the release valve used to initiate the test should be of equal or greater ID than the well casing to assure free flow of air from the well and that no interference or noise occurs to degrade data quality. The release valve on the pneumatic head has an ID of 1.0 inches (25.4 mm). A pneumatic head adapter (207304) is available for 1.5-inch and 2-inch (38 and 50mm) PVC wells. Custom adapters can be fabricated for larger wells.

CAUTION: The transducer is delicate. Do not step on or strike the transducer as it may be damaged. Do not submerge the transducer more than 15 ft (4.5 m) below the static water level. Do not place the transducer in water with high concentrations of solvents or where free product is present as it can be damaged.

CAUTION: The transducer is vented by a small tube running through the cable. Do not kink the transducer cable as the vent tube may be pinched. This can result in an inoperable transducer.

NOTE: Keep the transducer cable out of direct sunlight before and while tests are being performed. Sunlight will warm the air in the vent tube and may cause noticeable drift of the baseline (Cain et al., 2004). This can interfere with modeling of the slug test response and accurate calculation of K. Foam pipe insulation may be placed around exposed sections of transducer cable to prevent solar heating and baseline drift on sunny days. Keep excess loops of transducer cable in the shade, (e.g. inside a box or sample cooler).
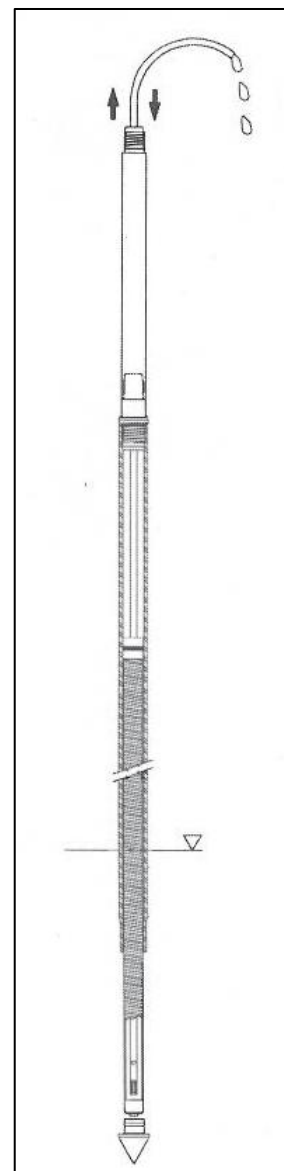

Figure 2: Development of an SP16 groundwater sampler with a check valve (214061, 214062 or similar) by surging and purging. This may be conducted manually or the 12V Mechanical Actuator (214106) may be used. Older wells may require redevelopment to obtain accurate slug test results.
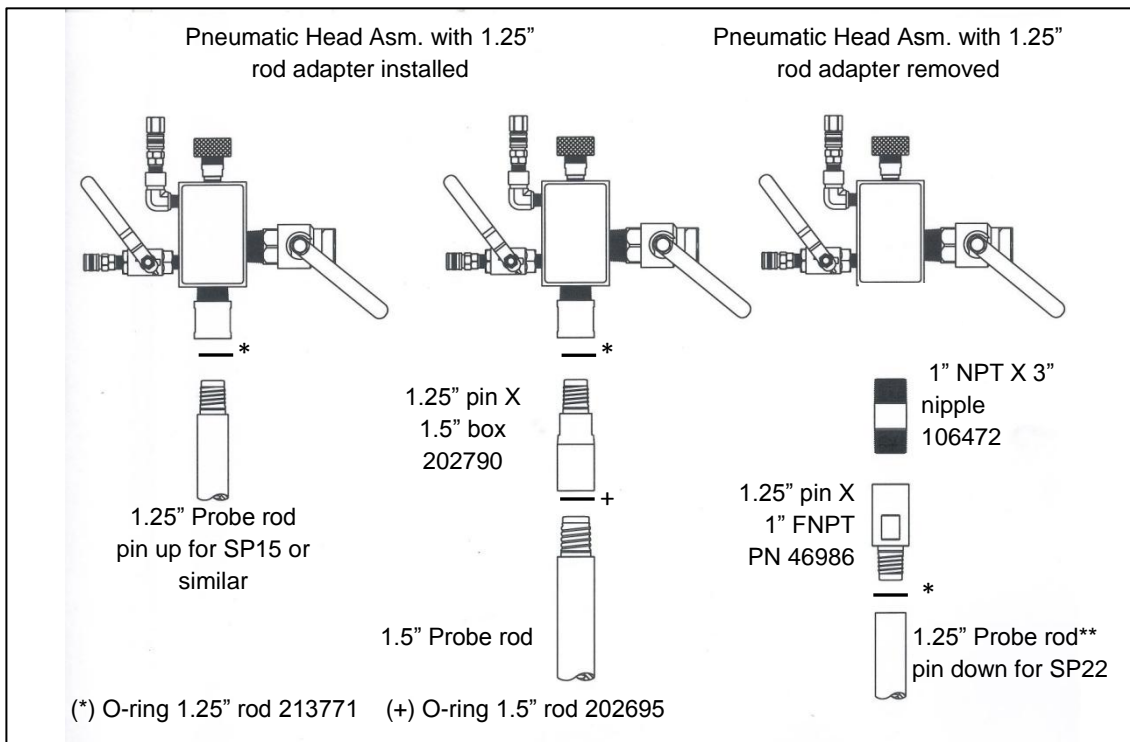
Pneumatic Head Asm. with 1.25"
rod adapter installed

Pneumatic Head Asm. with 1.25"
rod adapter removed

*

*

1" NPT X 3"
nipple
106472

1.25" pin X
1.5" box
202790

1.25" pin X
1" FNPT
PN 46986

1.25" Probe rod
pin up for SP15 or
similar

+

*

1.5" Probe rod

1.25" Probe rod**
pin down for SP22

(*) O-ring 1.25" rod 213771   (+) O-ring 1.5" rod 202695

Figure 3: Installation of the pneumatic head on different probe rod/groundwater sampler configurations. When slug testing PVC wells additional PVC adapters will be required to attach the pneumatic head to the well casing (Geoprobe® 2002b). ** Because of radius change in ID of 1.25" light weight rods they cannot be used for slug testing.

Figure 4: Transducer seal assembly showing the knurled cap, copper washer and split bushing on the transducer cable after the transducer is lowered to depth.

USB Cable 104158

Figure 5: The 15ft USB cable is used to attach the data acquisition module (GW2610) to the laptop computer for signal transmission. The USB cable also provides power from the laptop computer to operate the acquisition module and the transducer downhole. If needed the 12V power inverter (Figure 1, 107479) included with the kit may be attached to the Power Point of a Geoprobe® unit or vehicle to recharge the computer battery.

5.0 Acquisition Software and Acquisition Module

The Slug Test Acquisition software (V 3.0) is provided on a USB drive with the kit. Install the drive in one of the USB ports of the computer and follow the onscreen instructions for installation. This usually requires less than 2 minutes. A folder titled "dirim95" is created on the computer hard drive to store the acquisition software. The data files (*.dat) generated by slug testing are saved in a subfolder titled "logfiles" for later retrieval, viewing and modeling.

The USB cable (Figure 5, above) is used to connect the acquisition module (GW2610, Figure 6) to the computer for signal transmission. The USB cable also supplies power to the acquisition module and transducer. The power inverter (107479) supplied with the kit may be plugged into a vehicle or Geoprobe® unit power point to provide the electrical current required to operate the computer and slug test system. The transducer is attached to the sensor port on the acquisition module (Figure 6). The acquisition module converts the analog signal from the transducer to digital signal that is received by the computer for live-time display and storage in data files.

6.0 Initiate Software: Zero Transducer

When the software is started a blank graphing window opens showing the CONNECT icon in the upper right corner (Figure 7). Click on the CONNECT icon and the software will search the active com ports on the computer and locate the port the Acquisition Module is connected to and make the connection.

Figure 6: The USB cable and transducer cable are connected to the GW2610 Acquisition Module (214040).

Once the connection is made the ZERO TRANSDUCER window opens (Figure 8). Allow the transducer to cool to ambient groundwater temperature in the well for at least 3 to 5 minutes. Then gently raise the transducer above the water level (voltage readout drops and then stabilizes) and click on the CONTINUE icon and the transducer will be zeroed. Some fluctuation in the last couple of digits on the transducer readout is expected while zeroing, especially for higher frequency settings (e.g. 10Hz). Zeroing the transducer at atmospheric pressure lets the operator know how deep the transducer is below the water level in the well prior to testing and between tests. If you want to keep the previous zero level you can choose to BYPASS the zero function (recommend re-zeroing after moving to a new location). Now lower the transducer below the water level to the desired depth for slug testing. Usually the transducer is set at about 6 ft (2 m) below the water level for slug testing. Initial head values of greater than 5 ft (1.5 m) are usually not required for slug testing and larger head values may cause some errors of measurement in fast or oscillatory recovering wells. Smaller initial head values are usually preferred.
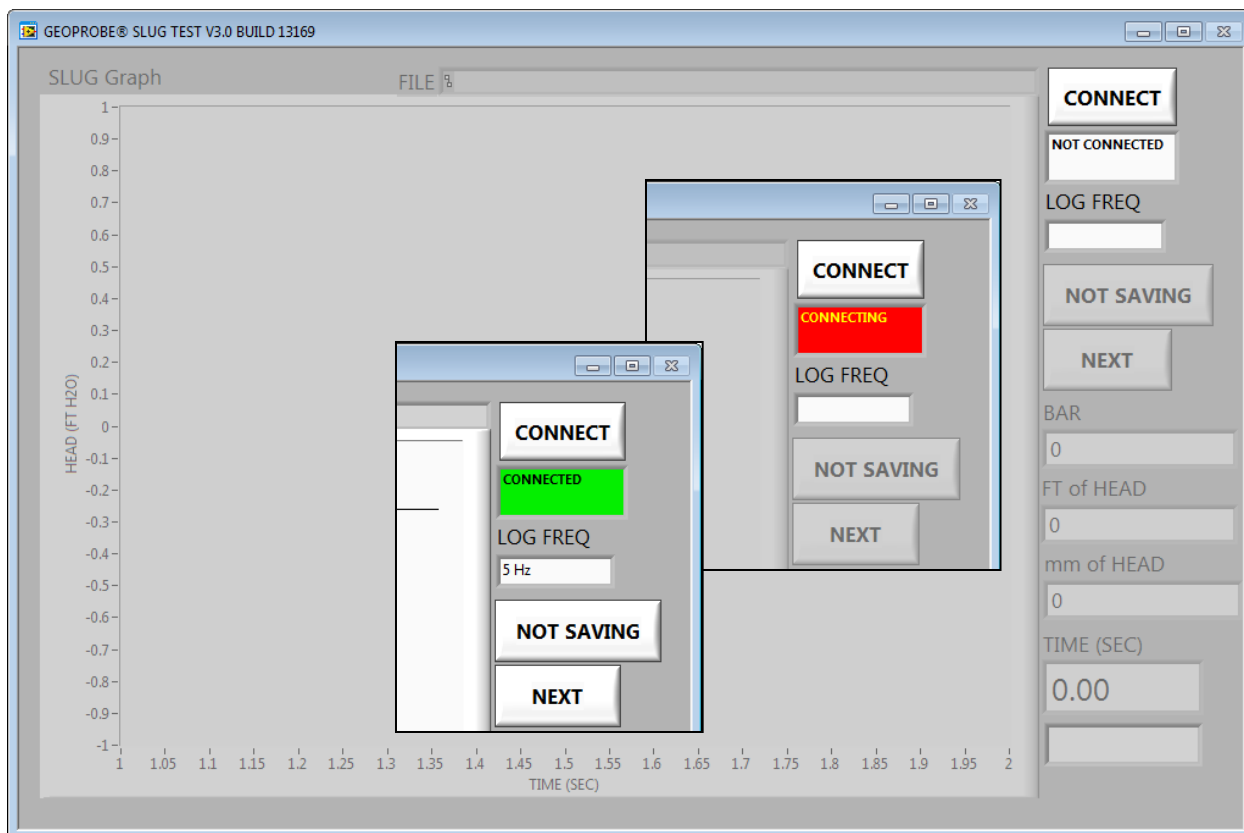
Figure 7: Click on the CONNECT icon and the software will search for the com port where the Acquisition Module is connected with the USB cable. The CONNECTING icon flashes red while searching for the correct com port. The icon changes to green CONNECTED when the connection to the correct com port is made. This search and connection usually requires less than a minute.

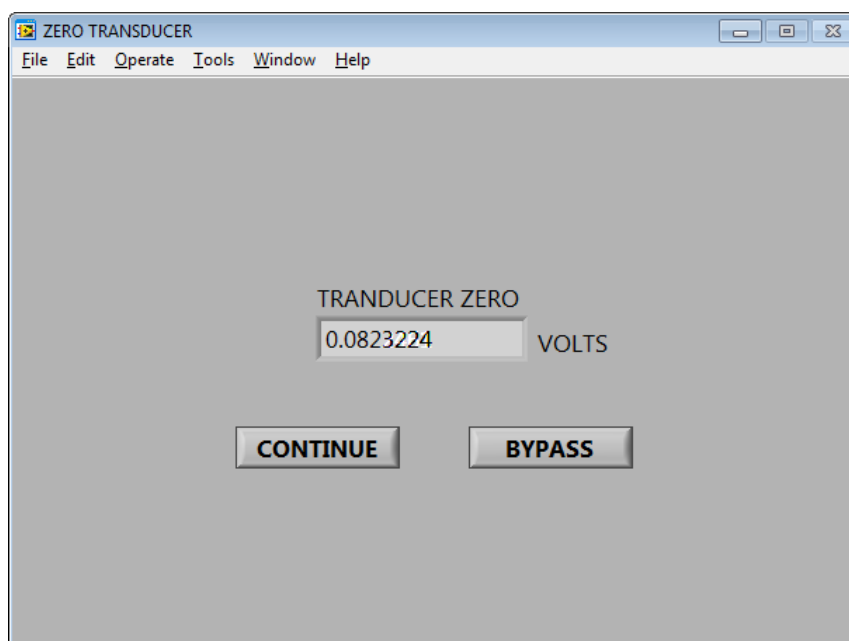**Figure 8: Allow the transducer to cool to ambient groundwater temperature in the well. Then raise the transducer above the water level and click on CONTINUE to zero the transducer at atmospheric pressure. You can select BYPASS if you prefer to keep the previous zero value.**

Once the transducer is zeroed the setup information window opens (Figure 9). Look at the metallic transducer body to see whether it is a 10 psi or 15 psi model and select the correct value under sensor type. Select your units preference. The units are presented as feet of head in English and as millimeters of head in metric. Choose the desired logging frequency based on the speed and type of recovery expected in the well. For wells that recover quickly (< 60 sec) or exhibit an oscillatory response a frequency of at least 5 Hertz (Hz) is recommended. For wells that require several minutes or longer to recover a frequency of 1 Hz or 2 Hz should be sufficient.

The MONITOR setting is useful for leak testing and initial evaluation of a well's response before saving data. Under this option no data is saved and you can simply run a test or two to observe the well response and select the best log frequency.

To run a slug test or series of slug tests and save the data to a file select the LOG option and click on the continue icon. The FILE NAME window opens (Figure 10) where a filename can be entered. The transducer serial number may be edited in this window.

Figure 9: Select the appropriate setting under each heading and click on the continue icon to proceed. Review text for details.
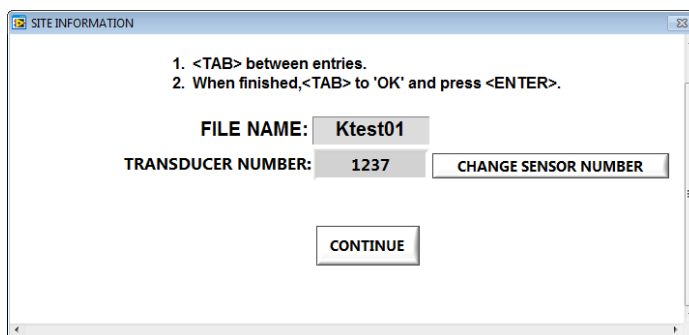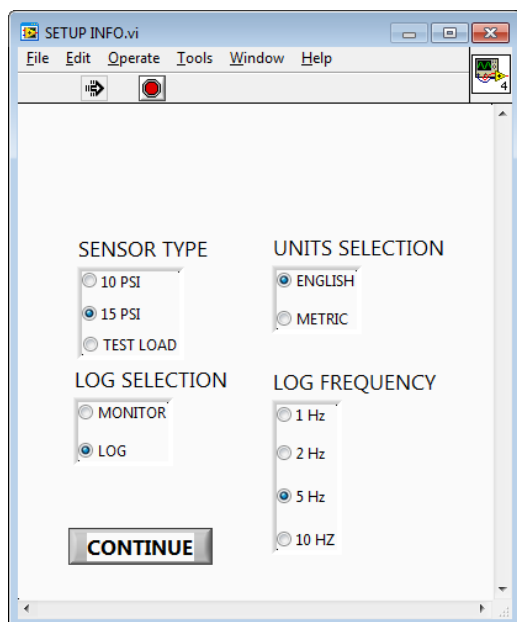

Figure 10: If the LOG option is selected in the setup window then the FILENAME window opens. Enter an appropriate file name. Click on CHANGE SENSOR NUMBER option to update the sensor serial number. The serial number is located on the metal body of the transducer. Tracking the serial number lets the operator know which transducer was used to run the slug tests. This can be useful quality control information.

Once you click on the continue icon at the setup info page or filename page the slug test graph window opens (Figure 11) where head pressure is plotted versus time. When the graph window first opens the auto scale function magnifies the baseline and you may see what appears to be large noise spikes. Lowering the transducer just into the water will auto-adjust the vertical scale so that the apparent noise is reduced. When you are prepared to start saving data click on the NOT SAVING icon (it will change to SAVING) and data will be sent to the filename previously specified.
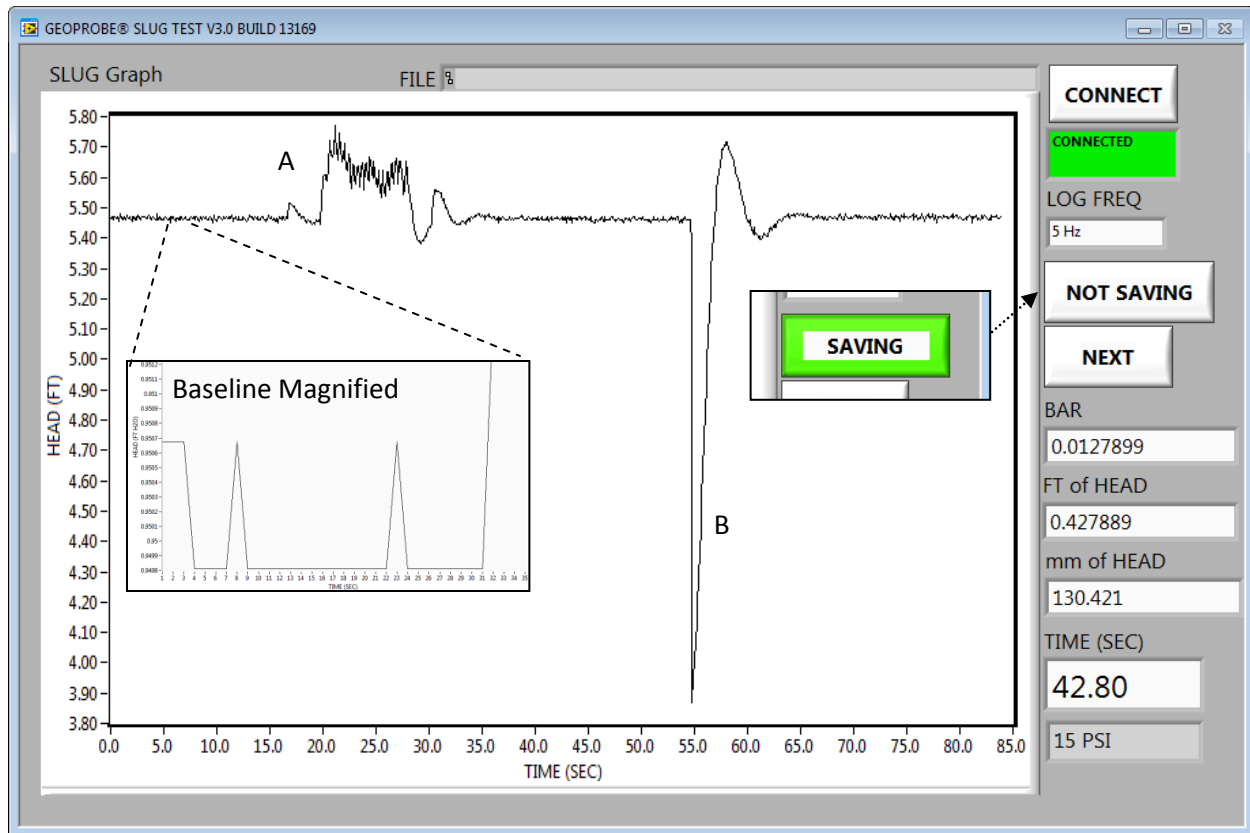
Figure 11: Once the setup info and file name are entered the slug test graph window opens where pressure head is plotted versus time. When the graph first opens the baseline may be magnified due to auto scaling. To start saving data to the file simply click on the NOT SAVING icon. It will change to a green SAVING icon to indicate that data is being saved to file. Air pressurization peaks (A) will be observed on screen when air is added to pressurize the well head. After the system pressure returns to equilibrium the release valve is opened on the pneumatic head to initiate the slug test (B). After slug testing is completed end the file by clicking on the NEXT icon.

When slug testing is complete at the well click on the NEXT icon to close the file. When the file is closed a popup window will open giving you the option to exit the program or continue (Figure 12). If continue is selected the program loops back to the Setup info window (Figure 9) so you can enter the parameters for the next slug test.
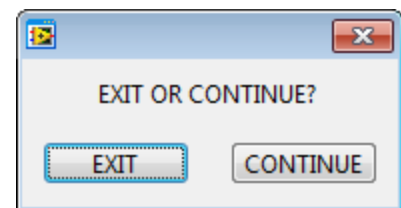

Figure 12: Selecting EXIT will take you out of the program. Selecting CONTINUE will loop you back to the setup information menu to enter data for the next slug test file.

NOTE: The SAVING icon must be present in the graphing window for data to be saved to the named file.

7.0 Leak Testing

To verify that rod or casing joints and the pneumatic head are air tight a leak test is performed (Figure 13). Insert the pressure gauge in the upright quick connect and attach the hand pump (or other air pressure source*) to the horizontal quick connect. If a higher pressure air source is used place the pressure regulator[**] assembly (102761) between the source and the inlet valve to prevent damage to the gauge and jetting air into the formation. Pressurize the well head to about 20 inches (50 cm) of water pressure (this is < 1 psi). This will require several pumps on the hand pump and will result in increased pressure readout on the computer screen (Figure 11-A) that will return to the original baseline pressure. The total air pressure + water pressure over the transducer will return to equilibrium with the formation hydrostatic pressure. If excess air pressure is applied the water level will drop below the transducer and the stabilized pressure observed onscreen will exceed the ambient water pressure observed by the transducer. Reduce excess air pressure so that valuable early time response data is not missed when the test is started.

Figure 13: Setup for leak test and rising head tests with the pressure gauge and hand pump. The gauges are graduated in inches and centimeters of water pressure (outer and inner marks respectively). Close the inlet valve after pressurizing.

Observe the pressure gauge for leak testing. Air pressure observed on the gauge (and computer screen, Figure 11-A) will bounce up and down as air is pumped into the well head and water flows out of the screen. Once pumping is stopped the air pressure should stabilize and the gauge readout indicates how far (inches/centimeters) the water level has been lowered in the well. Add more air if a larger initial head (H_o) displacement is desired. If the air pressure readout on the gauge continues to fall and returns to zero there is a system leak. (Remember, lower K formations will recover slowly from pressurization.) Use the leak check fluid (600149), included with the kit and apply it to exposed joints and fittings, watch for small bubbles to appear at leaks. Tighten any leaky fittings until an air tight system is obtained. Once the system is air tight slug tests may be conducted.

Leaks may occur down-hole at probe rod joints or well casing joints. Use a pipe wrench to snug the probe rod tool string and seal joints (**O-rings or equivalent must be used on all rod and casing joints**). If down-hole leaks cannot be sealed the pressure regulator and air supply may be used to stabilize **slow** leaks so that a successful slug test may be obtained. Install the regulator at the inlet valve and use the air supply to provide a steady air flow to offset small air leaks downhole.

*NOTE: An electric pressure/vacuum pump may be substituted for the manual pump for testing larger diameter/deeper wells and piezometers. Small 12V pumps (e.g. Cole Parmer model EW-79200-40) are convenient for operation in the field. Compressed gas cylinders may be used (e.g. air or N_2) but a regulator to reduce the pressure to <10 psi will be required. **Handling and transportation of compressed gas cylinders requires special safety precautions.** Review requirements with your supplier to assure compliance with DOT and local regulations.

**NOTE: the pressure regulator is only a 10 psi unit, applying excess pressure will damage the regulator.

8.0 Performing Slug Tests

Once leak testing is completed, the transducer zeroed and the file has been named (Sections 5, 6 & 7) you are ready to perform slug tests. Be sure to click on the **NOT SAVING** icon to begin **SAVING** so the data is saved to file (Figure 11).

The pressure required to perform a successful slug test is relatively low, not more than 1 to 2 psi (~7 to 14 kPa) maximum. Higher pressures and larger initial head values are generally not required to obtain a representative slug test as the calculated K value is independent of initial head magnitude (Butler 1997). (Larger H_o values may be preferred when unsaturated filter packs are present.) For underdamped (oscillatory) responses larger H_o values may actually result in attenuation of the test response and an under-estimation of K. Usually, H_o values between about 5 – 40 inches (~10 – 100 cm) of water pressure are used for pneumatic slug tests. For slow recovering overdamped responses (e.g. 15+ minutes) it may be useful to allow the test to recover only to about 90% before starting pressurization or evacuation for the next test, note this in the log book. For moderate to fast overdamped recoveries and all under-damped tests it is best to allow the formation to fully recover between tests. This is necessary so that accurate modeling and calculations can be obtained for these shorter duration tests.

To perform rising head tests install the pressure gauge on the pneumatic head and set the valve on the hand pump (600711) to pressure. For falling head tests install the vacuum gauge (Figure 13) on the pneumatic head and set the valve to vacuum on the hand pump.

Figure 13: Use the vacuum gauge to perform falling head tests or install the pressure gauge to conduct rising head tests and for leak testing.

Close the release valve (Figure B, cover) on the pneumatic head and pressurize or evacuate the well head to the desired H_o value. Close the inlet valve (Figure B). Allow the pressure to stabilize on the gauge and computer screen. Then **quickly** open the release valve to initiate the slug test. The slug test response is observed onscreen in real time (Figure 14). Note the difference in the response of the rising and falling head tests.

Basic field quality control may be performed by conducting repeat tests with the same initial head in the same data file (Figure 15). When this is done the operator can visually compare the peak height, symmetry, and recovery time of the repeat tests. If repeat tests with the same H_o value show noticeable differences in peak height, symmetry or recovery time it is an indication that further development of the well is required. Additional quality control may be obtained by performing repeat rising or falling head tests with differing H_o values (e.g. 10, 20 and 30 inches of water pressure). Later, these test responses can be normalized and overlaid to verify that the slug test responses were linear over the range of head values used to perform the slug tests. This also provides confidence that the results of the tests conform with the slug test model requirements (Butler 1997). Slug test procedures reviewed in this bulletin meet or exceed ASTM Standard Practice requirements (ASTM 2007a).
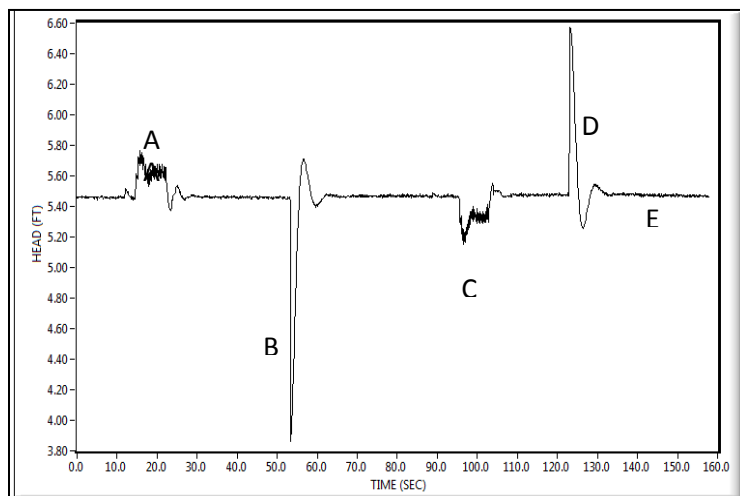
Figure 14: Performing a rising head test and then a falling head test. A: air pressurization peaks. B: rising head test. C: evacuation peaks. D: falling head test. E: stable baseline is about 5.46 ft (163 cm) for these tests, i.e. the static water level is that distance above the transducer sensor. These are examples of underdamped (oscillatory) tests.

Figure 15: Repeat of overdamped slug tests with approximately the same initial head value. These tests can be used for basic field QC. The H_o values were 20, 20 and 19 inches of water respectively. The similarity of peak height, symmetry and recovery time indicates that good quality tests were obtained. If noticeable variations occur between repeat tests further well development may be required.
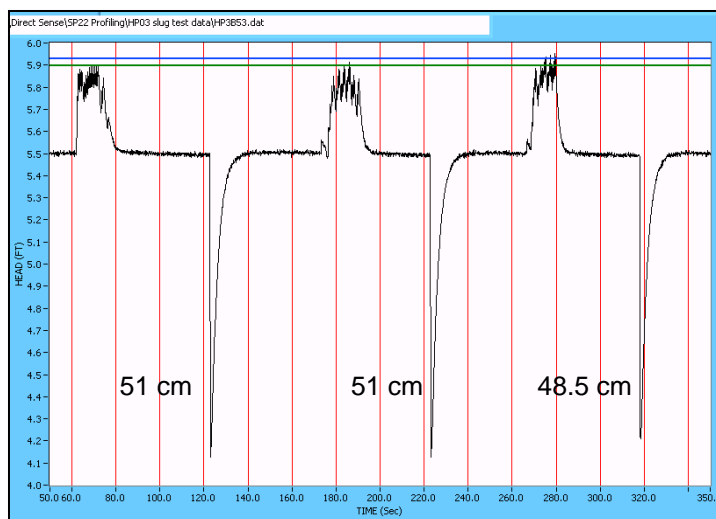
9.0 Document Test Parameters

The field team should document how the slug tests were performed in the field so that modeling and calculations can be performed correctly once the field work is completed. The slug test field data can be documented in a simple table or form (Figure 16).

Field information about the well construction geometry (Figure 17) and aquifer type (confined/unconfined) also will be required to complete modeling of the slug test data and calculation of the formation K.

Site: ABC Plating Corp
Well No: SP22A-53ft
Operator: Stephanie Jones
Date: Oct. 10, 2010   File: HP3A53

FileTime (sec)	H_o (in)	**R**ise **F**all	Notes
120	20	R	overdamped
220	20	R	Slow leak
320	40	R	Leak corrected
450	10	R	No leak
550	20	R	
50	30	F	New File = HP3B53
160	30	F	overdamped
280	10	F	
410	20	F	No leaks

Figure 16: Example table for documentation of slug testing information in the field. See page 14.

Geoprobe® Slug Test Field Information Form for Well Construction/Water Sampler Installation

Proj. Name: _____

Well #: _____

Date : _____

Operator: _____

File #s: _____

r_t =

R_c =

SWL =

TD =

L_w =

T_s =

h =

L_e =

L_s =

R_b =

R_c =

Impermeable Layer

Figure 17: Field form for use in documenting well or groundwater sampler construction that is slug tested. This data required so K value can be calculated. Copy for field use. See below for parameter definitions.

Parameter definitions for Figure 17:

Le = effective screen length   Ls = physical screen length

Lw = length of water column   Rs = screen radius

Rb = borehole/filter pack radius   Rc = casing radius

rt = radius of transducer cable   Ts = depth transducer submerged

SWL = static water level   TD = total well depth

h = saturated thickness of aquifer H_o = initial head change for slug test

In wells < 2 inch/50mm diameter the casing radius is corrected for the diameter of the transducer cable in the Slug Test Analysis software (see below). The corrected casing radius (Rcc) is calculated as follows:

$$Rcc = (Rc^2 - rt^2)^{1/2}$$ (after Butler et al. 2002)

10.0   Modeling and Calculation of K

Geoprobe® provides the user friendly Slug Test Analysis software package (GW1650 (214042): Geoprobe 2009b) with the kit. This is for modeling (Figure 18) and calculation of the formation hydraulic conductivity (K) with the kit. This package includes the Bouwer and Rice model (Bouwer and Rice, 1976) and the Hvorslev model (Hvorslev, 1951) for calculation of K. The software provides variants of these two basic models for confined or unconfined aquifers, partially or fully penetrating wells, and over or underdamped aquifer responses. A correction for oscillatory slug test responses in small-diameter wells (Butler 2002) also is included in the Geoprobe® analysis software.
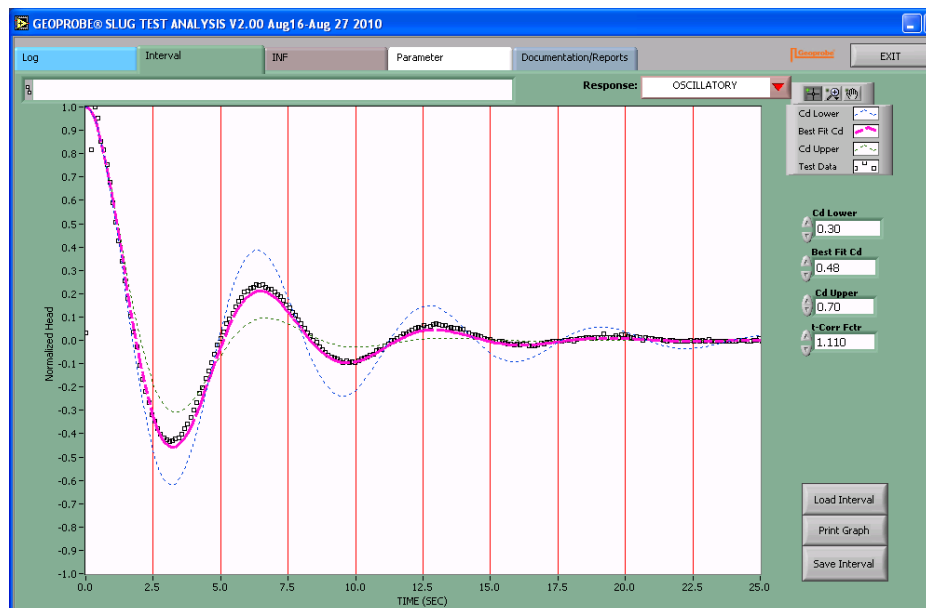

Figure 18: Modeling an underdamped slug test response with the Geoprobe® Slug Test Analysis Software package (GW1650).The software provides for input of well construction parameters, modeling and calculation of K with graphical print outs. The analysis software is included with the slug test kit.

11.0   References

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Geoprobe® Slug Test Field Data Form

Site Name: _____

Well No: _____

Screen Interval: _____

Operator: _____

Date: _____

File Name(s): _____

FileTime (sec)	H_o (in/cm)	**R**ise **F**all	Notes

MIP/HPT/EC/CPT log filename: _____

Sample Nos. _____

Aquifer Type: Unconfined   Confined   Leaky Confined   Perched

Screen Penetration: Full   Partial   Aquifer Thickness_____

Geologic Formation/Soils: _____

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your application, please contact Geoprobe® Systems.

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