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Standard Practice for
Direct Push Hydraulic Logging for Profiling Variations of Permeability in Soils[1]

This standard is issued under the fixed designation D8037/D8037M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This practice describes a method for rapid delineation of variations in formation permeability in the subsurface using an injection logging tool. Clean water is injected from a port on the side of the probe as it is advanced at approximately 2cm/s into virgin soils. Logging with the injection tool is typically performed with direct push equipment, however other drilling machines may be modified to run the logs by direct push methods (for example, addition of a suitable hammer and/or hydraulic ram systems). Injection logs exceeding 100 ft [30m] depth have been obtained. Direct push methods are not intended to penetrate consolidated rock and may encounter refusal in very dense formations or when cobbles or boulders are encountered in the subsurface. However, injection logging has been performed in some semi-consolidated or soft formations.

1.2 This standard practice describes how to obtain a real time vertical log of injection pressure and flow rate with depth. The data obtained is indicative of the variations of permeability in the subsurface and is typically used to infer formation lithology. The person(s) responsible for review, interpretation and application of the injection logging data should be familiar with the logging technique as well as the soils, geology and hydrogeology of the area under investigation.

1.3 The injection logging system may be operated with a built in electrical conductivity sensor to provide additional real time information on stratigraphy and is essential for targeting test zones. Other sensors, such as fluorescence detectors (Practice D6187), a membrane interface probe (Practice D7352) or a cone penetration tool (Test Method D5778) may be used in conjunction with injection logging to provide additional information. The use of the injection logging tool in concert with an electrical conductivity array or cone penetration tool is highly recommended (although not mandatory) to further define hydrostratigraphic conditions, such as migration pathways, low permeability zones (for example, aquitards) and to guide confirmation sampling. The EC log and injection pressure log may be compared in some settings to identify the presence of ionic contaminants or ionic injectates used for remediation.

1.4 The injection logging system does not provide quantitative permeability or hydraulic conductivity information. However, injection pressure and flow data may be used to provide a qualitative indication of formation permeability. Semi-quantitative values of permeability may be obtained by correlation of injection logging data with other methods (**1-4**).[2] Also, a log of estimated hydraulic conductivity (**5**) may be calculated for the saturated zone using an empirical model included in some versions of the log viewing software. The data allows for estimates of hydraulic conductivity (K) at the inch-scale using the corrected injection pressure and flow rate.

1.5 This tool is to be used as a logging tool for the rapid delineation of variations in permeability, lithology and hydrostratigraphy in unconsolidated formations. Direct push soil sampling (Guide D6282) and slug testing (Practice D7242) by means of groundwater sampling devices (Guide D6001) or direct push monitoring wells (Guide D6724 and Practice D6725) may be used to validate injection log interpretation, permeability and hydraulic conductivity estimates. Other aquifer tests (Guide D4043) in larger wells can also be used to obtain additional information about permeability and hydraulic conductivity. However, correlation of results from long screened wells with the fine detail of the hydraulic injection log data may be difficult at best due to the effect of scale in measurements of transmissivity (**6**).

1.6 All observed and calculated values shall conform to the guidelines for significant digits and rounding established in Practice D6026, unless superseded by this standard.

1.7 The values stated in either inch-pound units or SI units [presented in brackets] are to be regarded separately as standard. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in non-conformance with the standard.

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[1] This test method is under the jurisdiction of ASTM Committee D18 on Soil and Rock and is the direct responsibility of Subcommittee D18.21 on Groundwater and Vadose Zone Investigations.

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[2] The boldface numbers in parentheses refer to a list of references at the end of this standard.

1.8 *This practice offers a set of instructions for performing one or more specific operations. This document cannot replace education or experience and should be used in conjunction with professional judgment. Not all aspects of this practice may be applicable in all circumstances. This ASTM standard is not intended to represent or replace the standard of care by which the adequacy of a given professional service must be judged, nor should this document be applied without the consideration of a project's many unique aspects. The word "standard" in the title means that the document has been approved through the ASTM consensus process.*

1.9 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[3]

D653 Terminology Relating to Soil, Rock, and Contained Fluids

D1587 Practice for Thin-Walled Tube Sampling of Fine-Grained Soils for Geotechnical Purposes

D2434 Test Method for Permeability of Granular Soils (Constant Head) (Withdrawn 2015)[4]

D3740 Practice for Minimum Requirements for Agencies Engaged in Testing and/or Inspection of Soil and Rock as Used in Engineering Design and Construction

D4043 Guide for Selection of Aquifer Test Method in Determining Hydraulic Properties by Well Techniques

D5084 Test Methods for Measurement of Hydraulic Conductivity of Saturated Porous Materials Using a Flexible Wall Permeameter

D5088 Practice for Decontamination of Field Equipment Used at Waste Sites

D5092 Practice for Design and Installation of Groundwater Monitoring Wells

D5299 Guide for Decommissioning of Groundwater Wells, Vadose Zone Monitoring Devices, Boreholes, and Other Devices for Environmental Activities

D5778 Test Method for Electronic Friction Cone and Piezocone Penetration Testing of Soils

D5856 Test Method for Measurement of Hydraulic Conductivity of Porous Material Using a Rigid-Wall, Compaction-Mold Permeameter

D6001 Guide for Direct-Push Groundwater Sampling for Environmental Site Characterization

D6026 Practice for Using Significant Digits in Geotechnical Data

D6067 Practice for Using the Electronic Piezocone Penetrometer Tests for Environmental Site Characterization

D6187 Practice for Cone Penetrometer Technology Characterization of Petroleum Contaminated Sites with Nitrogen Laser-Induced Fluorescence

D6282 Guide for Direct Push Soil Sampling for Environmental Site Characterizations

D6724 Guide for Installation of Direct Push Groundwater Monitoring Wells

D6725 Practice for Direct Push Installation of Prepacked Screen Monitoring Wells in Unconsolidated Aquifers

D7242 Practice for Field Pneumatic Slug (Instantaneous Change in Head) Tests to Determine Hydraulic Properties of Aquifers with Direct Push Groundwater Samplers

D7352 Practice for Direct Push Technology for Volatile Contaminant Logging with the Membrane Interface Probe (MIP)

3. Terminology

3.1 *Definitions:*

3.1.1 Definitions are in accordance with Terminology D653.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *atmospheric pressure (P_{atm}), n*—relative to injection logging, the atmospheric pressure is measured with the down-hole pressure sensor during the reference test when no water is being pumped through the probe, the bottom valve is open on the reference tube, and the water level in the reference tube is stable.

3.2.2 *corrected injection pressure (P_c), n*—relative to injection logging, the corrected injection pressure is calculated by subtracting the measured atmospheric pressure (P_{atm}) and the piezometric pressure (P_{piezo}) from the total injection pressure (P_{tot}) at a specified depth increment (i). That is:

$$P_{c(i)} = P_{tot(i)} - \left(P_{atm(i)} + P_{piezo(i)}\right)$$

3.2.3 *dissipation test, v—relative to injection logging*, a test made by halting the advancement of the probe, shutting off injection flow, and recording the change (decay) in ambient formation pressure with time, also called a pressure dissipation test.

3.2.3.1 *Discussion*—When the excess pressure in the formation caused by water injection and probe advancement has fully dissipated then the observed pressure provides a measurement of the formation piezometric pressure (P_{piezo}) when the probe is below the water level. It is recommended to perform dissipation tests in higher permeability materials (sandy) so that dissipation occurs quickly to stability. Changing pressure in the formation (such as caused by a nearby extraction or injection well) will result in changing piezometric pressure over time. These conditions will influence the piezometric profile determined from dissipation tests.

3.2.4 *injection port, n*—relative to injection logging, a replaceable screened orifice approximately 0.4-in. [10mm] in diameter on the side of the HPT probe where water is injected into the formation as the probe is advanced into the subsurface.

3.2.5 *piezometric pressure (P_{piezo}), n*—relative to injection logging, the piezometric pressure is the stabilized pressure measured during a dissipation test when the probe is below the piezometric surface, the probe is not moving and no water is being pumped through the probe.

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[3] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[4] The last approved version of this historical standard is referenced on www.astm.org.

3.2.6 *total injection pressure (P_{tot}), n*—relative to injection logging, the total injection pressure is the pressure observed by the down-hole sensor as the probe is being advanced while water is injected into the formation through the injection port.

3.2.7 *trigger, n*—relative to injection logging, mechanical interface between the operator and instrumentation to initiate or terminate data collection.

3.3 *Symbols:*

3.3.1 P_c—corrected injection pressure.

3.3.2 P_{tot}—total injection pressure.

3.3.3 P_{atm}—atmospheric pressure, as measured with the down-hole pressure sensor during a reference test.

3.3.4 P_{piezo}—piezometric pressure (same as Hydrostatic Pressure, μ_o, D653)

3.4 *Acronyms:*

3.4.1 *HPT, n*—Hydraulic Profiling Tool (see 6.1)

3.4.2 *MIP, n*—Membrane Interface Probe

3.4.3 *CPT, v*—Cone Penetration Test

3.4.4 *EC, adj*—Electrical Conductivity

3.4.5 *LIF, n*—laser induced fluorescence

3.4.6 *OIP, n*—Optical Image Profiler

4. Summary of Practice

4.1 This practice describes the field method for performing an injection log. A steel probe is advanced through unconsolidated soils and sediments at approximately 2cm/s while clean water is injected into the formation through a screened port on the side of the probe. An in-line pressure transducer just above the port (or at the surface) measures the pressure required to inject water into the formation while a flow meter at the surface measures the rate of water injection. Drive rods are incrementally added to the tool string as the probe is advanced to depth using direct push methods. Injection logs exceeding 100 ft [30m] depth have been obtained. Total log depth is controlled by soil and formation conditions and equipment push capacity.

4.2 The injection probe may include an electrical conductivity (EC) array. This array is used to measure the bulk formation electrical conductivity as the probe is advanced to depth and provides independent, real time stratigraphy data during the testing. Sometimes injection probes are run with a companion cone penetration test (CPT) which provides tip resistance and sleeve friction data as the probe is advanced to depth (D6067). While neither an EC array nor a CPT module is required to run the injection log the additional independent data can be very useful to confirm the HPT log result and to provide additional valuable information about the subsurface.

4.3 An electronics system with portable computer and software acquires the injection pressure, water flow rate and bulk formation EC or CPT data as the probe is advanced. The pressure, flow and EC or CPT data are plotted on screen versus depth as the log is obtained for live time viewing and interpretation. The measured injection pressure and flow rate along with the EC or CPT data provides information about formation permeability, lithology and hydrostratigraphy.

4.4 At selected depths below the water table a pressure dissipation test may be conducted. Insertion of the probe into the formation and injection of water induces excess pore pressure as the probe is advanced. To conduct a pressure dissipation test probe advancement is halted and water flow is stopped. The down-hole pressure transducer is used to monitor decay of the excess pore pressure versus time. When the pore pressure stabilizes the pressure transducer is measuring the potentiometric pressure at that depth in the formation. This data may be used to calculate the local water level and piezometric profile. Often it is useful to conduct dissipation tests at several depths during a log, especially between possible confining layers. This may help to identify confined layers with different hydraulic head or vertical hydraulic gradients across a formation.

4.5 Logging is continued to the desired depth or until refusal is encountered. At that point data acquisition is stopped and the injection probe is retracted using the hydraulic system of the direct push machine.

5. Significance and Use

5.1 The injection logging system provides a rapid and efficient way to ascertain the pressure required to inject water into unconsolidated formations at the given flow rate in real time (Fig. 1) (**1-4**, **7**).[5] The measured injection pressure and flow rate are then used to assess variations in formation permeability versus depth and infer changes in formation lithology and understand the local hydrostratigraphy (**1-4**, **8-16**). Log interpretation should be confirmed with targeted soil coring adjacent to selected log locations or running logs adjacent to one or more previously logged borings.

5.2 The tooling system described below is one commercially available injection logging system called the Hydraulic Profiling Tool (HPT) and this standard follows the operating procedure for this system (**7**). Other permeability profiling tools have been and can be used for measuring the same or similar parameters related to formation permeability and hydraulic conductivity (**1-4**, **11**, **12**, **and** **17**). Most of these tools utilize one injection port on the probe and measure the injection pressure at the surface. When the injection pressure is measured at the surface correction for frictional losses in the water supply tube are required. These corrections will need to account for the length and diameter of the supply tube, flow rate, temperature and viscosity of the fluid, and whether the flow is laminar or turbulent in the supply tube (**1**). When the pressure measurement is made down hole at the port these corrections are not required (**5**, **7**). At least one type of hydraulic profiling tool uses two down-hole ports and pressure transducers to measure pressure changes induced in the formation by injection from a separate screen at discrete intervals (**17**). This system may be used to provide an injection pressure log and conduct tests to measure hydraulic conductivity at discrete intervals. At least two systems enable the operator to collect ground water samples at selected depths as the probe is advanced (**11**,**14**).

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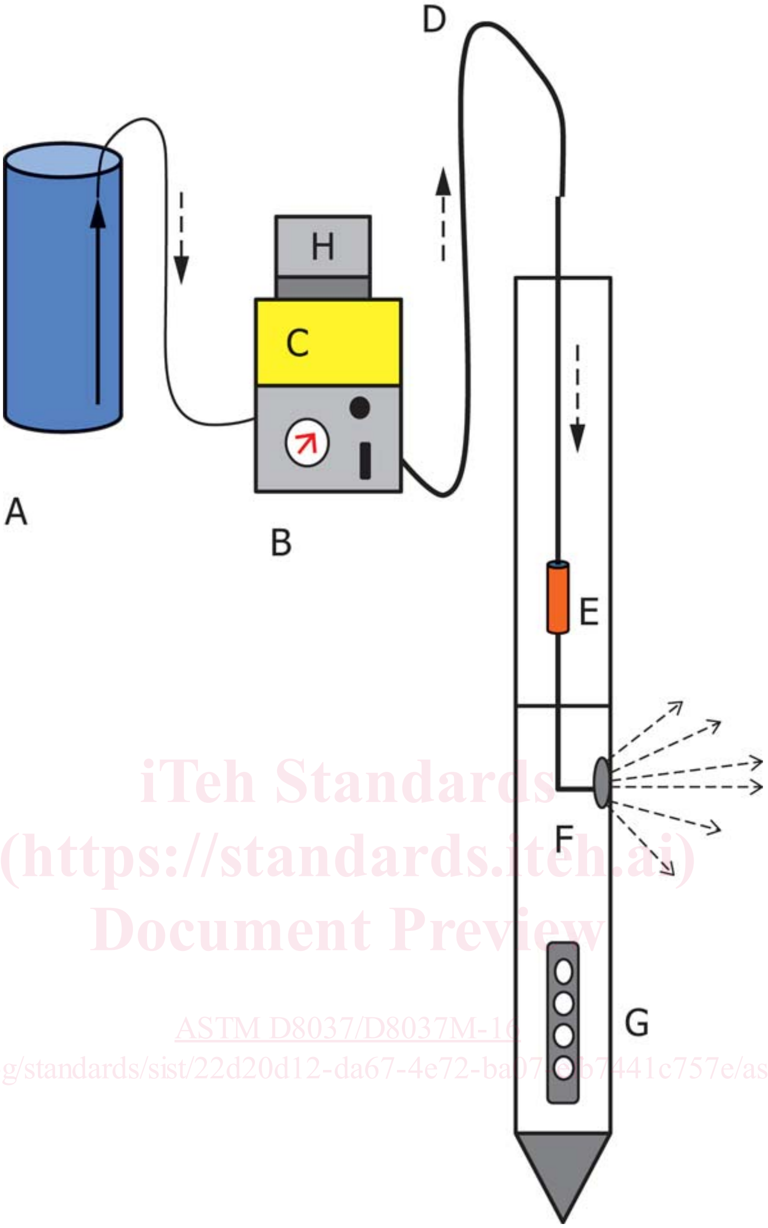
[5] The boldface numbers in parentheses refer to a list of references at the end of this standard.



The water container (A) provides water to the metering pump in the HPT flow module (B) and is pumped down hole via the trunkline (D) and through the inline pressure sensor (E) and out of the screened port (F) into the formation. As the probe is advanced at 2cm/s the inline pressure sensor (E) monitors the pressure required to inject water into the formation while the injection flow rate is measured with a flow meter in the flow module (B). The electrical conductivity array (G) simultaneously provides an EC log of the bulk formation as the probe is advanced. Analog signals are converted to digital output in the field instrument (C) and displayed on the computer screen (H) for live-time viewing in the field. Data is saved for later review and analysis.

FIG. 1 Schematic of an Injection Logging System, Demonstrating Principles of Operation

NOTE 1—Some early versions of the 2-port Permeameter suffered from anomalous K measurements when tests were conducted over small vertical intervals with significant changes in K over the decimeter to centimeter scale (**18**). More recent versions of the 2-port Permeameter overcome this limitation by measuring injection pressure from one port as the probe is advanced to verify homogeneity over the interval where quantitative K tests are performed (**17**). Additional work with driveable piezometers and injection logging tools has been conducted by several researchers (**19-23**).

5.3 Correlation of a series of injection logs across a site can provide 2-D and 3-D definition of variations in formation permeability, lithology and hydrostratigraphy (**2**, **8**, **9**, **13**, **14**, **15**).

5.4 Both contaminant migration pathways and low permeability zones (barriers) may be defined for environmental investigations. The injection logging system may be used to conduct water supply and groundwater resource investigations (**9**) or to evaluate sites for aquifer recharge (**14**) in appropriate geological settings. Some investigators use injection log data to assist in the development of groundwater models (**2**).

5.5 The data obtained from application of this practice may be used to guide soil (Guide D6282) and groundwater sampling (Guide D6001) or placement of long-term monitoring wells (Guide D6724, Practice D6725, and Practice D5092). The logs also may be used to select the location and screen intervals for water supply wells (**9, 14**) or dewatering wells.

5.6 The data can be used to optimize site remediation by knowing the depth and distribution of higher permeability zones and lower permeability zones. For example, the logs can guide where remediation fluids may be injected successfully or provide guidance about the required injection pressures.

5.7 The injection logging system may be configured with a soil electrical conductivity array (Fig. 1 and Fig. 2) for simultaneous logging of bulk formation electrical conductivity which also may be used to infer formation lithology or indicate changes in pore fluid ionic strength (**14, 15**). Alternately, the HPT system may be paired with a CPT probe to obtain information on soil/sediment types and strength of materials for foundation design (**24**). The HPT probe also may be coupled with a membrane interface probe for the detection of some volatile organic contaminants (Practice D7352) (**8**) or with a laser induced fluorescence (LIF) probe (D6187) or optical image profiler (OIP) (**25**) or fuel fluorescence detector probe (**26**) that uses ultraviolet light for the detection of fuels and related organic contaminants by fluorescence.

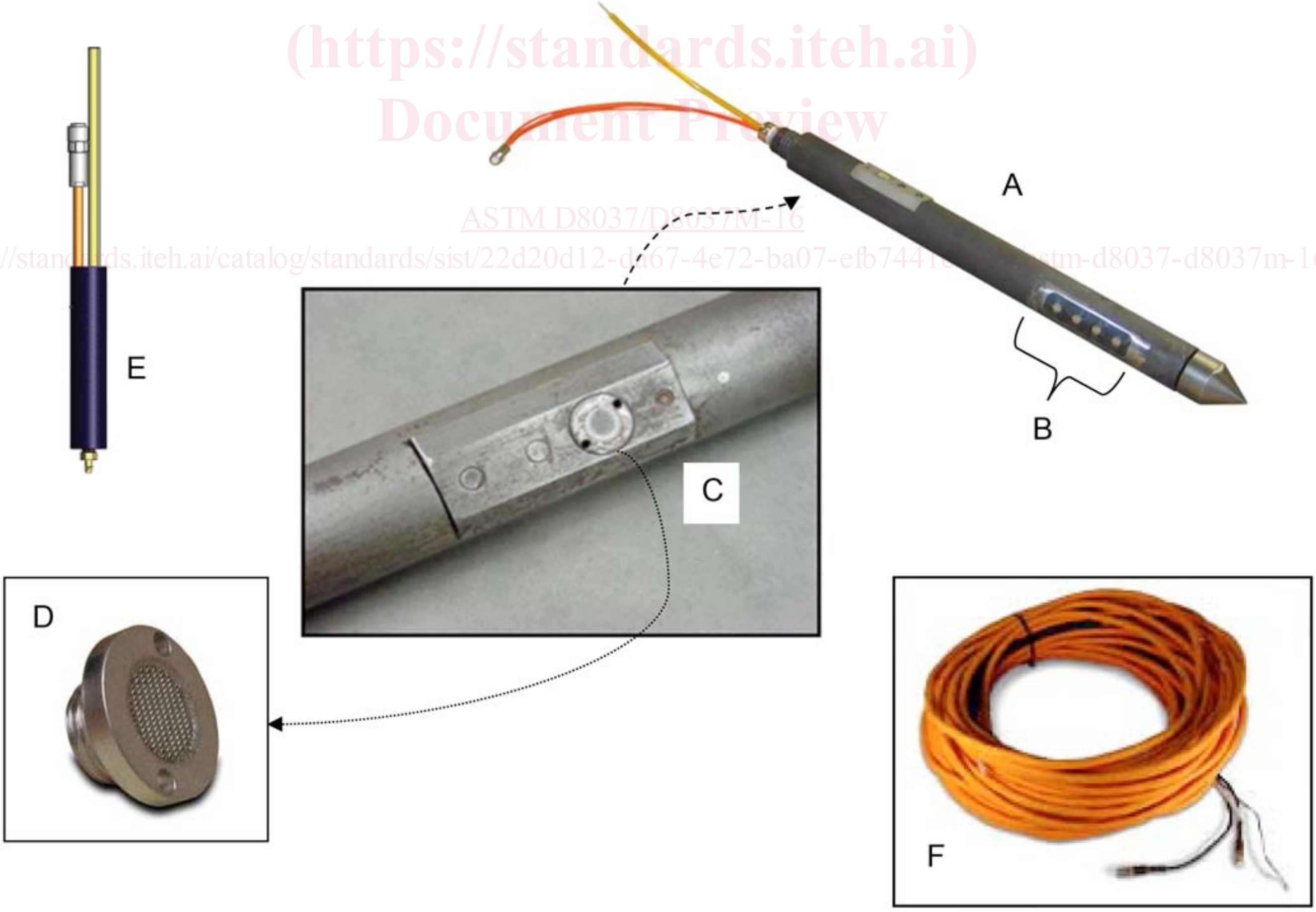
5.8 DP methods are not designed to penetrate consolidated rock (for example, granite, basalt, gneiss, schist, limestone or consolidated sandstone) and may have difficulty penetrating very dense formations (for example, highly compacted glacial tills) and heavily cemented soils (for example, caliche). Alluvial and glacial deposits with abundant cobbles and boulders usually cannot be penetrated. Other drilling methods can be used to pre-bore through surface obstructions and set surface casings.

NOTE 2—The quality of the result produced by this standard is dependent on the competence of the personnel performing it, and the suitability of the equipment and facilities used. Practitioners that meet the criteria of Practice D3740 are generally considered capable of competent and objective testing/sampling/inspection/etc. Users of this standard are cautioned that compliance with Practice D3740 does not in itself assure reliable results. Reliable results depend on many factors; Practice D3740 provides a means of evaluating some of those factors.

Practice D3740 was developed for agencies engaged in the testing and/or inspection of soils and rock. As such, it is not totally applicable to agencies performing this practice. However, users of this practice should recognize that the framework of Practice D3740 is appropriate for evaluating the quality of an agency performing this practice. Currently there is no known qualifying national authority that inspects agencies that perform this practice.

6. Apparatus

6.1 *General*—The following discussion provides descriptions and details for the Hydraulic Profiling Tool (HPT) and



A) injection logging probe, B) electrical conductivity array, C) screen mounted in probe, D) close up of removable screen, E) down-hole pressure sensor, F) trunkline

FIG. 2 Common Components of an Injection Logging Tool

system components (Fig. 1). Additional details on the HPT components and system described here are available in the manufacturer's operating procedure (**7**). Other injection logging systems may have different specifications and components.

6.2 *Hydraulic Profiling Tool*—A steel probe with a screened port on one side. The HPT screen allows for the injection of water into soils and unconsolidated formations as the probe is advanced steadily at a rate of approximately 2cm/s to depth. A down-hole pressure sensor monitors the total pressure required to inject water into the formation while simultaneously an up-hole flow meter measures the rate of water injection (Fig. 1).

6.2.1 The screen is set in a removable insert. It is constructed of stainless steel wire mesh and the orifice has a diameter of approximately 0.4-in. [10mm].

6.2.2 The down-hole pressure sensor operates in a pressure range of 10 psi to 100 psi [70kPa to 700kPa] with an accuracy rated at ±1 % full scale. Sensor accuracy at lower pressures generally exceeds manufacturer's specifications.

6.2.3 Plastic tubing is used to supply clean water to the screen. The tubing is usually included in the trunkline (Fig. 2).

6.3 *Trunkline*—This cable (Fig. 2) consists of electrical wires for the down hole pressure sensor, EC array and other optional probes or sensors (for example, CPT, MIP, LIF, OIP). The trunkline also contains the water supply line for the injection screen. This trunkline is packaged in a durable, protective jacketing and is pre-strung through the steel drive rods prior to logging.

6.4 *Pressure Sensor*—A replaceable pressure transducer assembly installed just above the injection probe in the tool string to measure the pressure required to inject water into unconsolidated materials while the probe is being advanced by direct push methods.

6.5 *Reference Tube*—A cylinder, closed on the bottom and open on the top, of specified height and diameter with a valve 6-in. [150mm] below the top edge of the cylinder. The injection probe is submerged under water in the reference tube to conduct a calibration check (reference test) on the down-hole pressure sensor.

6.6 *EC Test Jig and Test Load*—Devices used to perform the quality assurance test of the electrical conductivity array. Some arrays require only a test jig.

6.7 *Water Container*—A plastic or metal container, clean and free of any particulates or contaminants, used to hold at least 5 gallons [20 liters] of clean water. The water is pumped down hole to inject into the formation for injection logging.

6.8 *Flow Module*—The flow module (Fig. 3) is used to control and measure the rate of water flow delivered to the injection port. The water supply pump and flow meter are included in the module. A bypass line is included on the pump so when downhole pressure exceeds pump capacity flow bypass is permitted to prevent pump damage. An inline pressure sensor inside the module monitors the water pressure in the injection line (line pressure). A pressure gauge on the flow module allows for visual verification of the line pressure. A shut off valve on the module permits the operator to stop flow to the injection screen when desired (for example, during a pressure dissipation test).

6.9 *Field Instrument (FI)*—The primary function of this electronic component (Fig. 3) is to acquire the analog signals from the down-hole pressure sensor, flow meter, line pressure sensor, EC array and other optional down hole sensors and convert the signal to digital data for output to a laptop computer. The FI also supplies regulated voltage to the EC array for electrical conductivity logging.

6.10 *Laptop Computer*—A portable computer (Fig. 3) is used to acquire and display the digital log data on screen as the log is obtained using the data acquisition software. The data is saved for later review, plotting and reporting.

6.11 *Acquisition Software*—A software package designed to receive digitized HPT log data and plot it graphically on screen versus depth as the probe is advanced. Some software packages can display the injection pressure, water flow rate, electrical conductivity log, depth and rate of probe advancement as the log is obtained (**27**). The line pressure also may be displayed. Quality assurance tests also are performed with the acquisition software. Data for all of these parameters are saved in the log file.

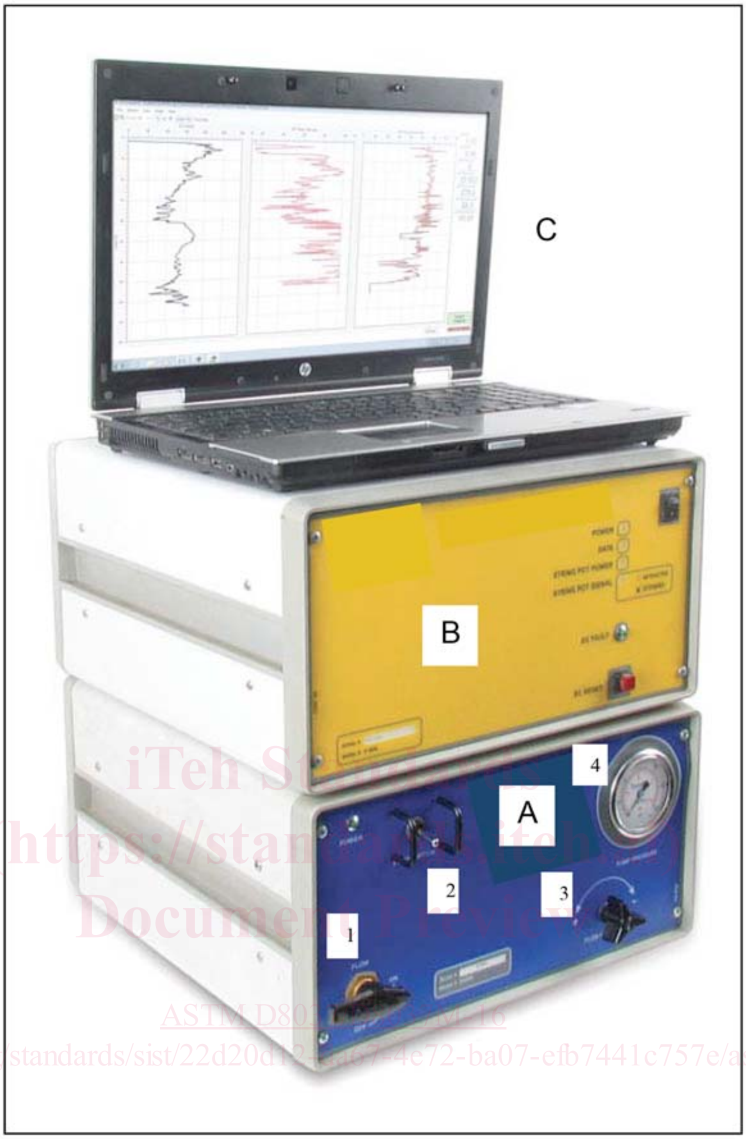
6.12 *Viewing Software*—A software package that allows the log file to be displayed graphically on screen and printed for reporting purposes from the saved acquisition file. Some software packages enable the user to review pressure dissipation test files to determine the piezometric pressure at the given depth and plot piezometric profiles (**28**). Some viewing software packages also may be used to create simple 2D cross sections from multiple logs. Log data also may be exported to other software programs for analysis and plotting and for creation of 2D and 3D representations of log data.

6.13 *Global Positioning System*—GPS connections for acquiring latitude and longitude coordinates of log locations are provided in some hardware/software systems. GPS data may be saved with the log file.

6.14 *Stringpot*—A depth measuring potentiometer (Fig. 4). It is mounted to the direct push machine or anchored to the ground. The stringpot transfers voltage to the data acquisition system as the length of the string changes during probe advancement. This allows for accurate measurement of the probe depth below ground surface and also rate of probe movement. When location elevations are surveyed elevations may be input to some viewing software packages to convert depth to elevation.

6.15 *Drive Rods*—Steel rods having adequate strength to sustain the force required to advance the probe into the subsurface. The rods are sequentially added to the tool string to advance the probe to depth. The trunkline is pre-strung through all rods before the logging process is started. Typical diameters for percussion probing applications are 1.5, 1.75 and 2.25 in. [38, 44 and 57mm]. When operated with a CPT system either 36mm or 44mm diameter CPT rods can be used.

6.16 *Direct Push Machine*—A track or vehicle mounted machine with hydraulic rams supplemented with vehicle



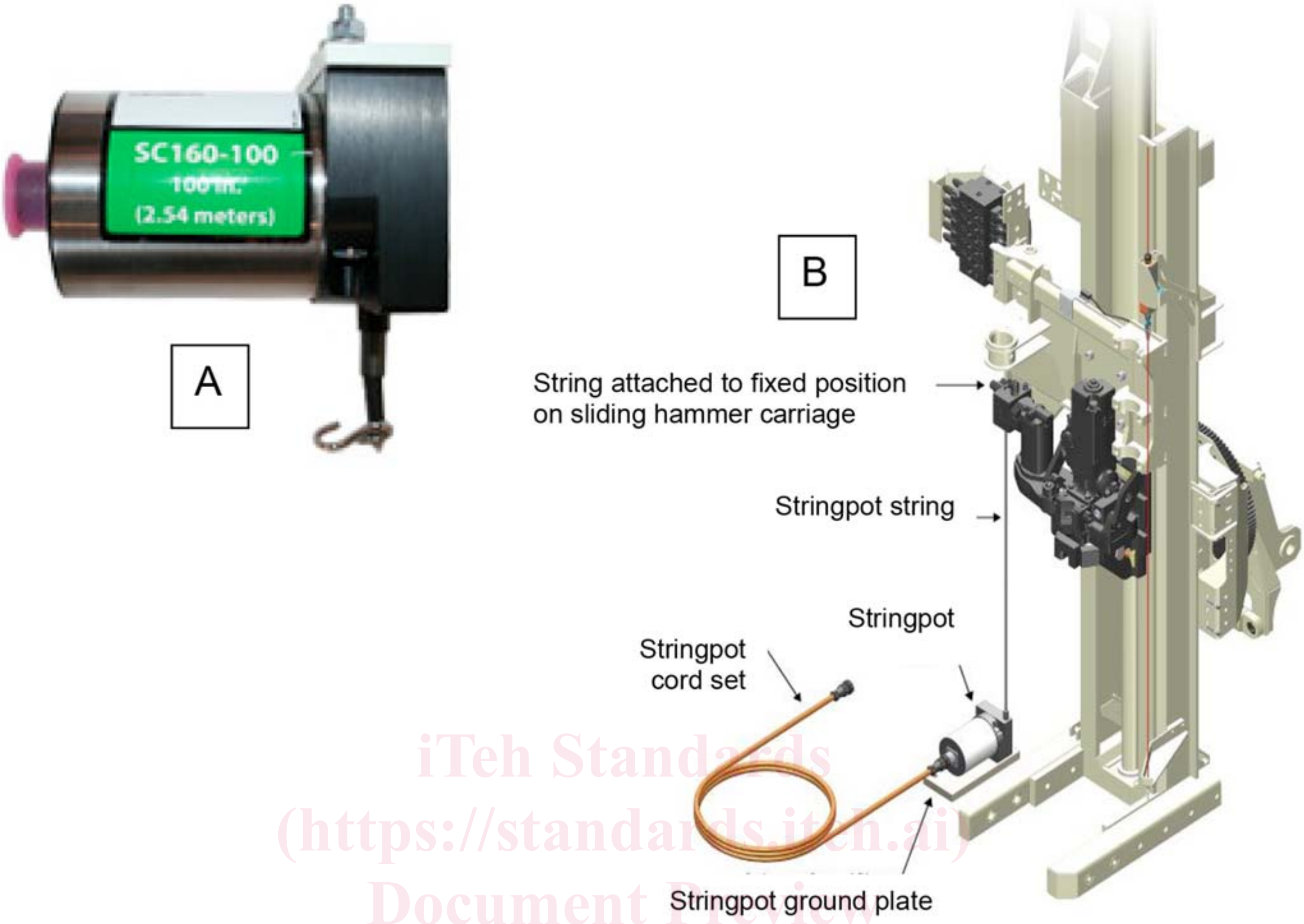
(A) The flow module, contains pump, flow meter and line pressure transducer:
  (1) flow shut-off valve
  (2) pump on-off switch
  (3) pump flow control valve
  (4) line pressure gauge
(B) Field instrument: converts analog signal to digital output for computer
(C) Laptop computer with acquisition and viewing software installed

FIG. 3 Common Electronic Components of an Injection Logging System

weight and/or a hydraulic hammer used to advance drive rods and tools into unconsolidated formations. Rotary drilling rigs can be modified to perform direct push advancement of tools and for injection logging, often by addition of a suitable direct push hydraulic hammer system and/or hydraulic rams. Depth of penetration is dependent on local formation conditions, but depths in excess of 20 to 30 meters are routinely achieved. Review site specific soil and geological data to determine if direct push logging is an appropriate method on a site-by-site basis.

7. Reagents and Materials

7.1 *Injection Fluid*—Clean water, free of any potential contaminants, is used for the injection fluid during injection logging. Distilled or de-ionized water may be used as the injection fluid if desired. Water is usually injected at a rate of 200mL/min to 300mL/min but higher or lower injection rates may be used if desired. For a typical 60 ft [20m] depth log about 10 to 15 gal [40 to 60L] of water is required. This includes continued flow during retraction of the probe that is



(A) Stringpot assembly.

(B) Anchoring the stringpot at ground surface and attaching the string to the sliding mast of the direct push machine to track depth as the probe is advanced into the subsurface.

FIG. 4 Stringpot Used to Track Probe Depth

required to keep the screen open and prevent damage to the down hole pressure sensor.

8. Preparation of Apparatus

8.1 *General*—The injection probe and logging system must be assembled and set up properly to obtain valid log data. Quality assurance tests must be performed before and after each log and at the end of the working day to verify pressure transducer and system performance. The following provides a brief overview of system preparation and QA test procedures for the HPT injection logging system, for complete details refer to the manufacturers operating procedure (7). If a different injection logging system is used follow the manufacturer's specifications for that system. At this time the HPT system is the only commercially available injection logging system.

8.2 *Regulatory Considerations*—Contact the appropriate state and local agencies to obtain drilling licenses and permits that may be required to conduct the logging operation. Local and state regulations also may control injection of clean water or any fluids into the subsurface. Contact the appropriate agencies to evaluate permitting requirements for injection of water or other fluids into the subsurface. Some agencies may require at least limited oversight during initial logging and water injection to verify procedures are acceptable. Water injection volumes may be below minimum reporting requirements in many jurisdictions.

8.3 *HPT System Assembly*—The following subsections provide a brief overview of the HPT probe and system assembly. Refer to the manufacturer's operating procedure (7) for complete details and guidance.

8.3.1 *HPT Probe to Trunkline Assembly*—The electrical conductivity and down-hole transducer connections are made after the trunkline is strung through the drive rods, probe drive head and connection tube (Fig. 5).

8.3.1.1 *Electrical Conductivity*—Thread the male and female connectors together. Snug the connectors gently and then wrap them with electrical tape as strain relief against vibration as the probe is driven to depth.

8.3.1.2 *Down-Hole Pressure Transducer*—Using appropriate tools and fittings connect the down-hole transducer to the water supply line (Fig. 5). Next connect the tubing at the top of the probe to the barb fitting on the base of the down-hole

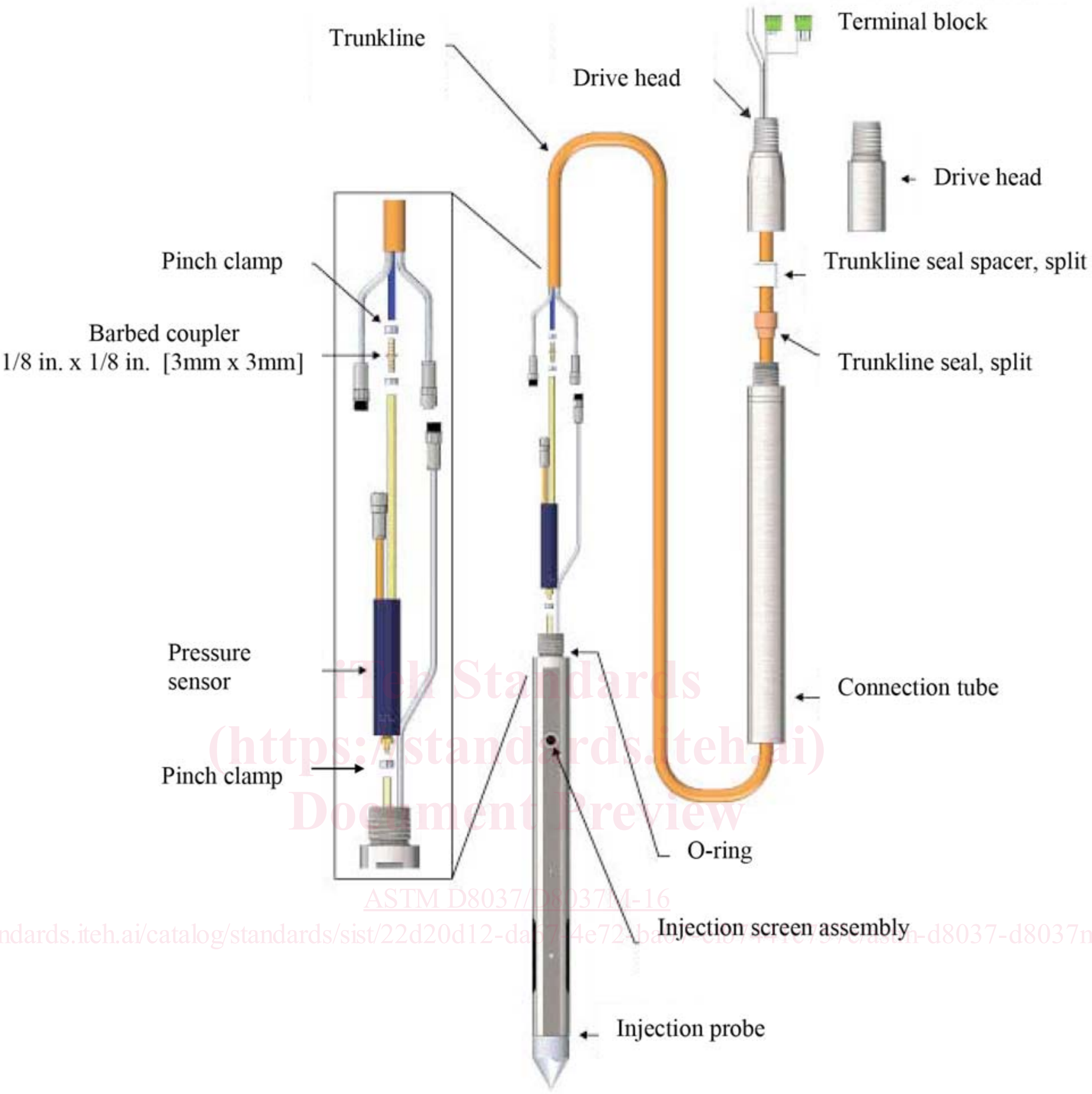


FIG. 5 Assembly of an Injection Logging Probe and Attachment to the Trunkline

pressure sensor. Before assembly cut the water supply tubing as required to prevent kinking of the tube during probe assembly and logging. Attach the electrical connector for the pressure sensor to the appropriate electrical connector at the end of the trunkline. Snug the connectors gently and then wrap them with electrical tape as strain relief against vibration as the probe is driven to depth.

8.3.1.3 *Seal and Probe Body Assembly*—Thread the connection tube onto the HPT probe (Fig. 5) being sure not to twist or kink the water supply tubes or damage any electrical connections. The water seal assembly is placed over the trunkline above the connection tube and below the drive head. Apply water to the seal to make assembling the drive head to the connection tube easier. Snug all threaded connections with pipe wrenches.

8.3.2 *Attach Trunkline to Flow Module and FI*—Connections between the trunkline and up hole electronics and water supply are made following manufacturers specifications.

8.3.2.1 *Down-Hole Sensor Connection*—The trunkline connection for the down-hole pressure sensor is installed in the receptacle on the back of the flow module. Refer to the manufacturer's operating procedure for details (7).

8.3.3 *Power and Communication Connections*—The power cords for both the FI and Flow Module are connected to a clean, grounded power supply. The power supplied by generators or landline must be properly grounded and free of excessive noise, both of which can impair signal integrity and quality. Connect the field instrument to the flow module using the serial cable between the ports on the back of each instrument. A USB cable is then used to connect the FI to a laptop computer in which the acquisition software has been installed.

8.3.4 *Stringpot Setup and Connection*—Anchor the string pot to the ground (Fig. 4) or use a machine specific bracket to attach the stringpot to the DP machine probe derrick. The string is then attached so that the string length changes as the HPT probe and tool string are advanced into the subsurface. Be sure string movement is free and unencumbered so depth tracking is accurate. The stringpot and string must be mounted so that if the DP machine foot is lifted off the ground during tool advancement depth is correctly tracked. The stringpot cable is then used to attach the stringpot to the field instrument for depth tracking.

8.4 *System Startup*—When all plumbing and electrical connections are completed initiate power to the flow module, field instrument and portable computer. Also start the injection pump to pump water into the trunkline and purge all air from the trunkline and probe plumbing and injection port.

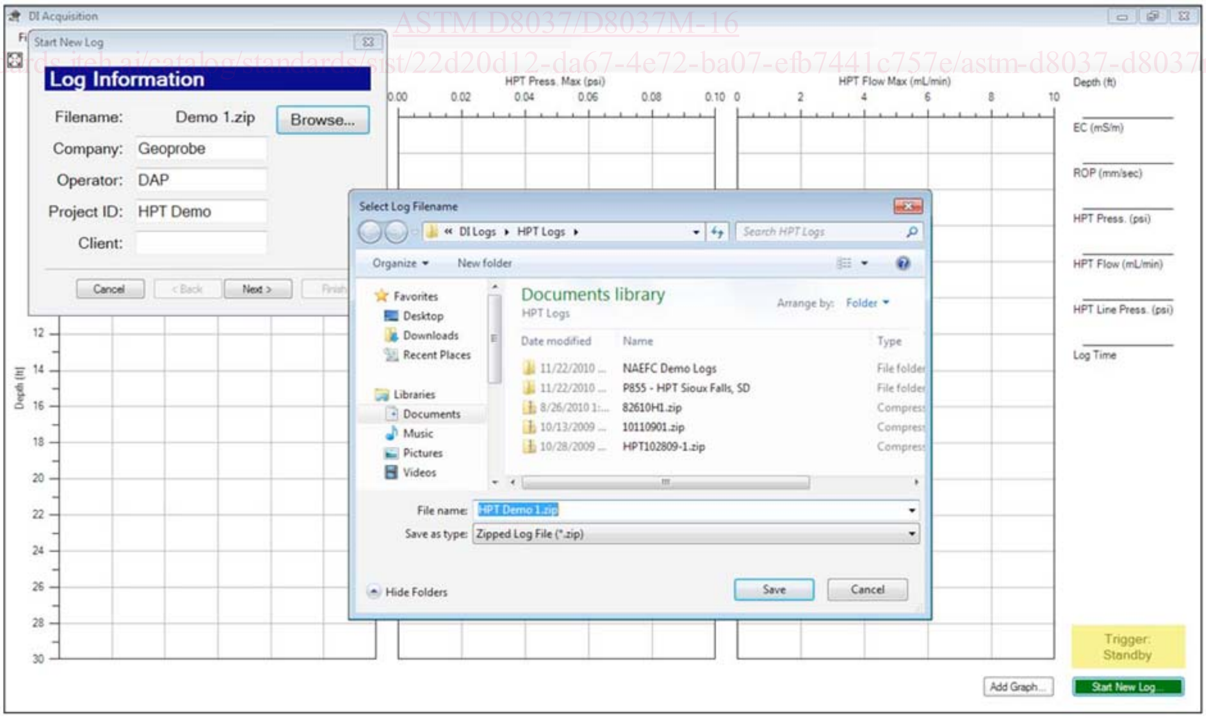
8.5 *Start Acquisition Software*—Initiate the acquisition software and start a new log (Fig. 6). Assign filename for the log and provide other requested information as prompted. Once the initial operating data is entered the software will then begin the quality assurance pre-log test sequence.

9. Quality Assurance Testing

9.1 The following steps outline the pre-log quality assurance tests required for the down-hole pressure sensor, EC array and EC system. For complete details refer to the manufacturer's operating procedure (7). If a different injection logging system is used follow the manufacturer's specification for that system. Both the EC array and the HPT pressure sensor circuits must be tested before and after each log to verify the log data is valid. If CPT or other sensors are run in tandem with injection logging then pre-log QA tests should be run on those systems.

9.2 *Electrical Conductivity QA Test*—Assemble the EC test load and test jig (Fig. 7) and attach the test jig to the EC array on the probe and perform the QA test as specified in the manufacturer's operating procedure. The QA test results are captured by the software and saved. If the readings are all within specified limits of the target values the EC array passes the QA test. If the system fails the QA test, then follow the onscreen instructions to select a dipole EC array for the probe. If the system indicates that no valid dipole arrays are available, then troubleshoot the system per the manufacturer's instructions and repeat the process until a valid EC array passes the QA test. For complete details refer to the manufacturer's operating procedure (7).

9.3 *Entry of System Operating Parameters*—Once the EC test is completed the acquisition software opens a window for the entry of operating parameters including the selection of the injection probe model, desired EC array (Wenner; top, middle or bottom dipole), rod length, string pot cable length, and down-hole sensor calibration data. Select the appropriate options and follow prompts in the software for adding calibration parameters for a new down-hole pressure transducer when required. If a new down-hole pressure sensor has been installed the calibration information for that sensor must be entered in the software to obtain accurate pressure data.



Log Information

Filename: Demo 1.zip
Company: Geoprobe
Operator: DAP
Project ID: HPT Demo
Client:

Date modified	Name	Type
11/22/2010 ...	NAEFC Demo Logs	File folder
11/22/2010 ...	P855 - HPT Sioux Falls, SD	File folder
8/26/2010 1:...	82610H1.zip	Compress
10/13/2009 ...	10110901.zip	Compress
10/28/2009 ...	HPT102809-1.zip	Compress

File name: HPT Demo 1.zip
Save as type: Zipped Log File (*.zip)

This is an example of one software system used for injection logging. Other similar systems may be used.

FIG. 6 Initiate Acquisition Software and Start New Log File to Prepare for Logging