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Standard Guide for Selection of Drilling Methods for Environmental Site Characterization[1]

This standard is issued under the fixed designation D6286; 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 guide provides descriptions of various drilling methods for environmental site characterization along with advantages and disadvantages associated with each method discussed. A comprehensive description of these drilling methods can be found in individual ASTM standards, see Section 2. This guide is intended to aid in the selection of drilling method(s) for environmental soil and rock borings and the installation of monitoring wells and other water-quality monitoring devices.

1.2 This guide does not address methods of well construction, well development, or well completion. These topics are covered in other ASTM documents, see Section 2.

1.3 This guide cannot address all possible subsurface conditions that may occur such as, geologic, topographic, climatic, or anthropogenic. Site evaluation for engineering, design, and construction purposes is addressed in Guide D420.

1.4 The values stated in SI units are to be regarded as the standard. Because dimensions of materials used in the drilling industry are given in inch-pound units by convention, rationalized inch-pound units also are used in this guide. Each system of units is to be regarded separately as standard.

1.5 This guide does not specifically address methods of lithologic sample collection, such as coring, that may require the use of a specific drilling method. Other ASTM guides should be consulted for sampling methods (see Guide D6169) and equipment necessary for specific projects.

1.6 This guide does not purport to comprehensively address all of the methods and the issues associated with drilling for environmental purposes. Users should seek qualified professionals for decisions as to the proper equipment and methods that would be most successful for their site investigation. Other methods may be available for drilling and qualified professionals should have flexibility to exercise judgment as to possible alternatives not covered in this guide. The guide is current at the time of issue, but new alternative methods may become available prior to revisions; therefore, users should consult with manufacturers or producers prior to specifying program requirements.

1.7 Pertinent guides addressing specific drilling methods, equipment and procedures are listed in 2.1. A comprehensive list of guides, methods, practices, and terminology for drilling is contained in Guide D5730. Other documents covering procedures for environmental site investigations with specific objectives or in particular geographic settings may be available from federal, state, and other agencies or organizations. The appropriate agency or organization should be contacted to determine the availability and most current edition of such documents.

1.8 *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.*

1.9 *This guide offers an organized collection of information or a series of options and does not recommend a specific course of action. This document cannot replace education and experience and should be used in conjunction with professional judgment. Not all aspects of this guide 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 consideration of a project's many unique aspects. The word "Standard" in the title of this document means only that the document has been approved through the ASTM consensus process.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D420 Guide to Site Characterization for Engineering Design

[1] This guide 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] 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.

***A Summary of Changes section appears at the end of this standard**

and Construction Purposes (Withdrawn 2011)[3]
D653 Terminology Relating to Soil, Rock, and Contained Fluids
D1586 Test Method for Penetration Test (SPT) and Split-Barrel Sampling of Soils
D1587 Practice for Thin-Walled Tube Sampling of Soils for Geotechnical Purposes
D2113 Practice for Rock Core Drilling and Sampling of Rock for Site Investigation
D2488 Practice for Description and Identification of Soils (Visual-Manual Procedure)
D3550 Practice for Thick Wall, Ring-Lined, Split Barrel, Drive Sampling of Soils
D5092 Practice for Design and Installation of Ground Water Monitoring Wells
D5730 Guide for Site Characterization for Environmental Purposes With Emphasis on Soil, Rock, the Vadose Zone and Groundwater
D5753 Guide for Planning and Conducting Borehole Geophysical Logging
D5781 Guide for Use of Dual-Wall Reverse-Circulation Drilling for Geoenvironmental Exploration and the Installation of Subsurface Water-Quality Monitoring Devices
D5782 Guide for Use of Direct Air-Rotary Drilling for Geoenvironmental Exploration and the Installation of Subsurface Water-Quality Monitoring Devices
D5783 Guide for Use of Direct Rotary Drilling with Water-Based Drilling Fluid for Geoenvironmental Exploration and the Installation of Subsurface Water-Quality Monitoring Devices
D5784 Guide for Use of Hollow-Stem Augers for Geoenvironmental Exploration and the Installation of Subsurface Water-Quality Monitoring Devices
D5872 Guide for Use of Casing Advancement Drilling Methods for Geoenvironmental Exploration and Installation of Subsurface Water-Quality Monitoring Devices
D5875 Guide for Use of Cable-Tool Drilling and Sampling Methods for Geoenvironmental Exploration and Installation of Subsurface Water-Quality Monitoring Devices
D5876 Guide for Use of Direct Rotary Wireline Casing Advancement Drilling Methods for Geoenvironmental Exploration and Installation of Subsurface Water-Quality Monitoring Devices
D6001 Guide for Direct-Push Ground Water Sampling for Environmental Site Characterization
D6151 Practice for Using Hollow-Stem Augers for Geotechnical Exploration and Soil Sampling
D6169 Guide for Selection of Soil and Rock Sampling Devices Used With Drill Rigs for Environmental Investigations
D6429 Guide for Selecting Surface Geophysical Methods
D6910 Test Method for Marsh Funnel Viscosity of Clay Construction Slurries

3. Terminology

3.1 *Definitions:*

3.1.1 For definitions of general terms used within this guide, refer to Terminology D653.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *borehole wall, n*—refers to the naturally-occurring soil(s)/rock(s) surrounding the borehole.

3.2.2 *kelly bar, n*—a formed or machined section of hollow drill steel used in rotary drilling, which is joined directly to the swivel at the top and to the drill pipe below. The flats or splines of the kelly engage the rotary table so that the rotation of the rotary table turns the kelly, which in turn, rotates the drill pipe and the rotary bit.

3.2.3 *mud rings, n*—soil or rock cuttings that form a ring or rings on the drill rod(s) during a rotary-drilling method, and as such, prevent drill cuttings from being carried up and out of the borehole. These rings can cause drill rods to become stuck in the borehole if sufficient drilling fluid is not injected or pumped downhole to keep the cuttings fluid so that the ring(s) cannot form on the drill rods and block the cuttings return as drilling progresses.

3.2.4 *orange-peel bucket or boulder catcher, n*—a bucket-type device, somewhat elliptical in shape resembling an orange peel, that is lowered down the borehole and used to remove boulders from the bottom of a borehole.

4. Significance and Use

4.1 The selection of particular method(s) for drilling monitoring wells (see Table 1) requires that specific characteristics of each site be considered. These characteristics would include, but are not limited to, the ambient hydrogeologic parameters and conditions existing at the site. This guide is intended to make the user aware of some of the various drilling methods available and the applications, advantages and disadvantages of each with respect to determining groundwater chemistry and other hydrogeologic properties data.

4.2 This guide can be used in conjunction with Guide D6169. There are several guides that deal with individual drilling methods (see Guides D5781, D5782, D5783, D5784, D5872, D5875, and D5876) and how to the complete them for water quality monitoring device installation (see Practice D5092).

5. Program Planning and Drilling Considerations

5.1 All factors affecting both surface and subsurface environment at a specific site requires professional judgment and must be considered by the geologist/hydrologist or experienced driller before a drilling method is selected. Significant soil and rock masses and groundwater conditions within a given site should be described and defined, both vertically and horizontally, before drilling. Site planning requires a reconnaissance site investigation that considers access to the drilling site and conditions for setting up the drilling equipment (**1**).[4] The extent of site characterization and specific methods used will be determined by study objectives. Study objectives also will affect the type and complexity of data collected. Sources of

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

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

TABLE 1 Well-Drilling Selection Guide

Drilling Method	Drilling Fluid	Casing Advance	Type of Material Drilled	Typical Drilling Depth, in m (ft)[A]	Typical Range of Borehole Sizes, in cm (in.)	Samples Obtainable[B]	Coring Possible	Reference Section
Power auger (Hollow-stem)	none, water, mud	yes	soil, weathered rock	<45 (150)	12.7–55 (5–22)	S, F	yes	6.2
Power auger (Solid-stem)	water, mud	no	soil, weathered rock	<45 (150)	5–25 (2–10)	s	yes	6.3
Power bucket auger	none, water (below water table)	no	soil, weathered rock	<45 (150)	45–120 (18–48)	S	yes	6.4
Hand auger	none	no	soil	<20 (70) (above water table only)	5–15 (2–6)	S	yes	6.5
Direct fluid rotary	water, mud	yes	soil, rock	>300 (1000)	5–90 (2–36)	S, R	yes	7.3
Direct air rotary	air, water, foam	yes	soil, rock	>460 (1500)	5–90 (2–36)	S, R, F	yes	7.4
DTH hammer	air, water, foam	yes	rock, boulders	<600 (2000)	10–40 (4–16)	R	yes	7.5.1
Wireline	air, water, foam	yes	soil, rock	>300 (1000)	7.6–15 (3–6)	S, R, F	yes	7.6
Reverse fluid rotary	water, mud	yes	soil, rock	<600 (2000)	30–90 (12–36)	S, R, F	yes	7.8
Reverse air rotary	air, water, foam	yes	soil, rock	>300 (1000)	30–90 (12–36)	S, R, F	yes	7.7
Cable tool	water	yes	soil, rock	<1500 (5000)	10–60 (4–24)	S, R, F (F–below water table)	yes	8
Casing-advancer	air, water, mud	yes	soil, rock, boulders	<600 (2000)	5–40 (2–16)	S, R, F	yes	9
Direct-push technology	none	yes	soil	Typical 6-7 (20-25) Maximum <30 (100)	3.8–7.6 (1.5–3)	S, F	yes	10
Sonic (vibratory)	none, water, mud, air	yes	soil, rock, boulders	<150 (500)	10–30 (4–12)	S, R, F	yes	11
Jet percussion	water	no	soil	<15.0 (50)	5–10 (2–4)	S	no	12
Jetting	water	yes	soil	<15 (50)	10 (4)	S	no	12

[A] Actual achievable drilled depths will vary depending on the ambient geohydrologic conditions existing at the site and size of drilling equipment used. For example, large, high-torque rigs can drill to greater depths than their smaller counterparts under favorable site conditions. Boreholes drilled using air/air foam can reach greater depths more efficiently using two-stage positive-displacement compressors having the capability of developing working pressures of 12 to 17 kPa (250 to 350 psi) and 14 to 21 m^3/h (500 to 750 cfm), particularly when submergence requires higher pressures. The smaller rotary-type compressors only are capable of producing a maximum working pressure of 6 kPa (125 psi) and produce 14 to 34 m^3/h (500 to 1200 cfm). Likewise, the rig mast must be constructed to safely carry the anticipated working loads expected. To allow for contingencies, it is recommended that the rated capacity of the mast be at least twice the anticipated weight load or normal pulling load.
[B] Soil = S (Cuttings), Rock = R (Cuttings), Fluid = F (some samples might require accessory sampling devices to obtain).

data that may be useful during initial site evaluation include, but are not limited to, topographic maps, aerial photography, satellite imagery, information from reconnaissance drilling, borehole geophysical-log data, geologic maps and reports, statewide or county soil surveys, water-resource reports, well databases, and mineral-resource surveys covering the proposed project area. Available reports of surface and subsurface investigations of nearby or adjacent projects should be considered and the information applicable to the current project evaluated and applied if determined reliable and beneficial. Site-specific surface geophysical surveys (2-5) and direct-push methods for soil and groundwater data collection (see Guide D6429 and Guide D6001) also may be useful for planning drilling locations.

5.2 Site investigations for the purpose of determining the specific placement locations of monitoring-well installations can vary greatly due to the availability of reliable site data. The general procedure, however, is as follows. First, gather factual information and data regarding the surface and subsurface conditions, then analyze the data for completeness and reliability, develop a conceptual framework or model of the site, and locate the monitoring wells based on information from the first three steps. To the extent possible, monitoring wells should be installed with an understanding of the ambient hydrogeologic site conditions. Monitoring wells often serve as part of an overall site investigation for a specific purpose, such as determining the chemical quality of the water, gaining insight into hydrochemical processes, or for predicting the effectiveness of aquifer remediation. In these cases, extensive additional geotechnical and hydrogeologic information may be required.

5.3 If the monitoring well also is to be sampled for water quality during the drilling process, the possible damage and subsequent aquifer contamination caused by drilling-fluid invasion of the borehole wall that may occur during drilling must be considered. For installation of monitoring wells designed for water-sample collection, preferred drilling methods are those that do not require the use of a drilling fluid, or if a drilling fluid is used, result in little or no drilling-fluid invasion of the borehole wall. Drilling-fluid invasion of the borehole wall normally results from the use of a poorly-controlled and improperly-designed drilling-fluid program.

5.4 Drilling methods that advance the casing as drilling proceeds are very effective methods to minimize the effects of drilling-fluid invasion of the borehole wall. Casing-advance drilling methods include, or can be used with, cable-tool drilling, hollow-stem auger drilling, reverse-circulation drilling using dual- or triple-wall drill pipe, fluid- and air-rotary drilling, rotosonic drilling methods, and driven wells. If the tendency of this method is to overream the hole, contamination may move along the casing during drilling.

5.5 Drilling methods that do not use a drilling fluid are preferable because they preclude possible aquifer contamination from such fluids. Such drilling methods that normally preclude the use of drilling fluids include hollow- and solid-stem auger drilling, hand auger drilling (only an effective shallow-drilling method when used to drill above the water table), bucket auger drilling, resonant sonic-drilling method, and cable-percussion drilling methods. Methods that normally require the use of a drilling fluid for drilling include jet-wash and jet-percussion drilling, reverse-circulation drilling, and fluid- and air-rotary drilling. In cases where drilling-fluid loss occurs during drilling, estimates of the amounts of fluid loss and depth(s) of these occurrences in the borehole should be documented. Drilling-fluid loss data may be useful in planning well-development techniques to be used upon completion of the borehole. Another important factor to be considered when evaluating this data is well-screen placement.

5.6 If drilling methods are not properly performed, poor quality samples, borehole damage, or poor quality monitoring-well installation(s) may result. It has been shown that improper drilling, particularly when drilling in unconsolidated materials (soils), can cause borehole damage. Preferential seepage paths can be formed close to the borehole by washing fine particles and creating "draining chimneys" that can be very difficult to seal (**6-8**). Drilling damages to the borehole usually are more severe in boreholes drilled in unconsolidated materials than those occurring in boreholes drilled in consolidated materials (rock). Although documentation of these occurrences is rare, it does occur. Occurrences of this nature are probably due to poor drilling-fluid control, poor drilling practice by an inexperienced driller. Damage can occur by drilling too hastily, and by use of incorrect speeds, pressures, and other variables controlled by the driller. Any drilling method using a circulating media to control cuttings removal can cause hydraulic fracturing of the drilled materials if too high of drilling rate or circulation pressure is applied.

5.6.1 Water without additives is not effective as a drilling fluid for two reasons, first, it does not have any cuttings-carrying capacity, having a Test Method D6910 Marsh-funnel viscosity of only 26 s, and secondly, it does not possess any gel-strength properties for building a mud rind on the borehole wall, allowing for borehole wall collapse, differential sticking of the drill tools to the borehole wall, and creation of "draining chimneys" due to fluid invasion and internal erosion of the borehole wall (**1, 9**). Also, water containing only natural clays should not be used as a drilling mud. This fluid mixture, containing only natural clays and water, will make only a heavy, clay-laden fluid that will not have the capacity (viscosity) to carry the drill cuttings uphole and will not make a thin mud rind on the borehole wall to inhibit its collapse (lack of gel strength). Instead, it will allow washouts of the borehole wall, fluid and clay penetration into the borehole wall, and perhaps, cause differential sticking and loss of the drill tools in the borehole. Channeling and chimneys of sand also can result in the borehole wall allowing preferential seepage paths close to the borehole.

5.6.2 When air-rotary drilling, downhole air pressures should be maintained and documented carefully. Uphole (return) air pressure(s) should be adequate to maintain cuttings removal from the borehole but not excessive enough to cause hydraulic fracturing of the materials being drilled. Such practice can result in a damaged borehole wall and the inability to form a proper seal between casing and the borehole wall in the completed installation. Borehole contamination, such as those discussed can occur (**1, 9**).

5.7 The practice of incremental drilling and sampling, using temporary casings through separate aquifers, can result in cross-contamination. To avoid or minimize the possibility of borehole cross-contamination or leakage from occurring whenever an aquitard or impermeable confining layer of material is drilled through, using any drilling method or a combination thereof, the following technique is suggested, particularly when drilling under saturated conditions. The impermeable material should be drilled into but not completely through. Casing should be installed into the impermeable material and pressure cemented/grouted into place. After the cement/grout has adequately cured, the material remaining in the casing can be drilled out. Borehole geophysical methods then can be used to evaluate the seal between the borehole annulus and the wall of the casing. After an acceptable seal has resulted, drilling completely through the confining layer can be done. Continue drilling/sampling/coring operations until the desired borehole depth has been reached. If other confining layer(s) are to be drilled in the same borehole, the above technique(s) can be followed. The next casing installed should be the next smaller size to the previously-installed casing (**9**).

5.8 Some methods that can be used in order to assess the hydraulic integrity of the borehole or a subsequent installation include the following.

5.8.1 *Indirect Method(s):*

5.8.1.1 Selected borehole geophysical logging methods (**10-12**).

5.8.1.2 Introduction of tracer(s) to the borehole combined with pumping tests (**13**).

5.8.2 *Direct Method(s)* (**6**, **7**)*:*

5.8.2.1 Pumping test(s) of the borehole.

5.8.2.2 Injection test(s) of the borehole.

5.8.2.3 Inflatable-packer testing of the borehole.

5.9 Ultimately, selection of a drilling method from several possible methods must be made only after weighing all of the advantages and disadvantages of each method against data-collection objectives. In some cases, a drilling method that minimizes the potential for subsurface contamination by the drilling process might limit the types of other data that can be collected, for example, borehole-geophysical data, from the well.

5.9.1 Geophysical surveys also should be used, when possible, to aid in the selection of a drilling method. Surface geophysical methods, such as seismic surveys and electrical-resistivity and electromagnetic-conductance surveys, can be valuable particularly when distinct differences in the properties of contiguous subsurface materials are indicated (**3**, **4**, **14**, **15**). Borehole-geophysical methods, such as fluid temperature and resistivity, natural gamma, gamma-gamma, neutron, sonic-velocity logging, caliper logging, and borehole televiewer logs (fracture logging), are useful to confirm specific subsurface geologic conditions. Borehole television logs allow a visual study of existing borehole-wall conditions, as well as viewing casing conditions in a cased borehole. Acoustic borehole televiewer logs can exhibit fracturing in the borehole. The orientation of the fractures, as well as the extent of fracture occurrence, can be determined using acoustic televiewer logs. Natural gamma logs, when used in conjunction with original driller's logs, are useful particularly for determining lithology in existing cased wells. Guide D5753 and the following references provide additional information on use of geophysical logging techniques (**4**, **8**, **10**–**11**, **16**–**17**). All of these data can play an important part in selecting a drilling method that can provide the best samples and most successful monitoring-well installation under the ambient hydrogeologic field conditions.

5.10 The advantages and disadvantages of the various drilling methods presented in this guide will vary depending on site-specific characteristics and project circumstances. Drilling depth and borehole diameters shown in Table 1 are nominal values for the method and may vary for specific cases or conditions.

5.10.1 The planning of the type(s) of drilling equipment to be used on the project should include sampling requirements and well-completion requirements consideration(s). For instance, grouting and placement of well screen(s) are common well-completion requirements, and the ability to accomplish either of these is dependent greatly on the type of equipment used. The accomplishment of satisfactory hole-abandonment procedures, as well as the ease at which any particular drilling equipment can be decontaminated also are important factors to be considered.

5.11 When using a drilling method that requires use of a drilling fluid, it is recommended that a controlled drilling-fluid program be employed in order to minimize possible drilling-fluid invasion effects on the borehole and cores obtained (**9**, **18**). Auger drilling tends to smear fine-grained sediment cuttings onto the borehole wall during the rotation of the auger flights. Cable-tool drilling can cause borehole damage by the cyclic upward and downward surging motion of the drill bit, which can force fine-grained sediment into the borehole wall. Soil compaction resulting from driving the casing also can occur in a cable-tool drilled borehole. Although reverse-circulation drilling commonly is considered a clean drilling method, invasion of fine-grained sediment into the borehole wall can occur because of the high positive hydrostatic head that must be maintained in the borehole during drilling. Also, if drilling mud or other additives are used in the reverse-circulation drilling method, borehole damage can occur. Air-rotary drilling methods also may damage the borehole by introducing air into the drilled materials or fracturing of the borehole wall if drilling air pressures are not closely monitored and are allowed to exceed the downhole pressure necessary to adequately keep the borehole free of cuttings.

5.12 Choice of drilling methods may differ depending on whether the data-collection objective is for hydrogeologic characterization or for groundwater quality sampling or not. For example, fluid-rotary drilling methods are good drilling methods to use for determining subsurface lithologic characterization because most borehole electric and sonic geophysical-logging tools require uncased fluid-filled boreholes. The same drilling methods, however, are less desirable for installation of water-quality monitoring wells because of the possible drilling-fluid effects on groundwater chemistry. Nevertheless, fluid-rotary drilling may be the method selected after considering the advantages and disadvantages of other drilling methods.

5.13 Selection of a drilling method must consider all aspects of monitoring-well installation, including casing materials and composition, screen(s), subsurface monitoring equipment and installation(s), grouting materials and placement procedure(s), as well as any other plans for well completion and development. For example, when a drilling method is used that might affect groundwater chemistry, the well development required to remove artifacts of the drilling can be intensive, time consuming, and affect water chemistry.

5.13.1 The drilling method selected must be practical logistically, and to the extent possible, minimize mechanical damage to the borehole. Local availability of a particular type of drilling rig/equipment also will be an extremely important factor to be considered before a drilling method can be selected. For instance, the availability of cable-tool rigs might be totally out of the question in some parts of the country where primarily rotary-type drilling methods are most prevalent because of the type(s) of drilling conditions in those areas. In addition, information on the geohydrology of the subsurface system might be required and can be obtained possibly by means of sampling during drilling or subsequent borehole-geophysical logging, or a combination of both methods. Final selection of a drilling method, therefore, should be made only after due consideration of all project objectives (**19**).

6. Auger-Drilling Methods

6.1 Auger-drilling methods include using hollow-stem continuous-flight augers, solid-stem continuous-flights augers, bucket augers, and hand-augers. All auger-drilling methods are limited usually to drilling in unconsolidated soils or weathered rock. Auger-drilling methods normally do not require the use of a drilling fluid during the drilling process; however, in cases where water-bearing sands or silts are drilled, the addition of water or drilling mud to the hollow-auger column may be necessary to inhibit the "blow in" of these fluid-like materials into the augers (see Guide D5784). The borehole is advanced by pushing the initial auger-column assembly below ground surface and initiating a low-velocity rotation to the auger flights or bucket-auger assembly. The lead auger section is equipped with a removable cutting head. The bucket auger, on the other hand, has hard-surfacing material around the bottom cutting edge of the bucket. As drilling progresses, auger flights or kelly rods, in the case of a bucket auger, are added to the drill stem until the desired depth is reached. The continuous auger flights carry drill cuttings to the surface.

6.2 *Hollow-Stem Auger Drilling*—The hollow-stem continuous-flight auger drilling method can be used for the installation of monitoring wells (see Practice D6151. The hollow auger flights serve as a temporary casing, which prevents caving and sloughing of the borehole wall while the monitoring-well casing is installed through the hollow auger (see Guide D5784). The hollow-stem auger-drilling method also allows for the utilization of the hollow-stem auger column as a casing for subsequent drilling activities in soils or rock (see Practice D2113). Borehole diameters up to about 55-cm (22-in.) can be drilled using hollow-stem augers. A monitoring-well casing can be installed through the hollow stem auger (auger I.D. up to 30-cm (12-¼-in.) available for insertion of casing or other instrumentation) once drilling is complete and prior to removing the augers from the borehole.

6.2.1 Soil sampling, using a split-barrel sampler, ring-lined barrel sampler (see Practice D3550), or thin-walled tube sampler (see Practice D1587), is accomplished during drilling by using a continuous sampler in the hollow-stem that advances with the auger flight or by a pause in drilling, driving, or pushing the sampler into the undisturbed material beyond the cutting head, and retrieving the sample before resuming drilling (see Test Method D1586 and Practices D1587 and D2488). The continuous auger flights carry drill cuttings to the surface. Soil samples also can be obtained during drilling, either as return by the auger flights or by pulling the augers and sampling the sediment stuck to the auger flights, but such samples are less satisfactory because the soil is disturbed and moved from the location of drilling and exposed to other soil stratum. Samples of this nature generally are not considered appropriate for chemical analysis. Groundwater samples can be obtained during drilling using a screened hollow-stem auger section. Direct-push methods also can be used in advance of the lead auger during drilling pauses to collect either fluid or soil samples or both.

6.2.2 Continuous hollow-stem soil-coring equipment consists of a rotating outer hollow-stem auger with a cutter-head bit at the bottom and a nonrotating inner sample barrel equipped with a smooth cutting shoe at the bottom (see Practice D6151). Some continuous hollow-stem auger sampling systems have a centralizer bushing mounted in the cutter head. The sampler is suspended in the hollow-stem auger column and retained in a stationary position by means of a bearing-assembly apparatus located either down the hole above the sampler assembly or located at the top of the hollow-stem auger column. The sample barrel cutting shoe is extended beyond the hollow-stem auger cutter-head bit in varying increments. The distance that the sample barrel cutting shoe is adjusted out beyond the hollow-stem auger cutting head is dictated by the stiffness of the material to be sampled (cored). The softer the soil to be cored, the greater the "lead" distance adjustment or cutting-shoe extension should be. The harder the soil to be cored, the shorter the lead-distance adjustment should be. When the sampler cutting shoe is extended beyond the hollow-stem auger, cutter-head bit the cutting edge of the sampler cutting shoe is forced into the soil ahead of the hollow-stem cutter head bit before the hollow-stem auger cutter-head bit cuts the soil away. The hollow-stem auger column and cutter-head bit rotates around the soil-coring barrel as the drill rig applies an axial force and rotation to the hollow-stem auger soil-coring column assembly.

6.2.3 *Advantages:*

6.2.3.1 Normally, precludes use of drilling fluids.

6.2.3.2 Auger drilling does not require the use of lubricants.

6.2.3.3 Continuous sampling possible during drilling using continuous sampler, split-barrel, or thin-walled samplers.

6.2.3.4 Continuous samples of groundwater can be collected during drilling, using screened auger flight(s).

6.2.3.5 The hollow-stem auger column can be used for subsequent drilling activities in soils or rock materials (see Practice D2113).

6.2.3.6 Auger-drilling equipment is relatively mobile.

6.2.3.7 Drilling is moderately fast.

6.2.4 *Disadvantages:*

6.2.4.1 Pressure equalization of water-bearing sands or silts and "blow in" of these fluid-like materials into the hollow-stem auger column can be a problem requiring use of fluid in the hollow auger to equalize the pressure head and keep the intrusive fluid-like materials from entering the hollow auger.

6.2.4.2 Soil samples returned by auger flight are disturbed, making it difficult to determine the precise depth from which the sample(s) came.

6.2.4.3 Upward vertical mixing of augered cuttings can occur.

6.2.4.4 Borehole wall can be smeared by previously-drilled clay.

6.2.4.5 Gravel pack and grout seal may be difficult to install.

6.2.4.6 Borings limited to relatively shallow depths in normal soils and soft rock.

6.2.4.7 Difficult drilling in extremely dry, fine materials, for example, playa-lake deposits.

6.2.4.8 Hollow-stem auger drilling difficult in saturated soils and soils containing very coarse gravels, cobbles, or boulders.