NVEnergy

November 5, 2015

Nevada Division of Environmental Protection
NDEP - Bureau of Corrective Actions
901 S Stewart St
Carson City, NV 89701
Attn: Alison Oakley

Re: NV Energy
Reid Gardner Station
PA-2, PA-3 and PA-5-7 Groundwater and Soil Characterization Work Plans

Dear Ms. Oakley,

Based on your concurrence letter dated October 22, 2015, enclosed are errata pages, revised cover sheets and spine labels dated November 2015 reflecting that the PA-2, PA-3 and PA-5-7 Groundwater and Soil Characterization Work Plans are considered final.

If you have any questions regarding the enclosed errata sheets, please contact me at 702-402-1319.

Respectfully submitted,

Michael Rojo
Supervisor, Environmental Services
NV Energy

CC: William Campbell, NDEP (electronic copy via FilesAnywhere)
Michael Rojo, NV Energy
Tony Garcia, NV Energy (two copies)
John Kivett, ARCADIS, US
Bob Forsberg, ARCADIS, US

NEVADA DIVISION OF
ENVIRONMENTAL PROTECTION

STATE OF NEVADA
Department of Conservation & Natural Resources
Brian Sandoval, Governor
Leo M. Drozdoff, P.E., Director
Colleen Cripps, Ph.D., Administrator

October 22, 2015

Michael Rojo
Environmental Services, Supervisor
NV Energy
6226 W Sahara Ave M/S 30
Las Vegas, NV 89146

Re: **NV Energy (NVE)**
Reid Gardner Station (RGS)
NDEP Facility ID #H-000530
Nevada Division of Environmental Protection (NDEP) Review of:
Document and Response to Comments Tracking Form for PA2, PA3, and PA5-7 Groundwater and Soil Characterization Work Plans, dated August 18, 2015

Dear Mr. Rojo:

The NDEP has received and reviewed NVE's submittal of the Response to Comments (RTCs) for the PA2, PA3, and PA5-7 Groundwater and Soil Characterization Work Plans (Work Plans). The RTCs were received by the NDEP on August 18, 2015. The Work Plans describe groundwater and soil investigations to be conducted in the area of former Pond 4B and 4C (PA2), 4A (PA3), and D, E, F, and G (PA5-7). The NDEP has two comments to the RTCs that are included in Attachment A. Once these editorial comments are addressed, the NDEP **concurs** with the revised pond work plans. NVE may finalize the work plans by sending revised pages and cover sheets for insertion into the draft documents.

Please contact me with any questions or comments about this letter at (775) 687-9396 or aoakley@ndep.nv.gov

Sincerely,

Alison Oakley, CEM
Environmental Scientist III
Bureau of Corrective Actions
NDEP-Carson City Office

Attachments (1)
Attachment A – NDEP Comments

ec: Jeff Collins, Nevada Division of Environmental Protection (NDEP)
Scott Smale, Bureau of Corrective Actions, NDEP Carson City
Todd Croft, Bureau of Corrective Actions, NDEP Las Vegas
Bill Campbell, Tribal Liaison, NDEP
Alan Tiney, Bureau of Water Pollution Control, NDEP
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cc: Alteha Tom, Moapa Band of Paiutes, Chairperson, P.O. Box 340, Moapa, NV 89025
Darren Daboda, Moapa Band of Paiutes, Environmental Director, P.O. Box 340, Moapa, NV 89025
Clark County Emergency Management, 500 S. Grand Central Parkway 6th Floor, P.O. Box 551713, Las Vegas, NV 89155-1713
Anitha Rednam, Department of Water Resources, 1416 9th Street, Room 1140, Sacramento CA 95814

Attachment A

1. Specific Comment #3 for PA2, PA3, and PA5-7 RTCs: The comment response for specific comment #3 is written more clearly than the text in the work plan. Suggested revision to the text in the work plan using the discussion listed in the response to comment #3 is:
   First priority is given to TDS because it is the key indicator for evaluating the extent of contamination. Because specific conductance and pH can be measured in the field from a small sample volume, they are also included as first priority analytes. The second priority ~~for~~ analytes, chloride, fluoride, nitrate, and sulfate, ~~is the same because~~ can ~~all~~ be analyzed from the same sample bottle as TDS. These parameters are also important for evaluating the extent of contamination. Alkalinity is next on the priority list because it is analyzed from the same sample bottle as TDS and it is needed to conduct a cation-anion balance on the higher priority analytes. Fourth priority is given to density because it can also be analyzed from the same bottle as TDS ~~the first three priority analytes~~. Density is used to evaluate potential density driven flow. Fifth priority is assigned to the metals~~,~~ ~~which~~ because they require an additional ~~can all be analyzed from the same~~ sample bottle. ~~, because t~~They are important indicators of the extent of contamination. Phosphorus and the metals speciation analytes are given lower priorities because they are only needed to support the geochemical CSM. After the discrete groundwater sampling is completed, the direct push sampling tool will be removed and the borehole will be backfilled with bentonite slurry.

2. PA2 Specific Comment #11 and PA3 Specific Comment #10: The response to Specific Comment #10 in the PA5-7 RTCs is more complete than the responses in the PA2 and PA3 RTCs. Suggest that you use the response provided in PA5-7 in the other two RTCs.

Document and Response to Comments Tracking Form
NV Energy – Reid Gardner Station
Administrative Order on Consent Implementation

Document Title PA5 to 7 Groundwater and Soil Characterization Work Plan

Preparer Stanley Consultants, Inc.

Draft #1

To NDEP | From NV Energy

Submittal Date 3/12/2015 | Comment Date 4/14/2015

Response Date 8/18/2015

Commenter Alison Oakley | Responder Mike Rojo

General Comment #1

In general, with regard to the objectives, the Work Plan states:

"The Muddy River is a potential receptor for affected groundwater from the pond source areas. If there is a meaningful pathway from the affected groundwater beneath the ponds to the Muddy River, and if the river is impacted above levels of regulatory concern, corrective action may be necessary. "

It should be noted that this may not be the only condition under which corrective action may be required. The use of the word "and" is concerning in that both conditions must be met. The use of the word "or" would be more appropriate. If a meaningful pathway exists but no current impacts are measured, there could be a change in future site conditions that may result in an impact. Similarly, if data suggests an impact (mass loading) exists, but the investigation does not identify the specific pathway, that may still result in the need for corrective action. In the end, any decisions made regarding active, passive, or no-action remedial alternatives must ultimately be protective of human health and the environment both currently and in the future.

The Work Plan should clarify that evaluation of potential impact to the Muddy River is based on the collective impacts of all sources associated with the Station and not just individual sources. For example, one might conclude that specific ponds do not add significant mass to the Muddy River above regulatory mass loading thresholds, but the collective mass loading from all of the pond areas does create an impact above a threshold.

General Comment #1 Response

The last paragraph on page 1-2 has been revised to replace references to ponds and pond source areas with references to the Site. As discussed during our quarterly AOC meeting in April 2015, NV Energy has not changed the word "and" to "or" as discussed in the comment. NV Energy believes this change is not appropriate because the use of the word "or" could imply that NV Energy would be responsible for addressing impacts to the river from sources that are not NV

Energy's. If there is a meaningful pathway or an impact exists, NV Energy will evaluate current and future risk to determine the need for corrective action, subject to NDEP approval.

General Sampling Comment #1

Provide a description of the criteria that will be used to determine soil sample intervals that "do not appear to be impacted" - e.g., P-26D, P-27D, and P-30D in PA5 to 7 Work Plan (Page 2-10 to 2-11).

General Sampling Comment #1Response

The following clarifying sentence was added to page 2-8; *"In particular, low EC data from the HPT logs, low field specific conductance measurements in direct push groundwater samples, and low TDS measurements in direct push groundwater samples could all be indications that the depths are not impacted."*

General Sampling Comment #2

Based on groundwater data presented in the Preliminary Geochemical Conceptual Site Model report, nitrate is minimally detected in Site groundwater at concentrations that are well below the maximum contaminant level (MCL) of 10 mg/L. The moderately reducing geochemical conditions in groundwater beneath the ponds likely limits migration of nitrate from the ponds in groundwater. It is recommended that groundwater samples for nitrate stable N and O isotope analysis be collected and put on hold until groundwater nitrate concentration data are provided by the standard analytical laboratory. If the nitrate concentration in a sample is well below the MCL, then nitrate isotope analysis may not be necessary for that sample.

General Sampling Comment #2 Response

We agree that nitrate concentrations above the MCL are not expected in the area of the ponds. Therefore, nitrogen isotope data are not needed as we discussed during the April 28-29, 2015 meeting. Nitrate isotope analysis was removed from Table 2-6 and Appendix A.

Specific Comment #1

<u>Page 2-5, Section 2.4, Discrete Groundwater Sampling:</u> This section states that discrete groundwater samples will be field filtered prior to submittal to a laboratory for analysis. Iron (Ill) is listed as an analyte in this section. Please clarify if sample volumes for Iron (III) analysis will be field filtered, and if so what size filter will be used. Since Iron (III) is typically present as a solid oxyhydroxide in groundwater samples, and filtering typically removes solid-phase Iron (III) from sample aliquots, it is recommended that samples for Iron (III) are not filtered before analysis.

Specific Comment #1 Response

Filtering will be performed using a 0.45 micron filter, as stated in Section 2.4. Although a fraction of the iron colloids may be removed by filtration, the samples must be filtered because they are direct push samples and are highly turbid. The data will be used to understand groundwater redox, with the possible co-occurrence of Fe(II) and Fe(III) indicating mixed redox conditions. The Work Plan has not been revised.

Specific Comment #2

<u>Pages 2-5, 2-6, Page 2-15, and Appendix A (Section 2.4 bullet and numbered lists, Table 2-4, and Table 1 Appendix A):</u> There are inconsistent terminologies that appear to be used among the discrete groundwater sampling analyte lists. For example "Total Dissolved Arsenic" is listed in bulleted list, "Total Arsenic" is listed in numbered list in section 2.4, "arsenic" is listed in Table 1 Appendix A, and "Arsenic, Dissolved" is listed in Table 2-4. Please review and revise these tables and related text as necessary to provide consistency in nomenclature, especially for the following parameters: arsenic, chromium, phosphorus, selenium, manganese, and iron.

Specific Comment #2 Response

The terminologies used in the Section 2.4 bulleted and numbered lists, Table 2-4 (now Table 2-6), and Table 1 in Appendix A were revised to be consistent. Note that all of the parameters in the Section 2.4 bulleted list will be analyzed after the sample is filtered in the field. Rather than listing "dissolved" after all of the parameters in the list, the text before the list notes that all of the parameters will be dissolved. "Total" is only used when referring to unfiltered metals samples.

The exception is phosphorus, which by EPA Method 365.2, can be reported as total or dissolved. This work proposes to use "dissolved" phosphorus because (1) the data will be used to evaluate the potential for groundwater transport of phosphorus, and (2) the dissolved phosphorus fraction (as opposed to particle-bound fraction) is more representative of mobile phosphorus in the aquifer.

Specific Comment #3

<u>Page 2-6, Section 2.4, Top of Page Numbered List:</u> Discrete Groundwater Samples Analyte priorities - The NDEP recommends moving sample volume for metals analysis prior to sample volume for alkalinity in the analyte priority list. Metals data provide basis for understanding potential migration of constituents of concern (COCs) from the ponds.

Specific Comment #3 Response

According to the laboratory, the bottle required for TDS, chloride, fluoride, nitrate, and sulfate analyses is also used for alkalinity and density analyses. Therefore, alkalinity and density are shown with a higher priority than metals because the metals analyses require an additional sample bottle. NVE has updated the list on page 2-4 in consideration of laboratory sample bottle requirements.

Specific Comment #4

<u>Pages 2-7 to 2-9, Section 2.6 Soil Sampling:</u> The last paragraph of Section 2.6 states that soil samples will be collected from all of the deep Pond wells (P-23D, -24D, -25D, -26D, -27D, and -30D) and analyzed for chemical, physical, leaching, and geochemical parameters. However, Table 2-1 does not reflect this as P-26D, -27D and -30D do not have any samples selected for soil leaching (SL). If these wells will not have SL samples selected, please include rationale as to why they are excluded in the text. Page 2-10, Soil Leaching Discussion: This text states that only

three wells (P-23D, -24D, and -25D) will have samples collected for SL testing; however, this doesn't match with Section 2.6 text.

Specific Comment #4 Response

Soil Leaching testing is not included for P-26D, -27D and -30D because they are outside the pond source area. The text in Section 2.6 was revised to include this rationale and to match Table 2-1.

Specific Comment #5

<u>Page 2-9, Soil Chemical (SC) Parameters (Section 2.6, Table 2-2, and Table 1 Appendix A):</u> Inconsistent terminologies appear to be used among the analyte lists. For example "Total Arsenic" is listed in bulleted list section 2.6, while "Arsenic" is listed in Table 1 Appendix A and Table 2-2. Please review and revise these tables and related text as necessary to provide consistency in nomenclature especially for the following parameters: arsenic, chromium, phosphorus, and selenium.

Specific Comment #5 Response

The terminologies used in the Section 2.6 bulleted lists, Table 2- 2, and Table 1 in Appendix A were revised to be consistent. "Total" is only used when referring to unfiltered metals samples.

Specific Comment #6

<u>Page 2-10, Soil Leaching CSL) Test Leachate Analyses (Section 2.6, Table 2-2, and Table 1 Appendix A):</u> Inconsistent terminologies appear to be used among the analyte lists. For example "Total Arsenic" is listed in bulleted list section 2.6, while "Arsenic" is listed in Table 1 Appendix A and Table 2-2. Please review and revise these tables and related text as necessary to provide consistency in nomenclature especially for the following parameters: arsenic, chromium, phosphorus, and selenium. Sodium and chloride are included in the section 2.6 list and in Table 2-2, but are not listed in Table 1 Appendix A. Add sodium and chloride to the Soil Leaching (SL) list of analytes in Table 1 Appendix A.

Specific Comment #6 Response

The terminologies used in the Section 2.6 bulleted lists, Table 2- 2, and Table 1 in Appendix A were revised to be consistent. Total is only be used when referring to unfiltered metals samples.

Sodium and chloride were added to the Soil Leaching parameter list in Table 1 in Appendix A.

Specific Comment #7

Page 2-11, Soil Geochemical (SG) Parameters (Section 2.6, Table 2-2, and Table 1 Appendix A): "Chromium (VI)" is listed in Section 2.6 and "chromium (hex)" is listed in Table 1 Appendix A, but hexavalent chromium is not listed as an analyte on Table 2-2. Please add hexavalent chromium to the table 2-2 analyte list (Speciation, dry weight) and use consistent nomenclature.

Specific Comment #7 Response

Hexavalent chromium is now consistently shown as Chromium (VI) throughout the report and in Table 1 in Appendix A. Chromium (VI) was added to the speciation parameter list in Table 2-2.

Specific Comment #8

<u>Page 2-11, Soil Geochemical (SG) Parameters and Page 2-12, Table 2-2:</u> Some of the "parameters" in the bullet list are not geochemical parameters, but are analytical methods. Specifically, x-ray diffraction (XRD), x-ray fluorescence (XRF), sequential extraction analysis, and batch adsorption tests are types of analytical methods used on sample to get specific analyte results. The parameters that result from using XRD, XRF, etc. should be listed. The same comment follows for the Geochemistry section of Table 2-2.

Specific Comment #8 Response

The analytical methods and procedures have been removed from the bullet list and the "Geochemistry" section of Table 2-2 has been removed as well. Table 2-3 has been added to provide a list of the specific parameters to be analyzed as part of the SG tests. Also, descriptions of the sequential extraction and batch adsorption test methods have been included in Appendix D.

Specific Comment #9

<u>Page 2-11 Table 2-2:</u> Use EPA Method 6020 to provide lower reporting limits for Sb, As, Cd, Se, and Tl that will be closer to their respective Lowest Applicable Standard values or provide rationale for using EPA Method 6010 for these constituents.

Specific Comment #9 Response

Table 2-2 has been revised to show that EPA Method 6020 will be used for antimony, arsenic, cadmium, selenium, and thallium analyses.

Specific Comment #10

<u>Page 2-11 Table 2-2:</u> TBDs are shown as place-holders for Methods and Reporting Limits. Please provide methods and reporting limits for all analyses listed in Table 2-2.

Specific Comment #10 Response

Table 2-2 has been revised to include the analytical methods and laboratory reporting limits for all of the listed parameters, with the exception of Compound Specific Isotope Analyses. The reporting limits for these methods are listed as "NS" (no standard available) because they are reported as ratios or percentages.

Specific Comment #11

<u>Page 2-16, Table 2-4:</u> $S0_4$, Cl, F, and P analyses listed as "dissolved". These analyses are typically conducted on whole water samples. Please provide rationale for running these analyses on filtered (dissolved) samples.

Specific Comment #11 Response

The table (now Table 2-6) has been revised to show sulfate, chloride, and fluoride are not dissolved analyses. However, phosphorus is still shown as dissolved because this better represents the concentration likely to be transported in groundwater.

Specific Comment #12

<u>Page 3-3, Table 3-2:</u> Include contingency for additional field meter calibration checks during the day if field parameter readings appear to be drifting or are anomalous.

Specific Comment #12 Response

Table 3-2 has been revised to show that field meters will be calibrated daily or if conditions change.

Final

To ______________________________ From ____________________________

Submittal Date ____________________ Approval Date ____________________

Approver _________________________

PA5 to 7 Groundwater and Soil Characterization Work Plan

Administrative Order on Consent Activities

NV Energy

Reid Gardner Station

Final

November 2015

20618.09.31

Certifications

NV Energy Certification

I certify that this document and all attachments submitted to the Division were prepared under the direction or supervision of NV Energy in accordance with a system designed to gather and evaluate the information by appropriately qualified personnel. Based on my inquiry of the person or persons who manage the system(s) or those directly responsible for gathering the information, or the immediate supervisor of such person(s), the information submitted and provided by NV Energy is, to the best of my knowledge and belief, true, accurate, and complete in all material respects. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for knowing violations.

Signature:	James D. Hopper Jr.
Name:	Don Hopper
Title:	Plant Director, Reid Gardner Station
Company:	NV Energy
Date:	8/12/15

Certified Environmental Manager Certification

I hereby certify that I am responsible for the services described in this document and for the preparation of this document. The services described in this document have been provided in a manner consistent with the current standards of the profession and to the best of my knowledge comply with all applicable federal, state and local statutes, regulations and ordinances.

Signature: Rebecca L. Svatos
Name: Rebecca L. Svatos
Title: Project Manager
Company: Stanley Consultants
Date: 8/14/15
EM Certificate Number: EM-1931
EM Expiration Date: 9/30/2015

Table of Contents

TABLES

APPENDICES

Section 1

Objectives

NV Energy and the Nevada Division of Environmental Protection (NDEP) entered into an Administrative Order on Consent (AOC) for the Reid Gardner Generating Station (Site) near Moapa, Nevada on February 22, 2008. The AOC calls for NV Energy to continue with environmental contaminant characterization activities and to identify clean-up measures, as necessary, for soil and groundwater at the Site. As part of the AOC implementation, NV Energy will be conducting multiple field investigations along the Muddy River and in the pond source areas during 2015. The Muddy River Investigation (MRI) Work Plan (approved by NDEP on April 13, 2015) includes investigations to be conducted adjacent to and in the river. This PA5 to 7 Groundwater and Soil Characterization Work Plan includes groundwater and soil investigations to be conducted in the area of the current E Ponds and the former D, F, and G Ponds as well as investigations on Hidden Valley Ranch property downstream and downgradient (east) of the Site in 2015. The following pond area work plans were submitted concurrently to the NDEP for implementation in 2015:

- PA2 – Ponds 4B and 4C Groundwater and Soil Characterization Work Plan
- PA3 – Pond 4A Groundwater and Soil Characterization Work Plan

All three Pond Area Work Plans include groundwater and soil investigations in the area of current and former ponds near the Muddy River on NV Energy property. Because the investigation areas are adjacent to the Muddy River and each other, some of the characterization activities identified in this PA5 to 7 Groundwater and Soil Characterization Work Plan may also address MRI objectives as well as objectives for one or more of the other two Pond Area Work Plans.

The PA5 to 7 Groundwater and Soil Characterization Work Plan was developed to gather data that will be used to address the following objectives in the area of the D/E/F/G Ponds and some areas downstream on Hidden Valley Ranch property:

1. Characterize horizontal and vertical extent of groundwater impacts
2. Evaluate plume stability (current and future)
3. Characterize potential secondary source beneath ponds
4. Evaluate whether preferential flow paths are present
5. Evaluate potential density-driven groundwater flow
6. Evaluate vertical hydraulic gradients
7. Gather information to support possible future groundwater modeling efforts
8. Estimate downgradient mass flux from groundwater underlying the D/E/F/G Ponds
9. Gather information to support corrective action planning
10. Gather data to contribute to geochemical understanding
11. Gather data to contribute to development of the Site-wide Conceptual Site Model (CSM)
12. Gather data to distinguish between naturally-occurring soil/groundwater and impacts from Ranch or Site operations

The Muddy River is a potential receptor for affected groundwater from the Site. If there is a meaningful pathway from the affected groundwater at the Site to the Muddy River, and if the river is impacted above levels of regulatory concern, corrective action may be necessary. Although many of the activities in this Work Plan involve characterization of soil and groundwater impacts, ultimately the objective for the data collected is for it to be sufficiently robust to support corrective action planning. To meet this objective, analytical data collected and analyzed when implementing this Work Plan will comply with the NDEP-approved Quality Assurance Project Plan (QAPP or NV Energy QAPP) (Stanley Consultants, 2011).

Section 2

Field Investigations

The PA5 to 7 Groundwater and Soil Characterization Work Plan includes subsurface investigations (soil and groundwater) in the E Pond area, former D, F, and G Ponds areas, and the downgradient Hidden Valley Ranch (former Dairy) property to the east of the Site. Utility clearance activities are anticipated to begin in March 2015 with monitoring well installation, groundwater investigations, soil investigations, and well abandonment to follow in April through June 2015. The new wells will initially be sampled after development and sampled again as part of the semi-annual groundwater monitoring event in September 2015. Figure 1A in Appendix A presents the proposed PA5 to 7 Groundwater and Soil Characterization Work Plan locations in the vicinity of the D/E/F/G Ponds while Figure 1B in Appendix A presents the proposed locations on the downgradient Hidden Valley Ranch property east of the D/E/F/G Ponds. Both figures include existing Discharge Monitoring Report (DMR) surface water sampling locations used as part of this study and existing monitoring well locations that will be used for reference in evaluating data collected during the implementation of the PA5 to 7 Groundwater and Soil Characterization Work Plan. Table 1 in Appendix A summarizes the investigation activities along with the objectives that are being addressed by each type of field activity. The following paragraphs describe the PA5 to 7 field activities.

2.1 Investigation Team

During the PA5 to 7 Groundwater and Soil Characterization Work Plan implementation, the Stanley Consultants Project Lead will be responsible for completing the work in accordance with this Work Plan. The Stanley Consultants Field Team Leader will be responsible for each field activity and will report to the Project Lead. Utility clearance and drilling/monitoring well installation will be performed by others contracted by NV Energy. NV Energy will survey monitoring wells installed as part of this Work Plan as well as other sampling locations (i.e., HPT-1-RA, HPT-KMW-5R, HPT-1-PA7, HPT-2-PA7, HPT-3-PA7, SS-1, SS-2, SS-3, SS-4, SS-5, SS-6, and SS-7). Veritas Laboratories (and subcontracted laboratories) will perform laboratory analyses and data validation will be performed by Ordway and Associates, a subcontractor to Stanley Consultants. OGI will collect groundwater samples from the newly installed monitoring wells as part of the second semi-annual groundwater monitoring event in September 2015.

2.2 Utility Clearance

All locations will be air-knifed to a depth of six feet below ground surface (bgs) prior to the initiation of any intrusive drilling activities (i.e., Hydraulic Profiling Tool, Sonic drilling, direct push). The drilling contractor hired by NV Energy will be responsible for performing a utility clearance for all proposed boring locations, calling each drilling location into the North Underground Service Alert (USA), and meeting with relevant utility service staff in the field, if needed, to clear individual boring locations. The drilling contractor will also be responsible for obtaining all necessary work permits (i.e., drilling, dust permit, well installation, etc). The drilling contractor will be required to present documentation from USA to the Field Team Leader that each location is cleared of underground utilities prior to starting intrusive activities.

2.3 Hydraulic Profiling Tool

Prior to conducting any Sonic drilling or monitoring well installation, a Hydraulic Profiling Tool (HPT) will be advanced at each location to evaluate the geology in accordance with the manufacturer's information in Appendix C. This information will be used to evaluate where to collect soil samples and set monitoring well screens during the Sonic drilling activities and also where to collect discrete groundwater samples (where applicable). The HPT is a logging probe that continuously measures the pressure required to inject a constant flow of water into adjacent soil as the probe is advanced at a constant rate into the subsurface. The injection pressure log that is created is then used to correlate to formation permeability. During the PA5 to 7 Groundwater and Soil Characterization Work Plan implementation, the injection pressure log will be used to infer hydrostratigraphy, including zones of relatively higher permeability that may represent potential preferential migration pathways for groundwater. The HPT probe will also measure and record electrical conductivity (EC); however, given the variability of Total Dissolved Solids (TDS)- impacts to groundwater at the Site, EC interpretation will need to consider both local geology and water quality.

Figures 1A and 1B in Appendix A show (as pink triangles) the 12 HPT locations proposed as part of the PA5 to 7 Groundwater and Soil Characterization Work Plan (HPT-1-RA, HPT-1-PA-7, HPT-2-PA-7, HPT-3-PA-7, HPT-P-23, HPT-P-24, HPT-P-25, HPT-P-26, HPT-KMW-4R, HPT-KMW-5R, HPT-KMW-21, and HPT-KMW-30). These figures also show (as blue triangles) the locations along the Muddy River where HPT borings will be advanced as part of the MRI Work Plan implementation prior to implementation of this PA5 to 7 Work Plan. At all 12 PA5 to 7 locations, the HPT will be advanced to the upper portion of the Muddy Creek Formation, if possible, anticipated to be at a depth of approximately 100 feet bgs or 120 feet below the top of pond berms.

For quality control purposes, the first PA5 to 7 HPT boring will be advanced adjacent to an existing monitoring well with known lithology such as KMW-4, KMW-5, or P-9R. The known lithology in these areas will be used to better evaluate the EC log, injection pressure log, and other output from the HPT (i.e., hydrostatic pressure, hydraulic conductivity) and correlate it with the hydrostratigraphy. Discrete HPT groundwater samples will be collected from the first HPT location and tested in the field for specific conductance to evaluate how the groundwater quality impacts the EC readings. These discrete groundwater samples will also be submitted to a laboratory for fast turnaround (24 – 72 hours) TDS analysis to establish an appropriate ratio of conductivity to TDS. In addition, the HPT operator will be required to provide EC calibration procedures. These quality control steps will be taken at other HPT locations, as necessary, to ensure that the HPT logs are being evaluated properly and that water quality changes with depth are being properly monitored.

After completion, all HPT borings will be backfilled with a bentonite grout slurry to eliminate a potential conduit for groundwater migration.

2.4 Discrete Groundwater Sampling

Discrete groundwater sampling with direct push technology using a protected screen sampler (GeoProbe SP15 or equivalent - see manufacturer's information in Appendix C) will be conducted at DP-P-24 following HPT advancement at that location. Direct push borings will be advanced to a maximum of 80 feet below the bottom of the ponds or 100 feet below the top of the pond berm. Groundwater samples will be collected by the field geologist, where groundwater is present, at 0.5' – 1.0', 2.0'-2.5', 4.5'-5', 10', 15', 20', 40', 60', and 80' below pond bottom (pond bottom approximately 10 – 15 feet below top of berm) in accordance with American Society for Testing and Materials (ASTM) Standard D6001-05 (2012), Standard Guide for Direct-Push Groundwater Sampling for Environmental Site Characterization, provided in Appendix B. The sample depths are intended to be at the same approximate depths as the soil samples described below to evaluate geochemical equilibrium between soil and groundwater and to assess attenuation parameters. Sampling intervals may be adjusted based on the lithology encountered, saturated interval, and screen length of the sampling tool.

Field measurements for pH, specific conductance, temperature, and turbidity will be made on the discrete groundwater samples. The discrete groundwater samples collected for laboratory analysis will be field filtered with a 0.45 micron filter prior to submittal to a laboratory to be analyzed for dissolved concentrations of the following parameters (see Table 2-6 for laboratory methods and reporting limits):

- Density (a physical test)
- Alkalinity (bicarbonate)
- Alkalinity (carbonate)
- Alkalinity
- Antimony
- Arsenic
- Arsenic (III)
- Arsenic (V)
- Barium
- Boron
- Cadmium
- Calcium
- Chloride
- Chromium
- Chromium (VI)
- Fluoride
- Iron (II)
- Iron (III)
- Magnesium
- Manganese
- Molybdenum
- Nickel
- Nitrate
- Phosphorus
- Potassium
- Selenium
- Selenium (0)
- Selenium (-II)
- Selenium (IV)
- Selenium (VI)
- Sodium
- Sulfate
- TDS
- Thallium
- Vanadium

Due to the limited amount of groundwater that can be obtained using a protected screen sampler, and considering laboratory sample bottle requirements, the analytes will be prioritized as follows:

1. TDS, specific conductance, pH
2. Chloride, Fluoride, Nitrate, Sulfate
3. Alkalinity (all three forms)
4. Density
5. Metals (Antimony, Arsenic, Barium, Boron, Cadmium, Calcium, Chromium, Magnesium, Manganese, Molybdenum, Nickel, Potassium, Selenium, Sodium, Thallium, Vanadium)
6. Phosphorus
7. Metal Speciation [Arsenic (III,V), Chromium (VI), Iron (II,III), Selenium (0,-II,IV,VI)]

First priority is given to TDS because it is the key indicator for evaluating the extent of contamination. Because specific conductance and pH can be measured in the field from a small sample volume, they are also included as first priority analytes. The second priority analytes; chloride, fluoride, nitrate, and sulfate; can be analyzed from the same sample bottle as TDS. These parameters are also important for evaluating the extent of contamination. Alkalinity is next on the priority list because it is analyzed from the same sample bottle as TDS and it is needed to conduct a cation-anion balance on the higher priority analytes. Fourth priority is given to density because it can also be analyzed from the same sample bottle as TDS. Density is used to evaluate potential density driven flow. Fifth priority is assigned to the metals because they require an additional sample bottle. They are important indicators of the extent of contamination. Phosphorus and the metals speciation analytes are given lower priorities because they are only needed to support the geochemical CSM.

After the discrete groundwater sampling activity is completed, the direct push sampling tool will be removed and the borehole will be backfilled with a bentonite grout slurry.

2.5 Sonic Drilling

After the HPT boring is completed and the data evaluated at each location, soil samples will be collected and monitoring wells will be installed using Sonic drilling technology in accordance with ASTM D6914-14, Standard Practice for Sonic Drilling for Site Characterization and the Installation of Subsurface Monitoring Devices, provided in Appendix B. Sonic drilling will allow field geologists to observe continuous soil cores which will be lithologically logged by the Unified Soil Classification System (USCS) in accordance with ASTM D2488. Soil cores (or chips) from the deepest boring at each location will be collected and stored, in sequence, in wooden boxes or other appropriate containers for one year for future observation. The cores will be removed from each drilling location upon completion of monitoring well installation activities and stored at a designated location at the Site.

The Sonic borings will be completed first at locations P-23, P-24, P-25, P-26, KMW-4R, KMW-21, and KMW-30. These locations require continuous sampling to a depth where the top of the Muddy Creek Formation can be confirmed by visual inspection by the field geologist, estimated to be at 100 feet bgs or 120 ft below the top of the berms. The upper portion of the Muddy Creek Formation at the Site has been described as being a massive (several feet thick) reddish brown, very stiff, hard, dry, lean clay that is non-cohesive and non-plastic with gypsum crystals or pods. Beneath the upper clay layer are thin to massive beds of very fine well graded, loose, saturated sand (sugar sand) (Stanley Consultants, 2014). At some locations, particularly in the plant site, the contact between the alluvium and the underlying Muddy Creek Formation has been marked by a thin (<1 foot) cemented sandstone layer (NTL, 1980). A similar situation may exist at former boring IMW-5D located between the Muddy River and Pond 4B-1. In this boring, a cemented sand layer is described at 90-96 feet bgs underlain by a reddish-brown stiff clay (Intellis, 1986). The Muddy Creek Formation can be distinguished visually from the overlying Quaternary Alluvium which is described in existing soil boring logs as brown to gray interbedded, poorly sorted very coarse to fine sand, silt, and soft to stiff clay with varying amounts of fine to coarse gravel and cobbles. The individual alluvial layers range from a few inches to several feet thick. Based on previous subsurface investigations at the Site, flowing sands may be encountered during the PA5 to 7 drilling activities.

The subsequent shallow borings (for wells screened less than 25 feet below the groundwater surface) and/or medium borings (for wells screened between 25 and 50 feet below the groundwater surface) at locations P-23, P-24, P-25, P-26, P-27, P-30, KMW-4R, KMW-21, KMW-24, and KMW-30 will be drilled only to the depth necessary to set monitoring wells.

2.6 Soil Sampling

Subsurface soil samples will be collected with the Sonic drill rig by boring to the desired sample depth and using the appropriate equipment (described below) to collect representative samples. When it is necessary to collect an undisturbed soil sample (i.e., for soil permeability and/or leaching tests), the thin-walled sampler will be inserted into the borehole once the desired sample depth is reached and pushed ahead of the drill stem and casing to collect the sample. Other than undisturbed samples, soil samples will be collected from the extracted (disturbed) continuous soil cores following logging activities by the onsite geologist. Soil samples will be transferred from the sampling device to the appropriate sample containers. Sample containers will be filled to the top, taking care to prevent soil from remaining in the lid threads prior to being sealed to prevent potential contaminant migration to or from the sample. After sample containers are filled, they will be immediately sealed, labeled, chilled if appropriate, and processed for shipment or delivery to the laboratory. Bulk samples for physical analyses will be collected the same way and transferred into plastic bags. All sampling activities will be in accordance with the Standard Operating Procedures (SOPs) in Appendix E of the NV Energy QAPP.

In borings P-23D, P-24D, and P-25D, soil samples will be collected for soil chemical (SC) analyses, soil physical (SP) analyses, soil leaching (SL) tests, and soil geochemical (SG) parameter analyses, as summarized in Table 2-1. Borings P-26D, P-27D and P-30D will be sampled for SC, SP and SG analyses only. Since P-26D, P-27D and P-30D are located outside the pond source area, the SL analyses are not necessary.

Table 2-1 Potential Soil Sampling Intervals

Boring	Target Depth (feet bgs or below pond bottom)	Type of Analyses			
		Soil Chemical (SC)	Soil Physical (SP)	Soil Leaching (SL)	Soil Geochemical (SG)
P-23D	0.5 – 1.0	X	Select 3samples based on changes in lithology	X	X
	2.0 - 2.5	X		X	
	4.5 - 5.0	X			X
	10	X			
	15	X			
	20	X			X
	40	X	Select ≤5 samples based on changes in lithology		
	60	X			
	80	X			
P-24D	0.5 – 1.0	X	Select 3samples based on changes in lithology	X	X
	2.0 - 2.5	X		X	
	4.5 - 5.0	X			X
	10	X			
	15	X			
	20	X			X
	40	X	Select ≤ 5 samples based on changes in lithology		
	60	X			
	80	X			
P-25D	0.5 – 1.0	X	Select 3 samples based on changes in lithology	X	X
	2.0 - 2.5	X		X	
	4.5 - 5.0	X			X
	10	X			
	15	X			
	20	X			X
	40	X	Select ≤ 5 samples based on changes in lithology		
	60	X			
	80	X			
P-26D	0.5 – 1.0	Select ≤4 samples based on changes in lithology	Select ≤4 samples based on changes in lithology		Select 2 soil samples based on HPT in distinct lithologies
	2.0 - 2.5				
	4.5 - 5.0				
	10				
	15				
	20				
	40				
	60				
	80				
P-27D	0.5 – 1.0	Select ≤4 samples based on changes in lithology	Select ≤4 samples based on changes in lithology		Select 2 soil samples based on HPT in distinct lithologies
	2.0 - 2.5				
	4.5 - 5.0				
	10				
	15				
	20				
	40				
	60				
	80				
P-30D	0.5 – 1.0	Select ≤4 samples based on changes in lithology	Select ≤4 samples based on changes in lithology		Select 2 soil samples based on HPT in distinct lithologies
	2.0 - 2.5				
	4.5 - 5.0				
	10				
	15				
	20				
	40				
	60				
	80				

Note: Depth of sample collection subject to change based on field conditions.

A maximum of nine soil samples will be collected in P-23D, P-24D and P-25D for SC analyses at the approximate depth intervals below the pond bottom specified in Table 2-1 (pond bottom is approximately 10 – 15 feet below top of pond berm). In addition, up to four soil samples will be collected from P-26D, P-27D, and P-30D for SC analyses based on lithologic changes. Discrete soil samples for SC analyses will be collected from at least two distinctly different lithologies (e.g., clay and sand). The SC parameters are as follows (see Table 2-2 for laboratory methods and reporting limits):

Soil Chemical (SC) Parameters

- Antimony
- Arsenic
- Boron
- Cadmium
- Chromium
- Fluoride
- Molybdenum
- Phosphorus
- pH
- Selenium
- Sulfate
- Sulfide
- Sulfite
- Thallium
- Moisture content (physical analysis)

In borings P-23D, P-24D and P-25D; three samples each will be selected from the first 20 feet below the pond bottom and up to five samples each from more than 20 feet below the pond bottom for SP analyses. The field geologist will select some of the undisturbed samples for laboratory permeability testing. In addition, four samples will be collected from P-26D, P-27D, and P-30D for SP analyses, but no permeability testing. The sample intervals will be selected by the field geologist based on visual inspection of the physical properties (i.e., color, texture, moisture content, etc.) of the lithology at each boring location to characterize those changes in lithology. The SP analyses are as follows:

Soil Physical (SP) Analyses

- Atterberg Limits (ASTM D4318)
- Bulk Density (ASTM D7263)
- Grain size (ASTM D422)
- Percent moisture (ASTM D2216)
- Permeability (selected SP samples) (ASTM D5084

Two undisturbed soil samples each will be collected from P-23D, P-24D, and P-25D at the approximate depths shown in Table 2-1 for SL testing using the Sequential Batch Leaching Test (SBLT) in accordance with the method included in Appendix D. Groundwater from existing monitoring well BG-1S will be used as the leaching solution for the tests. The leachate from the tests will be analyzed for the following parameters:

Soil Leaching (SL) Test Leachate Analyses

- Antimony
- Arsenic
- Boron
- Cadmium
- Chloride
- Chromium
- Chromium (VI)
- Fluoride
- Molybdenum
- Phosphorus
- pH
- Selenium
- Sodium
- Sulfate
- TDS
- Thallium

Three undisturbed samples each will be collected from P-23D, P-24D, and P-25D at the approximate depths shown in Table 2-1 for SG analyses. In addition, two undisturbed samples each will be collected from P-26D, P-27D, and P-30D from two distinctly different lithologies (e.g., clay and sand). The SG samples from P-26D, P-27D, and P-30D will be collected from depths that do not appear to be impacted by PA5 to 7 based on HPT logs and field data. In particular, low EC data from the HPT logs, low field specific conductance measurements in direct push groundwater samples, and low TDS measurements in direct push groundwater samples could all be indications that the depths are not impacted. The SG speciation parameters are as follows:

Soil Geochemical (SG) Parameters

- Arsenic (III)
- Arsenic (V)
- Selenium (0)
- Selenium (-II)
- Selenium (IV)
- Selenium (VI)
- Chromium (VI)
- Iron (II)
- Iron (III)

Table 2-3 provides additional information on the SG parameters.

2.7 Soil Forensics

Surface soil samples will be collected from locations SS-1 through SS-7 as discrete samples from the soil surface using a decontaminated stainless steel hand trowel or similar instrument. Sample containers will be filled to the top, taking care to prevent potential contaminant migration to or from the sample. Sample containers will be closed as soon as they are filled, labeled, chilled if appropriate, and processed for shipment or delivery to the laboratory. These samples will be analyzed for XRD, XRF, LOI, and compound specific isotope analyses (CSIA) of sulfate and oxygen, as summarized in Tables 2-2 and 2-3 and according to the methods included in Appendix D. This data will be used to evaluate whether the surface deposits are from natural wicking of salts to the surface or due to groundwater contamination and/or past seepage from the pond berms.

Table 2-2 Soil Parameters

Parameter	Analytical Method	Laboratory Reporting Limit (mg/kg)	Lowest Applicable Standard (mg/kg)[a]
METALS (DRY WEIGHT)			
Antimony	EPA 6020	0.25	0.27[b]
Arsenic	EPA 6020	0.25	0.0015[c]
Boron	EPA 6010B	10	13[c]
Cadmium	EPA 6020	0.25	0.25[d]
Chromium	EPA 6010B	2.0	23[d]
Molybdenum	EPA 6010B	2.0	2.0[c]
Selenium	EPA 6020	0.20	0.26[b]
Thallium	EPA 6020	0.25	0.014[c]
SPECIATION (DRY WEIGHT)			
Speciation: Arsenic (III, V)	Modified EPA 6800	0.05	NS
Speciation: Selenium (0, -II, IV, VI)	Modified EPA 6800	0.11	NS
Iron (II)	SM 3500 F+2D	1.0	7.56
Iron (III)	SM 3500 F+2D	5.0	7.56
Chromium (VI)	EPA 7196A	1.0	0.00067
GENERAL MEASUREMENTS AND INORGANICS (DRY WEIGHT)			
Fluoride	EPA 9056	4.0	120[c]
Moisture Content	SM 2540G	0.10	NS
pH	EPA 9045C	1.68 units	NS
Phosphorus	SM 4500PB	5.0	0.99
Sulfate	EPA 9056	20	6,000[e]
Sulfide	EPA 9034	5.0	NS
Sulfite	SM 4500-SO3B	20	NS
SOIL LEACHING POTENTIAL			
Arsenic	Modified EPA 200.8	0.04 µg/L	NS
Antimony	Modified EPA 200.8	0.04 µg/L	NS
Boron	Modified EPA 200.8	4.0 µg/L	NS
Cadmium	Modified EPA 200.8	0.04 µg/L	NS
Chloride	Modified EPA 1312/EPA 9056	2.0 mg/L	NS
Chromium	Modified EPA 200.8	0.04 µg/L	NS
Chromium (VI)	Modified EPA 7199	0.01 µg/L	NS
Fluoride	Modified EPA 1312/EPA 9056	0.40 mg/L	NS
Molybdenum	Modified EPA 200.8	0.01 µg/L	NS
pH	Modified EPA 1312/EPA 9045D	1.0 units	NS
Phosphorus	Modified EPA 1312/SM 4500	0.10 mg/L	NS
Selenium	Modified EPA 200.8	0.01 µg/L	NS
Sodium	Modified EPA 200.8	10 µg/L	NS
Sulfate	Modified EPA 1312/EPA 9056	2.0 mg/L	NS
TDS	Modified EPA 1312/SM 2540C	20 mg/L	NS
Thallium	Modified EPA 1312/ICP-DRC-MS	0.01 µg/L	NS
SOIL FORENSICS			
Compound Specific Isotope Analysis (CSIA) sulfate 34S/32S (d34S)	Barium Sulfate Precip. & EA-IRMS	50	NS
Compound Specific Isotope Analysis (CSIA) oxygen $^{18}O/^{16}O$ ($d^{18}O$))	Barium Sulfate Precip. & TCEA-IRMS	50	NS

NS denotes no standard available

[a]These values are provided for information purposes only to identify appropriate target method reporting limits, and have not yet been agreed upon with NDEP.

[b] ***EPA MCL-based SSL:*** *EPA MCL-based soil leaching to groundwater soil screening level (SSL)* (November 2014)

[c] ***EPA Risk-based SSL:*** *EPA risk-based soil leaching to groundwater soil screening level (SSL)* (November 2014)

[d] ***BTV Non-clay:*** *Site-specific soil background threshold value (BTV) for non-clays* (August 2014)

[e] ***BTV > 20':*** *Site-specific background threshold value (BTV) for soils greater than 20 feet below ground surface* (August 2014)

Table 2-3 Soil Geochemical Parameters

Parameter	Method	Rationale
Soil Mineralogy[1]	X-Ray Diffraction (XRD)	Identify minerals in soils for comparison to those discussed in Preliminary Geochemical CSM Report
Indicator parameters[2] (As, Cd, Cl, Cr, Fe, Mo, Mn, Na, P, S, Sb, Se, Tl)	X-Ray Fluorescence (XRF)	Quantify concentrations of indicator parameters in soils to compare to CSM predictions of mineral buffering and attenuation via mineral sequestration
Volatile Soil Compounds	Loss On Ignition (LOI)	Measures mass of compounds not reported by XRF; LOI includes carbon and hygroscopic water in oxyhydroxides, salts, and clays
Mineralogy of parameters (As, B, Cd, Cr, F, Fe, Mn, Mo, Sb, Se, SO4 , Tl)	Sequential Extraction Analysis (See Appendix D)	Parameter-bearing minerals often occur at concentrations below XRD detection limits; Extractions provide the chemical forms of COCs (i.e. adsorbed and/or precipitated/co-precipitated minerals)
Mineral Adsorption Potential	Batch Adsorption Tests (See Appendix D)	Provides the adsorption capacity of soil iron-oxyhydroxides in soils
TOC	EPA 9060	Quantify the concentrations of organic carbon for reductive degradation and/or adsorption of COCs

Footnotes:

1) Minerals may include, for example, gypsum, calcite, and/or mirabilite

2) XRF does not report boron or fluoride; these will be analyzed separately using EPA 6010B and 9056, respectively

2.8 Monitoring Well Installation

All Sonic drilled borings will be completed with four-inch-diameter groundwater monitoring wells per ASTM-D5092-04, Standard Practice for Design and Installation of Ground Water Monitoring Wells (see Appendix B), with a minimum of 10 foot of threaded schedule 40 polyvinyl chloride (PVC) #10 (0.01 inch) slotted screen, a threaded end plug or point, and an expandable locking cap. Well casing will be threaded schedule 40 PVC with “O-rings” between five- and ten-foot lengths. The PVC will extend to within 0.5 foot of the ground surface for flush-mount wells on the pond berms (P-24 and P26), and three feet above the ground surface for aboveground completions at locations P-23, P-25, P-27, P-30, KMW-4R, KMW-21, KMW-24, and KMW-30. The annular space around the well screen will be backfilled with #12 silica sand to two feet above the top of the screen. A sanitary seal comprised of a minimum of two feet of hydrated bentonite chips or pellets will be installed on top of the sand. A bentonite grout slurry will be installed on top of the seal and extend to the upper two feet of the schedule 40 PVC riser pipe. A concrete cap will be placed around the pipe to keep the pipe from sinking. The grout will be allowed to cure and settle for 72 hours prior to installing the concrete surface seal and manhole (road box) or protective steel casing. If necessary, additional grout will be added to the borehole to return the level to within two feet of the ground surface. Stainless steel centralizers will be used to keep the well in the middle of the borehole during construction. Flush-mount well completions will be finished with a weather-tight cast-iron lid "Test Well" manhole, secured with concrete, and centered over the PVC casing. Aboveground well completions will be finished with a locking outer protective steel casing concreted into place, with three bollards placed around each well for protection.

Table 2-4 summarizes well construction information for the monitoring wells to be installed during the implementation of this Work Plan. The depth of the screened interval in each well will be dependent on the depth and thickness of the saturated zone; at a minimum, 10-foot screens will be used for all wells. Shallow four-inch-diameter monitoring wells at locations P-23S, P-24S, P-25S, P-26S, KMW-4SR, KMW-21S, and KMW-30S will be advanced to a depth of approximately eight feet into the groundwater table such that the 10-foot screen will extend approximately two feet above the groundwater table. The medium depth wells in the vicinity of the ponds; P-23M, P-24M, P-25M, P-26M, P-27M, and P-30M; will be screened within a range of approximately 25 – 50 feet into the groundwater table. The medium depth wells may be completed (screened) just below the first significant clay layer beneath the ponds. The medium depth wells on the Hidden Valley Ranch; KMW-4MR, KMW-21M, KMW-24M, and KMW-30M; will be completed within a range of approximately 25 – 50 feet into the groundwater table consistent with the previously installed wells (KMW-3M, KMW-4M, KMW-5M and KMW-6M). The deep wells; P-23D, P-24D, P-25D, P-26D, P-27D, P-30D, KMW-4DR, KMW-21D, KMW-24D, and KMW-30D; will be screened at a depth greater than 50 feet into the groundwater table at the estimated vertical extent of the groundwater impacts (i.e., at the depth at which EC stabilizes in the HPT profile, or as determined based on other indications, such as consistently low EC/TDS from discrete groundwater samples at multiple depth intervals). The bottom of the deepest well, P-24MC, will be set approximately at the contact with the Muddy Creek Formation. The HPT and Sonic cores at all locations will be used to evaluate screened intervals that will meet the objectives of this Work Plan. While the intent is to set well screens in accordance with the existing shallow, medium, and deep guidelines used at the Site, the lithology encountered at each location will ultimately dictate screen placement.

Table 2-4 Monitoring Well Construction Information

Boring	Well Diameter (inches)	Well Completion	Approximate Total Depth (feet bgws)
P-23S	4	Aboveground	25
P-23M	4	Aboveground	25 - 50
P-23D	4	Aboveground	50 - 75
P-24S	4	Flush-mount	25
P-24M	4	Flush-mount	25 – 50
P-24D	4	Flush-mount	50 - 75
P-24MC	4	Flush-mount	75-120
P-25S	4	Aboveground	25
P-25M	4	Aboveground	25 – 50
P-25D	4	Aboveground	50 - 75
P-26S	4	Flush-mount	25
P-26M	4	Flush-mount	25 – 50
P-26D	4	Flush-mount	50 - 75
P-27M	4	Aboveground	25 – 50
P-27D	4	Aboveground	50 - 75
P-30M	4	Aboveground	25 – 50
P-30D	4	Aboveground	50 - 75
KMW-4SR	4	Aboveground	25
KMW-4MR	4	Aboveground	25 – 50
KMW-4DR	4	Aboveground	50 - 75
KMW-21S	4	Aboveground	25
KMW-21M	4	Aboveground	25 – 50
KMW-21D	4	Aboveground	50 - 75
KMW-24M	4	Aboveground	25 – 50
KMW-24D	4	Aboveground	50 - 75
KMW-30S	4	Aboveground	25
KMW-30M	4	Aboveground	25 – 50
KMW-30D	4	Aboveground	50 - 75

bgws – below groundwater surface

Wells will be developed after installation in accordance with SOP 2044 in Appendix E of the NV Energy QAPP.

2.9 Monitoring Well Abandonment

There are 12 existing monitoring wells in the PA5 to 7 area to be abandoned. These wells were installed on the Hidden Valley Ranch property located east of the Station as part of a previous investigation in 1998. The wells were installed in four three-well clusters with a shallow (approximately 25 feet bgs), medium (approximately 50 feet bgs), and deep (approximately 75 feet bgs) well in each cluster. The wells have fallen into disrepair such that they are no longer useable.

These 12 wells will be abandoned in accordance with NAC 534 and any other applicable regulations. Table 2 – 5 below summarizes the physical properties of the wells when they were installed.

Table 2-5 KMW Monitoring Well Construction Information

Well ID	Well Diameter (inches)	Well Completion	Well Depth (feet bgs)	Screen Interval (feet bgs)
KMW-3S	2	Aboveground	25	5 - 25
KMW-3M	2	Aboveground	50	40 - 50
KMW-3D	2	Aboveground	70	60 - 70
KMW-4S	2	Aboveground	25	5 - 25
KMW-4M	2	Aboveground	49	39 - 49
KMW-4D	2	Aboveground	67	57 - 67
KMW-5S	2	Aboveground	25	5 - 25
KMW-5M	2	Aboveground	50	40 - 50
KMW-5D	2	Aboveground	75	65 - 75
KMW-6S	2	Aboveground	25	5 - 25
KMW-6M	2	Aboveground	50	40 - 50
KMW-6D	2	Aboveground	73	63 - 73

2.10 Water Forensics Sampling

One grab sample of process wastewater will be collected from the Effluent Forwarding Pump Station (EFPS) or other appropriate location that contains Station scrubber effluent. In addition, one grab sample each will be collected at Muddy River sampling locations MR-1, MR-2, MR-3, and MR-4. These samples will be tested in the field for pH, temperature, and specific conductance and the samples will be submitted to the laboratory for analysis for the Water Forensics (WF) parameters specified in Table 1 in Appendix A. The laboratory analytical methods for the WF parameters are included in Table 2-6. In addition, groundwater samples will be collected from selected new and existing wells, as listed in Table 1 in Appendix A, during the second semi-annual monitoring event in September 2015 for laboratory analyses of WF parameters. The WF data will be used to establish chemical signatures for the different water types (native groundwater, pond area groundwater, Ranch groundwater, scrubber effluent, and Muddy River). WF data from groundwater samples collected in the Ranch area during the second semi-annual groundwater monitoring event will be compared with the WF results for the different water types to evaluate whether Ranch groundwater is impacted by Station activities, the Muddy River and/or by Ranch activities.

2.11 Groundwater Elevation Measurement

Groundwater levels will be manually measured at all wells after development and on a quarterly basis, starting with the second semi-annual groundwater monitoring event in September 2015. The groundwater levels will be measured with an electronic water level meter in accordance with SOP 2043 in Appendix E of the NV Energy QAPP.

Where well clusters are installed, the groundwater elevation in each well in the cluster will be measured. The groundwater elevation measurements in each well in the cluster will be compared to determine whether there are upward or downward gradients in the alluvial aquifer at that location.

2.12 Groundwater Sampling

Following well development activities at all new PA5 to 7 wells, an initial measurement of field pH, specific conductance, temperature, and water level will be recorded and a groundwater sample collected for TDS laboratory analysis. As part of this Work Plan, a second set of groundwater samples will be collected from all new PA5 to 7 wells during the second semi-annual groundwater monitoring event in September 2015. NV Energy will evaluate the results of the semi-annual groundwater sampling event and determine whether these additional wells need to be incorporated into the groundwater monitoring network. These groundwater samples will be collected for field measurement of pH, specific conductance, temperature, turbidity, dissolved oxygen (DO), oxygen reduction potential (ORP), dissolved iron (II), and dissolved manganese. In addition, groundwater samples will be collected for laboratory analyses. Table 2-6 shows the parameters and methods for the field and laboratory analyses. Sampling procedures are specified in Section B2 of the NV Energy QAPP

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Table 2-6 Groundwater Analytical Parameters

Parameters	Analytical Method	Target Method Reporting Limit (mg/L)	Lowest Relevant Standard (mg/L)[a]
Field Parameters			
pH	EPA 150.1	NA	NS
Specific Conductance	EPA 120.1	NA	NS
Temperature	SM 2550 B	NA	NS
Turbidity	EPA 180.1	NA	NS
Dissolved Oxygen (DO)	SM 5210B	NA	NS
Oxidation Reduction Potential (ORP)	APHA SM2580	NA	NS
Fe (II)-dissolved	HACH Method 8146	NA	NS
Manganese-dissolved	HACH Method 8034	NA	NS
General Chemistry			
Alkalinity (bicarbonate)	EPA SM-2320B	6	NS
Alkalinity (carbonate)	EPA SM-2320B	6	NS
Alkalinity	EPA SM-2320B	6	NS
Ammonia (Nitrogen, Ammonia (as N))	EPA 350.1	0.50	0.209[d]
Dissolved Organic Carbon (DOC)	SM 5319 B	1.0	NS
Chloride	EPA 300.0/9056A	2.0	400[c]
Density	Veritas SOP/ ASTM D1429-13 (See Appendix D)	1.0	NS
Fluoride	EPA 300.0/9056A	0.40	0.80[e]
Nitrate (as N)	EPA 300.0/9056A	0.10	10[b]
Nitrite	EPA 300.0/9056	0.10	1[d]
Specific Conductance	EPA 9050A	2.0 umhos/cm	NS
Phosphorous, Dissolved	EPA 365.2	0.10	0.1[f]
Sulfate	EPA 300.0/9056A	2.0	500[c]
Sulfide	SM-4500S2 D	0.050	NS
Sulfite	SM-4500-SO3B	2.0	NS
Total Dissolved Solids (TDS)	SM-2540C	20	723[g]
Total Oxygen Demand (TOD)	ASTM D6238	20	NS
Total Kjeldahl Nitrogen (TKN)	EPA 351.2	0.50	NS
Metals			
Aluminum, Dissolved	EPA 6010B	0.10	0.05[d, f]
Antimony, Dissolved	EPA 200.8/EPA 6020	0.0030	0.006[b]
Arsenic, Dissolved	EPA 200.8/EPA 6020	0.003	0.000052[e]
Barium, Dissolved	EPA 200.7/EPA 6010	0.010	2[b]
Boron, Dissolved	EPA 200.7/EPA 6010	0.050	0.75[h]
Cadmium, Dissolved	EPA 200.8/EPA 6020	0.001	0.000 5[i, j]
Calcium, Dissolved	EPA 200.7/EPA 6010	2.0	NS
Chromium, Dissolved	EPA 200.7/EPA 6010	0.002	0.1[b]
Iron, Dissolved	EPA 200.7/EPA 6010	0.10	0.30[d, f]
Magnesium, Dissolved	EPA 200.7/EPA 6010	2.0	150[c]
Manganese, Dissolved	EPA 200.7/EPA 6010	0.001	0.02[d]
Molybdenum, Dissolved	EPA 200.7/EPA 6010	0.003	0.1[e]
Nickel, Dissolved	EPA 200.7/EPA 6010	0.01	0.39[e]
Potassium, Dissolved	EPA 200.7/EPA 6010	0.50	NS
Selenium, Dissolved	EPA 200.8/EPA 6020	0.002	0.005[i]
Sodium, Dissolved	EPA 200.7/EPA 6010	0.50	NS
Thallium, Dissolved	EPA 200.8/EPA 6020	0.0010	0.0002[e]
Vanadium, Dissolved	EPA 200.7/EPA 6010	0.010	0.086[e]
Water Forensics			
Compound Specific Isotope Analysis (CSIA) on water (hydrogen 2H/1H (δD)	CRDS	NS	NS
CSIA on water (oxygen 18O/16O (δ18O)	CRDS	NS	NS
CSIA on sulfate(34S/32S (δ34S)	CRDS	5.0	NS
CSIA on sulfate (18O/16O (δ18O))	CRDS	5.0	NS
Coliform Bacteria	SM 9223	1.0 MPN/mL	Not present

Note: Target Method Reporting Limits assume that laboratory dilution will not be required.

Note: Dissolved parameters will be filtered at the laboratory

NA denotes no limit available
NS denotes no standard available
SOP denotes standard operating procedure
[a] These values are provided for information purposes only to identify appropriate target method reporting limits, and have not yet been agreed upon with NDEP
[b] ***Federal/Nevada Primary MCL:*** *Primary Maximum Contaminant Level (MCL)* **--** January 2013.
[c] **Nevada** ***Secondary MCL:*** *Nevada Secondary MCL* – January 2013
[d] ***NDEP BCL - Residential Water:*** *NDEP Basic Comparison Level (Residential Water)***—** Source: *Updated User's Guide and Tables* (August 2013).
[e] ***EPA Tap Water*** **:** *EPA Regional Screening Level (RSL) (Tap Water)-* - EPA's Risk Assessment Guidance for Superfund, Part B Manual (1991). (EPA, November 2014).
[f] ***Nevada Water Quality Standard Beneficial Uses:*** *NAC 445A.2168* (Muddy River at the Glendale Bridge)
[g] ***Nevada Water Quality Standard for Salinity:*** *NAC 445A.1233 "Below Hoover Dam"; flow-weighted annual average standard*
[h] ***Nevada Water Quality Standard Irrigation:*** *NAC 445A.1236* (Standards for toxic materials applicable to designated waters)
[i] ***Nevada Water Quality Standard Aquatic Life 96-hour average****: NAC 445A.1236* (Standards for toxic materials applicable to designated waters); hardness = 300 mg/L in formulas for cadmium; standard may be exceeded once every three years
[j] Laboratory method reporting limit below lowest applicable water quality standard for dissolved cadmium cannot be achieved by standard laboratory methods; values below method reporting limit will be considered in compliance with applicable water quality standards

After completion of the groundwater elevation measurements, all wells will be purged prior to sampling in accordance with the NV Energy QAPP. At each sampling location, all bottles designated for a particular analysis will be filled sequentially before bottles designated for the next analysis are filled in accordance with the NV Energy QAPP. Groundwater samples will be transferred from the tubing directly into the appropriate sample containers with preservative, if required, chilled if appropriate, and processed for delivery or shipment to the laboratory. When transferring samples, care will be taken not to touch the tubing to the sample container.

2.13 Sample Containers, Preservation, and Storage

Veritas Laboratories will provide the appropriate sample containers and preservatives for all groundwater and soil sampling events. The sample containers, preservation, and storage will be as specified in Table 3 in Section B2 of the NV Energy QAPP and per Section 3.0 of the Veritas Quality Assurance Quality Control Plan in Appendix C of the NV Energy QAPP.

2.14 Surveying

The locations of the HPT borings, surface soil samples, and newly installed monitoring wells will be surveyed by NV Energy surveyors consistent with the previous monitoring well surveying at the Site. In addition to surveying the horizontal and vertical locations, the ground surface elevation and north side of the top of casing at each well will be surveyed. All surveying will tie into the existing Site coordinate system and the data will be provided electronically by the surveyors so it can be integrated into the AOC Geographic Information System (GIS).

2.15 Field Documentation

All documentation of field activities will be as specified in Section A9.0 of the NV Energy QAPP. Sample handling and shipment will be as specified in Section B3.0 and detailed in Appendix E of the NV Energy QAPP. Field data will be recorded in the logbook, on field activity forms, and/or electronically. Photographs of field activities will be taken and included in the PA5 to 7 Groundwater and Soil Characterization Implementation Report. At the end of each day, the Field Team Leader will send a report to the Project Lead summarizing the field activities completed that day.

2.16 Decontamination

All equipment that comes into contact with soil and groundwater will be decontaminated prior to each use in accordance with the EPA Region 9 decontamination procedures referenced in Appendix E of the NV Energy QAPP. Where practical, disposable equipment will be used and will not be decontaminated.

2.17 Investigation Derived Waste

Investigation-derived waste will be disposed in accordance with applicable regulations. Soil cuttings will be screened with a photoionization detector (PID) and if less than 100 parts per million (ppm) the cuttings will be temporarily containerized and then disposed of in NV Energy's onsite landfill in accordance with the Southern Nevada Health District (SNHD) permit. Well development and decontamination water will be containerized and disposed in the onsite evaporation ponds in accordance with NV Energy's Authorization to Discharge permit. Decontamination chemicals such as non-phosphate detergent and deionized (DI) water will be collected and containerized as described in SOP 2006 Appendix E of the NV Energy QAPP.

Section 3

Quality Control

Quality control (QC) measures will be conducted in accordance with the NV Energy QAPP. The collection of QC samples (e.g. equipment blanks, duplicate samples, etc.) as well as the data validation process is discussed below.

3.1 Quality Control Samples

In accordance with Table 4 in Section B5.2 of the NV Energy QAPP, the QC requirements pertaining to soil and water samples collected for laboratory analysis are listed in Table 3-1. The frequency of these activities will be based on the combined field activities occurring at any given time during the implementation of the MRI, PA2, PA3, and PA5 to 7 Work Plans.

Table 3-1 QC Sampling and Analysis Summary

AOC Implementation Activity	Organization	Frequency of Activity
Field Blank	Stanley Consultants /OGI	1 per day or 5% of primary field samples (whichever is less) as specified in Section B5.2.2.1 of the QAPP
Equipment Rinsate Blank	Stanley Consultants /OGI	1 per day or 5% of primary field samples (whichever is less) as specified in Section B5.2.2.1 of the QAPP
Blind Field Duplicate Sample	Stanley Consultants /OGI	1 per day, per medium, per analytical method as specified in Section B5.2.2.3 of the QAPP. No duplicate samples required for soil samples.

AOC Implementation Activity	Organization	Frequency of Activity
Trip Blank	Stanley Consultants /OGI/ Veritas Laboratories	Not applicable – no volatile organic analyses
Lab Reagent Blank	Veritas Laboratories	As specified in standard method SOP, Appendix C of the QAPP
Method Blank	Veritas Laboratories	As specified in standard method SOP, Appendix C of the QAPP
Matrix Spike/Matrix Spike Duplicate	Veritas Laboratories	As specified in standard method SOP, Appendix C of the QAPP
Lab Control Sample	Veritas Laboratories	As specified in Appendix C of the QAPP
General Bottle Control	Veritas Laboratories	Certified by Manufacturer

During the PA5 to 7 Groundwater and Soil Characterization sampling events, blanks and duplicate samples will be collected in accordance with the NV Energy QAPP and Table 3-1. Sampling locations will be documented in the field logbook and/or on the Field Summary Forms in Appendix D of the NV Energy QAPP. Field blanks will be used to check for analytical artifacts and/or site background contaminants introduced by sampling, transportation, and analytical procedures. These QC samples will be collected by pouring laboratory-provided DI water into sample containers provided by Veritas Laboratories in the area of the field investigations.

Equipment or rinsate blanks will be used to check field decontamination procedures and will be collected by pouring laboratory-provided DI water through a sampling device after decontamination. If the sampling equipment (i.e., disposable bailer) is certified contaminant-free by the manufacturer, equipment blanks will not be collected during the use of that device.

Field duplicate samples will be used to evaluate the variance of the sampling and laboratory analysis methods. These QC samples will be collected by the same procedures and at the same time as the corresponding primary field sample in accordance with the NV Energy QAPP. The primary and duplicate samples will be assigned different (unique) sample identifiers (i.e., Sample IDs) that do not indicate to the laboratory that they are duplicate samples. No duplicate samples are required for soil samples.

The HPT operator will perform a pre-log Quality Assurance (QA) test on the probe tool prior to each boring. A test jig and test load will be used to verify the electrical continuity and isolation of the EC system. A reference tube will be used to verify the accuracy of the pressure sensors. If the results are more than 10% out of range, the probe fails the QA test. The results of the QA test are automatically saved to the information file for each log. Initially, HPTs will be advanced adjacent to former soil boring locations where logs are available to confirm the interpretation of the HPT logs. In addition, HPT profiles will be compared to Sonic soil cores as they become available. Periodically, groundwater samples will be collected for laboratory TDS analyses and field specific conductance measurements to verify the accuracy of the EC logs. If discrepancies are found, the HPT operator will recalibrate, repair or replace the probe, if necessary.

3.2 Field Equipment Calibration

Field equipment will be calibrated as shown in Table 3-2. The frequencies meet the minimum requirements specified by the equipment manufacturer, industry SOPs, and EPA guidance.

Table 3-2 Field Equipment Calibration Frequency

Field Instrument	Calibration Checks	
	Pre-Field Bench Check at Mobilization	On-Site
Temperature/pH Meter	X	Daily or if conditions change
Specific Conductance meter	X	Daily or if conditions change
DO	X	Daily or if conditions change
ORP	X	Daily or if conditions change
HACH Dissolved Iron (II)	X	Daily or if conditions change
HACH Dissolved Manganese	X	Daily or if conditions change
Turbidimeter	X	Daily or if conditions change
Hydraulic Profiling Tool	X	Prior to use at each boring location

3.3 Data Usability/Validation

Data from all soil samples collected for SC analyses will be submitted to Ordway and Associates for third party data validation and usability determination. Stage 2B and 4 data validation will be conducted in accordance with the Revised Data Validation Memorandum of Understanding dated March 5, 2010 and approved by the NDEP on March 10, 2010, as provided in Appendix H of the NV Energy QAPP. Data validation will not be conducted on the soil samples collected for the other specialized analyses (SG, SP, SL, and SF).

Groundwater samples from the new PA5 to 7 wells will be submitted for third party data validation (excluding the density and WF analyses). However, due to the anticipated large number of samples to be analyzed, Stage 4 data validation will be conducted on 10% of the samples in each sample delivery group rather than 20%, as specified in the Revised Data Validation Memorandum of Understanding dated March 5, 2010. Discrete groundwater samples collected by HPT from any of the PA5 to 7 wells and by direct push from DP-P-24 will not be validated because these samples are screening analyses only. The surface water samples collected for WF analyses are specialty analyses that will also not be validated. Because groundwater samples collected as part of NV Energy's semi-annual groundwater monitoring program are not validated, the groundwater samples from the existing monitoring wells that are collected during the second semi-annual monitoring event in September 2015 will also not be validated. However, a cation-anion balance check will be conducted in accordance with Section D2 of the NV Energy QAPP on all groundwater samples collected from the new PA5 to 7 wells and the existing wells as part of NV Energy's semi-annual groundwater monitoring program.

Section 4

Field Variances

During the implementation of the PA5 to 7 Groundwater and Soil Characterization Work Plan, it may be necessary to make minor modifications to the planned activities in the field as conditions change. The Field Team Leader will consult with the Project Lead and the Quality Assurance Officer (QAO) on available options and the potential impact to the investigation objectives. If the selected alternative is deemed to have no significant impact on the investigation objectives, it will be implemented and documented in the PA5 to 7 Groundwater and Soil Characterization Report. However, if the modification is deemed to have a potentially significant impact on the investigation objectives, work will stop until the NDEP or their representative can be consulted regarding the changes. If concurrence with the modifications to the PA5 to 7 Groundwater and Soil Characterization Work Plan cannot be reached, NV Energy may decide to proceed at risk knowing that NDEP may not agree to use of the data for decision making purposes.

It is anticipated that saturated soils and locations without existing roads may limit NV Energy's ability to install some monitoring wells and HPT borings. NDEP will be notified if any of the planned locations cannot be accessed in spite of NV Energy's efforts to clear vegetation and provide access suitable for the field vehicles.

All modifications to the NDEP-approved PA5 to 7 Groundwater and Soil Characterization Work Plan will be documented and discussed in the PA5 to 7 Groundwater and Soil Characterization Report.

Section 5

Data Evaluation and Reporting

The following section explains how the data collected during the implementation of the PA5 to 7 Groundwater and Soil Characterization Work Plan will be evaluated to address the objectives presented in Section 1 (objectives are listed in *italics*). In addition, a data management approach is provided to describe how the data will be compiled, reviewed and reported.

5.1 Data Evaluation

1. *Characterize horizontal and vertical extent of groundwater Impacts.* The data used to meet this objective will include specific conductance data, TDS data, and EC logs from HPT borings; discrete groundwater sampling data from DP-P-24; and groundwater quality data from newly installed and existing monitoring wells. The vertical extent of groundwater impacts in the alluvial aquifer will be evaluated using data collected with depth. Groundwater quality (i.e., TDS) changes with depth will be evaluated to determine the depth at which concentrations do not appear to be impacted by the ponds. The groundwater quality data collected from newly installed and existing monitoring wells during the semi-annual groundwater monitoring event in September 2015 will be used to prepare contaminant contour maps for representative parameters (e.g., TDS). This data will be used to evaluate the lateral extent of groundwater impacts.

2. *Evaluate plume stability (current and future).* The data used to meet this objective will be the same as the data used to meet the first objective. The contaminant contour maps developed to meet the first objective will also be used to evaluate plume stability by comparing the current lateral extent of groundwater impacts with the lateral extent indicated by contours developed using historic data (where appropriate). Groundwater quality data from the newly installed wells will be entered into the EPA Monitoring and Remediation Optimization System (MAROS, 2006) model to be developed with data from existing monitoring wells in the PA5 to 7 area. The MAROS model will use

statistical methods to evaluate overall plume stability as well as concentration trends in individual wells.

3. *Characterize potential secondary source beneath ponds.* The potential secondary source will be characterized by analyzing soil samples collected with depth beneath the ponds at P-23D, P-24D, and P-25D. The potential for contaminants from these soils to leach over time will be evaluated through SBLT analyses of these soil samples. In addition, data from soil samples analyzed for geochemical parameters will be used to evaluate the potential for geochemical conditions to limit migration of contaminants from the soils beneath the ponds to receptors and to confirm the geochemical CSM.

4. *Evaluate whether preferential flow paths are present.* The geologic and hydrogeologic information collected during the HPT borings and the Sonic drilling will be used to evaluate subsurface conditions and the potential presence of preferential flow paths. The geologic data will be used to update previously prepared geologic fence diagrams (CSM2 and MRI-3 on Figure 1A and CMS-1 on Figure 1B) as well as to create a new one (MRI-P2 on Figure 1B). Isopach diagrams of areas with higher permeability may be prepared, if appropriate. Permeability data from HPT logs and samples collected from P-23D, P-24D, and P-25D will be used to evaluate the permeability of different geologic units observed and their potential to be preferential flow paths.

5. *Evaluate potential density-driven groundwater flow.* Groundwater samples collected with depth during the discrete groundwater sampling in DP-P-24 as well as from the newly installed monitoring wells will be submitted for laboratory density testing. This density data, along with TDS concentrations in the samples, will indicate whether there is the physical potential for density-driven groundwater flow. Groundwater density information will be combined with other measurements and analyses to evaluate the potential for density-driven groundwater flow.

6. *Evaluate vertical hydraulic gradients.* Groundwater elevations from existing and new wells installed at different depths at the same location will be compared to evaluate vertical hydraulic gradients at each location.

7. *Gather information to support possible future groundwater modeling efforts.* Essentially all of the data collected will support future groundwater modeling efforts because it will inform the Site-wide CSM. For example, the geologic information will be used to define the depth of the alluvial aquifer. Hydraulic conductivity data from HPT borings and soil samples will be used to identify an appropriate hydraulic conductivity value to use in a model. The groundwater elevation data from new and existing wells will be important for setting up and calibrating a model.

8. *Estimate downgradient mass flux from groundwater underlying the D/E/F/G Ponds.* The mass flux of TDS in groundwater from the D/E/F/G Ponds will be calculated approximately in accordance with the Interstate Technology and Regulatory Council (ITRC) guidance document on the method for measurement of mass flux and mass discharge (ITRC, 2010). Calculations will be made to estimate the mass flux of TDS

from groundwater underlying the ponds to the Muddy River and Hidden Valley Ranch, if any. These data will inform the Muddy River Investigation.

9. *Gather information to support corrective action planning.* All of the information collected to support previous objectives will also be used to evaluate whether corrective action is needed to protect potential receptors and, if so, what types of corrective action approaches might be feasible for the PA5 to 7 area.

10. *Gather data to contribute to geochemical understanding.* Groundwater data collected from the newly installed monitoring wells will be used to evaluate the geochemical conditions in the groundwater. This data will be combined with the soil analyses that evaluate the speciation of metals, the leaching potential of soils, and the capacity of the soils to attenuate contaminants. Paired data from collocated discrete groundwater and soil sampling at DP-P-24 will also be used to evaluate geochemical equilibrium, which will be used to inform the geochemical CSM. All of this data will be used to refine the existing preliminary geochemical CSM that evaluates whether contaminants in the PA5 to 7 area are likely to reach potential receptors at concentrations of concern.

11. *Gather data to contribute to development of the Site-wide CSM.* All of the data from this investigation will be used to strengthen the Site-wide CSM.

12. *Gather data to distinguish between naturally-occurring soil/groundwater concentrations and impacts from Ranch or Site operations.* The surface soil data will be used to evaluate whether the surface deposits are from natural wicking of salts to the surface or due to groundwater contamination and/or past seepage from the pond berms. The WF data will be used to establish chemical signatures for the different water types (native groundwater, Station groundwater, Ranch groundwater, scrubber effluent, and Muddy River). WF data from groundwater samples collected in the Ranch area will be compared with the WF results for the different water types to evaluate whether Ranch groundwater is impacted by Station activities, the Muddy River and/or by Ranch activities.

5.2 Data Management

Each day, the Stanley Consultants Project Lead will review and compile the following information:

- Field progress
- Field notes and observations
- Field measurements
- Chain-of-custody forms
- HPT logs
- Sonic boring logs (field notes)
- Photographs

Each week, the Stanley Consultants Project Lead will provide NDEP, NV Energy, and the California Department of Water Resources (CDWR) with a report that includes the daily information for the past week as well as the following information, when available:

- Schedule of field activities (previous week, current week, next two weeks)
- Tables of field measurements
- Tables of non-validated laboratory results – estimated to be available six weeks following data collection
- Boring logs/well construction diagrams

If NDEP has comments regarding the format or content of the information presented in the weekly report, NV Energy requests that those comments be provided in a timely manner so necessary adjustments can be made to the data management and field activities.

In December 2015, a workshop will be conducted with NDEP to discuss data collected during implementation of the PA2, PA3, and PA5 through 7 Work Plans as well as the MRI Work Plan. This workshop will focus on the present data collected in 2015 and how it supports a Conceptual Site Model (CSM) for the Reid Gardner Station. In 2016, PA2, PA3, and PA5 through 7 Work Plan Implementation Reports will be prepared presenting the results of the pond work plan implementation.

Section 6

Schedule

NV Energy plans to begin the PA5 to 7 Groundwater and Soil Characterization field activities in March 2015 with the drilling activities scheduled to be completed in June 2015. The second semi-annual groundwater sampling event is scheduled for September 2015. In accordance with the AOC, NDEP will be notified at least 14 days prior to conducting sampling activities outlined in this Work Plan. The tentative schedule of field activities proposed in this Work Plan is presented in Table 6-1 below.

Table 6-1 Proposed Field Activities Schedule

Activity	Field Schedule	Locations
Utility Clearance and HPT Borings	March/April 2015	HPT-P-23, HPT-P-24, HPT-P-25, HPT-P-26, HPT-KMW-4R, HPT-KMW-5R, HPT-KMW-21, HPT-KMW-30, HPT-1-RA, HPT-1-PA-7, HPT-2-PA7, HPT-3-PA-7,
Discrete Groundwater Sampling	April/May 2015	DP-P-24
Sonic Drilling, Soil Sampling, Well Installation, and Surveying	April through June 2015	P-23S/M/D, P-24S/M/D/MC, P-25S/M/D, P-26S/M/D, P-27M/D, P-30M/D, KMW-4SR/MR/DR, KMW-21S/M/D, KMW-24M/D, KMW-30S/M/D
Well Abandonment	June/July 2015	KMW-3S/M/D, KMW-4S/M/D, KMW-5S/M/D, and KMW-6S/M/D
Surface Soil Sampling, EFPS sampling, and river sampling	April/May/June 2015	EFPS, MR-1, MR-2, MR-3, MR-4, SS-1, SS-2, SS-3, SS-4, SS-5, SS-6, and SS-7
Groundwater Elevation Measurement and Sampling	Following well development and September 2015	P-23S/M/D, P-24S/M/D/MC, P-25S/M/D, P-26S/M/D, P-27S/M/D, P-30S/M/D, KMW-4SR/MR/DR, KMW-21S/M/D, KMW-24S/M/D, KMW-30S/M/D

Section 7

References

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Stanley Consultants, 2014. *Background Conditions Report*, NV Energy, Reid Gardner Station, Moapa, Nevada, December 2014.

Section 8

Acronyms and Abbreviations

AOC	Administrative Order on Consent
ASTM	American Society for Testing and Materials
BCL	Basic Comparison Level
bgs	below ground surface
bgws	below groundwater surface
BTV	Background Threshold Value
CEM	Certified Environmental Manager
CSIA	Compound-Specific Isotope Analysis
CSM	Conceptual Site Model
DI	Deionized
DMR	Discharge Monitoring Report
DO	Dissolved Oxygen
DOC	Dissolved Organic Carbon
EC	Electrical Conductivity
EFPS	Effluent Forwarding Pump Station
GIS	Geographic Information System
HASP	Health and Safety Plan
HPT	Hydraulic Profiling Tool
ITRC	Interstate Technology and Regulatory Council
LOI	Loss On Ignition
MAROS	Monitoring and Remediation Optimization System
MCL	Maximum Contaminant Level
mg/kg	milligrams per kilogram
mg/L	milligrams per liter
MRI	Muddy River Investigation
MRL	Method Reporting Limit
MW	Monitoring Well
NDEP	Nevada Division of Environmental Protection
ORP	Oxidation Reduction Potential
pH	Measure of acidity or alkalinity

PID	Photoionization Detector
ppm	parts per million
PVC	Polyvinyl Chloride
QA	Quality Assurance
QAO	Quality Assurance Officer
QAPP	Quality Assurance Project Plan
QC	Quality Control
SBLT	Sequential Batch Leaching Test
SC	Soil Chemical analyses
SF	Soil Forensics
SG	Soil Geochemical analyses
Site	Reid Gardner Station Property (entire property)
SL	Soil Leaching analyses
SNHD	Southern Nevada Health District
SOP	Standard Operating Procedure
SP	Soil Physical testing
TDS	Total Dissolved Solids
TKN	Total Kjeldahl Nitrogen
TOC	Total Organic Carbon
TOD	Total Oxygen Demand
USA	Underground Service Alert
USCS	Unified Soil Classification System
XRD	X-Ray Diffraction
XRF	X-Ray Fluorescence
WF	Water Forensics

Appendix A

Figures and Table

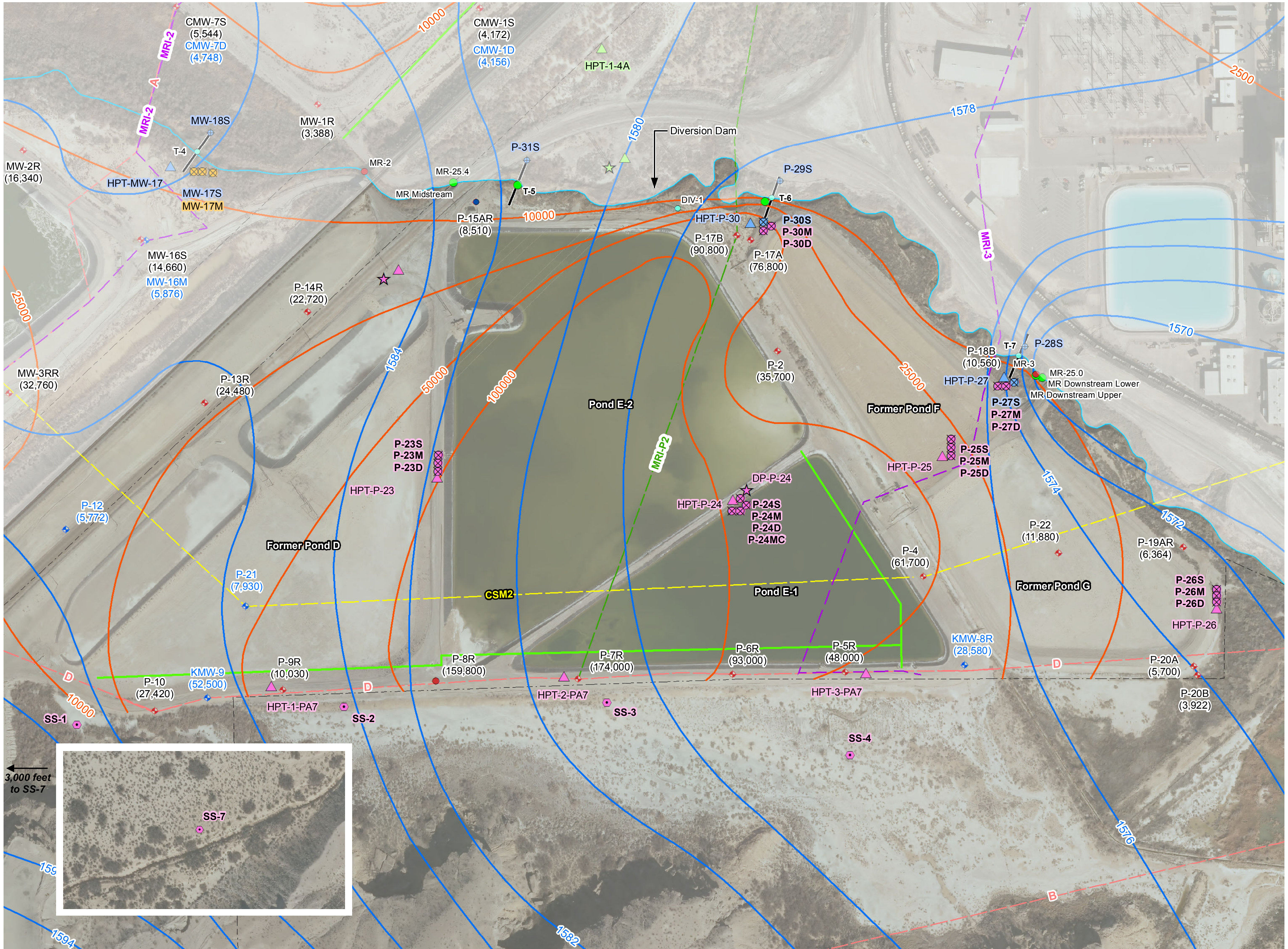
TABLE 1
NV Energy Reid Gardner Station - Proposed 2015 AOC Activities
PA5, PA6, PA7 - Ponds D/E/F/G Groundwater and Soil Characterization Work Plan

Field Activity	Objectives	Location/Quantity	Discussion	Field Measurements	Laboratory Analyses
Hydraulic Profiling (by Direct Push Hydraulic Profiling Tool [HPT])	1. Characterize horizontal and vertical extent of groundwater impacts 2. Evaluate plume stability (current and future) 4. Evaluate whether preferential flow paths are present 5. Evaluate potential density-driven groundwater flow 6. Evaluate vertical hydraulic gradients 7. Gather information to support possible future groundwater modeling efforts 8. Estimate downgradient mass flux from groundwater underlying the ponds to the D/E/F/G ponds 9. Gather information to support corrective action planning 11. Gather data to contribute to development of the Site-wide CSM	HPT-P-23, HPT-P-24, HPT-P-25, HPT-P-26, HPT-KMW-4R, HPT-KMW-30, HPT-KMW-21, HPT-1-RA, HPT-1-PA7, HPT-2-PA7, HPT-3-PA7, HPT-KMW-5R	HPT push conducted at each well location to collect continuous geologic information & water quality data with depth; assist with determining well location & screened interval. Push each HPT to top of Muddy Creek Formation & collect confirmatory soil lithology sample, if possible. Hydraulic conductivity data collected at selected locations during HPT push. Collect TDS samples to check correlation with conductivity. HPT-1-RA will help evaluate extent of groundwater contamination on Ranch property. HPT-1-PA-7, HPT-2-PA-7, and HPT-3-PA-7 will help evaluate horizontal & vertical extent of groundwater contamination in area of highest concentrations.	Specific conductance, hydraulic conductivity	TDS (selected samples)
Discrete Groundwater Sampling in Pond Area (by Protected Screen Sampler)	1. Characterize vertical extent of groundwater impacts 2. Evaluate plume stability (current and future) 3. Characterize potential secondary source beneath ponds 5. Evaluate potential density-driven groundwater flow 7. Gather information to support future groundwater modeling efforts 9. Gather information to support corrective action planning 10. Gather data to contribute to geochemical understanding 11. Gather data to contribute to development of the Site-wide CSM	DP-P-24 Collect 9 groundwater samples, where present, at 6"-12" , 2.0' -2.5', 4.5'- 5', 10', 15' , 20' , 40', 60' and 80' below pond bottom (~10-15 below top of berm)	Groundwater sampling by protected screen sampler (e.g., "Geoprobe SP15" or equivalent) (paired soil sampling described below) to evaluate geochemical equilibrium between soil and groundwater and assess attenuation parameters. Push decontaminated protected-screen sampler to each sampling depth interval. Sampling intervals may be adjusted based on procured tool screen length. Analyses may be prioritized due to limited sample volume and/or time required to recharge. TDS laboratory analyses will be fast turnaround (~24 hrs) and will be used to confirm HPT conductivity.	General measurements: pH, specific conductance, temperature, turbidity	Field filtered: GW-C, GW-P, arsenic speciation (III, V), selenium speciation (0,-II, IV, VI), chromium (VI), iron (II), iron (III))
Soil Sampling in Pond Area (by Sonic Boring)	3. Characterize potential secondary source beneath ponds 4. Evaluate whether preferential flow paths are present 7. Gather information to support future groundwater modeling efforts 9. Gather information to support corrective action planning 10. Gather data to contribute to geochemical understanding 11. Gather data to contribute to development of the Site-wide CSM	P-23D, P-24D, P-25D Collect 9 samples at 6"-12", 2.0' -2.5', 4.5'- 5', 10', 15' , 20' , 40', 60' and 80' below pond bottom (~10-15 below top of berm) for soil chemical (SC) analysis, where there are changes in lithology (i.e. grain size, visual appearance). Pick three samples in 0-20' below pond bottom and up to 5 samples below 20 feet below pond bottom to characterize changes in lithology and for soil physical (SP) analysis. Selected physical samples will be analyzed for permeability. Collect two samples at 6-12" and 2.0-2.5' below pond bottom for soil leaching (SL) analysis Collect three samples at 6-12", 4.5-5.0', and 20' below pond bottom for soil geochemical (SG) analysis. No batch adsorption tests inside the pond area.	The center of the ponds are likely areas of greatest impacts (potential secondary source material). Originally there was one E Pond that was later divided into two ponds. P-23D is a location previously requested by NDEP. P-24D uses an existing berm to get close to the center of the former Pond E without removing pond solids. P-25D is used to evaluate both former Ponds F & G. Sonic boring will be conducted to the top of the Muddy Creek Formation (estimated to be 100' bgs) and penetrate into Muddy Creek Formation for confirmation. Boreholes penetrating the Muddy Creek formation will be backfilled and the well set at the bottom of the alluvial. Laboratory permeability tests will be undisturbed. Soil leaching and geochemical samples will be undisturbed, if possible. Soil leachant could be alluvial groundwater from BG-1S, KMW-2M or KMW-2D.	Geology will be logged and soil core will be saved for future reference.	SC, SP, SL, SG
Soil Sampling outside Pond Area (by Sonic Boring)	4. Evaluate whether preferential flow paths are present 7. Gather information to support future groundwater modeling efforts 9. Gather information to support corrective action planning 10. Gather data to contribute to geochemical understanding 11. Gather data to contribute to development of the Site-wide CSM	For KMW-4DR, KMW-30D, KMW-21D, KMW-24D, boring log only For P-26D, P-27D, P30-D, collect up to 4 soil samples based changes in lithology (i.e. grain size, visual appearance), for chemical and physical analyses. Collect two soil geochemical samples from each location based on HPT (two different lithologies). No speciation outside the pond area.	P-26 was selected as the furthest downgradient location on NVE property to evaluate contaminant concentrations and mass flux leaving the Station. KMW-4DR, KMW-30D, and KMW-24D replace wells that have been destroyed or will be abandoned. KMW-21 is a new well. They will all evaluate the extent of groundwater contamination on the ranch property. Deep sonic boring will be conducted to the top of the Muddy Creek Formation (estimated to be 100' bgs) and penetrate into Muddy Creek Formation for confirmation. Soil samples outside the ponds are needed to understand geology along the flowpath and near the river. Soil samples are also needed to quantify the attenuation capacity near the river and downgradient of the ponds. Soil geochemical samples will be collected at two different lithologies -fine grain and coarse grain, and from non-impacted soils. Soil geochemical samples will be undisturbed, if possible.	Geology will be logged and soil core will be saved for future reference.	P-26D, P-27D,and P-30D : SC, SG, SP
Surface Sampling	9. Gather information to support corrective action planning 11. Gather data to contribute to development of the Site-wide CSM 12. Gather data to distinguish between naturally-ocurring soil/groundwater concentrations and impacts from Ranch or site operations	For SS-1 , SS-2, SS-3, SS-4, SS-5, SS-6, and SS-7 sample precipitate on soil surface.	Evaluate whether surface deposits in this area where groundwater is at or near the surface are from natural wicking of salts to the surface or due to groundwater contamination and/or past seepage from the pond berms.	None	SF
Monitoring Well Installation (by Sonic Boring)	1. Characterize horizontal and vertical extent of groundwater impacts 2. Evaluate plume stability (current and future) 4. Evaluate whether preferential flow paths are present 5. Evaluate potential density-driven groundwater flow 6. Evaluate vertical hydraulic gradients 7. Gather information to support future groundwater modeling efforts 8. Estimate mass flux from groundwater underlying the ponds to the Muddy river 9. Gather information to support corrective action planning 11. Gather data to contribute to development of the Site-wide CSM	P-23S/M/D, P-24S/M/D/MC, P-25S/M/D, P-26S/M/D, P-27M/D, P-30M/D, KMW-4SR/MR/DR, KMW-30S/M/D, KMW-21S/M/D, KMW-24M/D	These wells evaluate the horizontal and vertical extent of groundwater contamination in the area of the ponds as well as downgradient under the Ranch property. A deeper well, MW-24MC, will be installed at the bottom of the alluvium to evaluate water quality and vertical gradients. Discrete groundwater TDS and HPT conductivity will aid in setting screens.	Geology will be logged and soil core will be saved for future reference.	None
Groundwater Sampling	1. Characterize horizontal and vertical extent of groundwater impacts 2. Evaluate plume stability (current and future) 4. Evaluate whether preferential flow paths are present 5. Evaluate potential density-driven groundwater flow 6. Evaluate vertical hydraulic gradients 7. Gather information to support future groundwater modeling efforts 8. Estimate mass flux from groundwater underlying the ponds to the Muddy River 9. Gather information to support corrective action planning 10. Gather data to contribute to geochemical understanding 11. Gather data to contribute to development of the Site-wide CSM 12. Gather data to distinguish between naturally-ocurring soil/groundwater concentrations and impacts from Ranch or site operations	For P-23S/M/D, P-24S/M/D/MC, P-25S/M/D, P-26S/M/D, P-27S/M/D, P-30S/M/D, KMW-4SR/MR/DR, KMW-30S/M/D, KMW-21S/M/D, KMW-24S/M/D, and existing wells, see lab analyses GW-C and GW-P For BG-1S, BG-1D, P-8R, P-23S/M/D, P-24S/M/D, P-26S/M/D, KMW-4SR/MR/DR, KMW-30S/M/D, KMW-21S/M/D, KMW-22, KMW-24S/M/D, KMW-26,-see lab analyses W-F	Sample new and existing wells concurrent with Q3 Groundwater Monitoring Report (GMR) semi-annual groundwater sampling event. Also sample selected wells to evaluate the isotopic signature of potential sources (ponds, ranch). Sample new wells after development.	General measurements-pH, specific conductance, temperature, turbidity (new wells after development and during Q3 GMR event) Geochemistry-DO, ORP, Fe(II) dissolved, manganese dissolved (new wells only during Q3 GMR event)	GW-C, GW-P, W-F, TDS (after development)
Surface/Pond Water Sampling	1. Characterize horizontal and vertical extent of groundwater impacts 11. Gather data to contribute to development of the Site-wide CSM 12. Gather data to distinguish between naturally-ocurring soil/groundwater concentrations and impacts from Ranch or site operations	EFPS, MR-1, MR-2, MR-3, MR-4	Collect surface water and pond water samples to evaluate the isotopic signature of potential sources. The surface/pond water signatures will be compared to groundwater in the Ranch. Sample concurrent with Q3 semi-annual groundwater sampling event.	pH, temperature, conductivity	W-F
Well Abandonment	N/A	KMW-3S/M/D, KMW-4S/M/D, KMW-5S/M/D, KMW-6S/M/D	Plug and abandon existing wells that are in poor condition and no longer useable for groundwater monitoring; eliminate potential conduit for surface contamination reaching the subsurface.	None	None

Notes:

SC	Soil Chemical Analyses (dry weight)- arsenic, antimony, boron, cadmium, chromium, fluoride, molybdenum, phosphorus,selenium, sulfate, sulfide, sulfite, thallium, moisture content, pH
SG	Soil Geochemical Analyses-arsenic speciation (III, V), selenium speciation (0,-II, IV, VI), chromium (VI), iron (II), iron (III), X-Ray Diffraction (XRD), X-Ray Fluorescence (XRF), Loss On Ignition (LOI), sequential extraction analysis, batch adsorption tests, total organic carbon (TOC)
SP	Soil Physical Analyses -atterberg limits, bulk density, grain size, percent moisture, permeability
SL	Soil Leaching potential by Sequential Batch Leaching Test (SBLT) using non-impacted groundwater as a leaching solution-arsenic, antimony, boron, cadmium, chloride, chromium, chromium (VI), fluoride, molybdenum, phosphorus, selenium, sodium, sulfate, total dissolved solids, thallium, pH
SF	Soil forensics- X-Ray Diffraction (XRD), X-Ray Fluorescence (XRF), Loss On Ignition (LOI), compound specific isotope analysis (sulfate (34S/32S (δ34S) and 18O/16O (δ18O))
GW-C	Groundwater Chemical Analyses for new wells (GMR analytes, lab filtered where applicable)- arsenic, dissolved; alkalinity (bicarbonate); alkalinity (carbonate); alkalinity; boron, dissolved; cadmium, dissolved; calcium, dissolved; chloride; chromium, dissolved; fluoride; magnesium, dissolved; manganese, dissolved; molybdenum, dissolved; nickel, dissolved; nitrate (as N); potassium, dissolved; selenium, dissolved; sodium, dissolved; specific conductance; sulfate; total dissolved solids; vanadium, dissolved; plus antimony, dissolved; barium, dissolved; thallium, dissolved; phosphorus, dissolved; (additional contaminants of concern). Existing wells will be sampled in accordance with GMR sampling requirements plus additional contaminants of concern.
GW-P	Groundwater Physical Analysis-density
W-F	Water Forensics-compound specific isotope analysis on water (2H/1H (δD) and 18O/16O (δ18O)) and sulfate (34S/32S (δ34S) and 18O/16O (δ18O)), coliform bacteria, aluminium, ammonia, iron, nitrite, sulfide, sulfite, TKN, dissolved organic carbon (DOC), total oxygen demand (TOD) . Add for BG-1S, BG-1D, KMW-22, and KMW-26: calcium, chloride, magnesium, manganese, potassium, sodium, sulfate. Add for EFPS, MR-1, MR-2, MR-3, MR-4: alkalinity (bicarbonate), alkalinity (carbonate), alkalinity, calcium, chloride, magnesium, manganese, potassium, sodium, sulfate
Well Clusters (S)	Shallow well screened across the observed groundwater table and less than 25 ft below the top of the observed groundwater surface
Well Clusters (M)	Medium depth well screened between 25 to 50 ft below the observed groundwater table surface
Well Clusters (D)	Deep well screened greater than 50 ft below the observed groundwater table surface
Well Clusters (MC)	Deeper well installed at the bottom of the alluvium

HPT will be utilized prior to Sonic drilling and monitoring well installation
HPT is assumed to have a maximum depth limit of 100 ft bgs
All new PA5, PA6, and PA7 wells will be 4-inch diameter



Legend

Proposed HPT with 2" Well
- MRI Work Plan

Proposed Sonic with 4" Well
- MRI Work Plan
- PA-2 Work Plan
- PA-3 Work Plan
- PA-5,6,7 Work Plan

Proposed Soil Surface Sample
- PA-5,6,7 Work Plan

Proposed Water Forensics Sample or Water Levels
- PA-5,6,7 Work Plan
- MRI Work Plan

Existing Monitoring Location (TDS in mg/L - 2013 Q3 GMR)
- Deep or Medium
- Shallow

Existing Surface Water Monitoring Location
- Surface Water Sampling
- Surface Water Elevation

Groundwater Elevation Contour (ft) 2013-Q3
TDS Concentration Contour (mg/L) 2013-Q3
Muddy River Transect
Muddy River Cross-Section (Existing)
Muddy River Cross-Section (Proposed by NDEP)[2]
CSM Workshop Cross-Section (Existing)
Background Report Cross Section (Existing)
Groundwater Trench
Muddy River

Proposed Geo-Probe
- PA-3 Work Plan
- PA-5,6,7 Work Plan

Proposed HPT
- MRI Work Plan
- PA-3 Work Plan
- PA-5,6,7 Work Plan

275 137.5 0 275 550 Feet

Notes:
1. Aerial imagery provided by Clark County Assessor Office; photographs taken Spring 2013
2. Muddy River cross-section lines (proposed by NDEP) to be created after work plan implementation

Stanley Consultants INC.

August 2015

PA5, PA6, PA7 PROPOSED SAMPLING
Ponds D/E/F/G Groundwater and Soil Characterization Work Plan

NV Energy
Reid Gardner Station
Moapa, NV
Figure 1A

REV	No.	REVISION DESCRIPTION	DATE	DRWN	CHKD	APVD
4		Submittal to NDEP (revised report)	8/06/15	CC	JS	RLS
3		Submittal to NDEP	5/12/15	CC	JS	RLS
2		Submittal to NDEP	3/12/15	CC	JS	RLS
1		Submittal to NDEP	1/09/15	CC	AE	RLS
0		Submittal to NDEP	12/01/14	JS/CC	TK/AE	RLS

0 1 in.
At full size
1 inch = 275 feet

NVEnergy

20618.09.38

REV. 4

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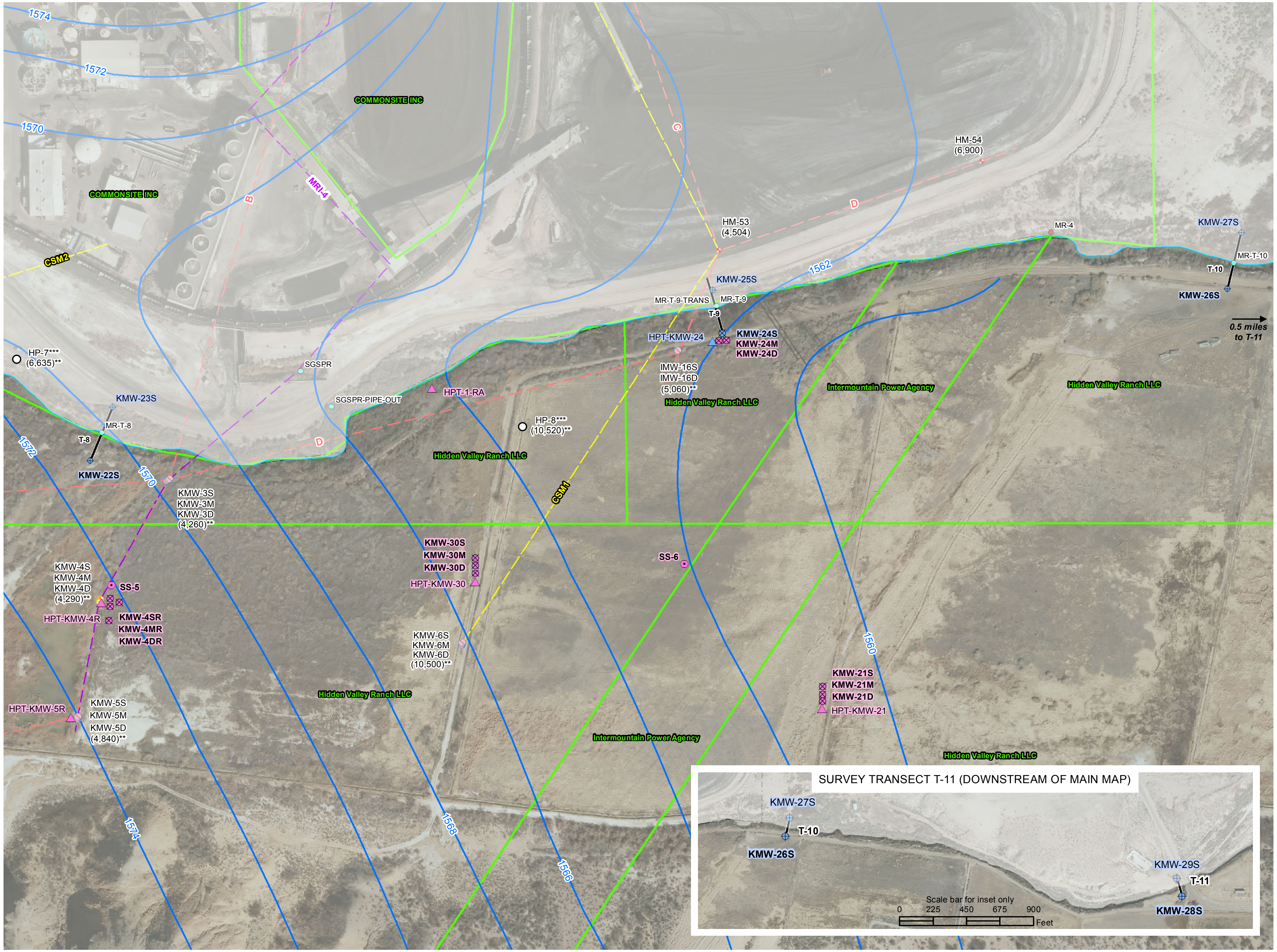

Legend

Proposed HPT with 2" Well
- MRI Work Plan

Proposed Sonic with 4" Well
- MRI Work Plan
- PA-5,6,7 Work Plan

TransparencyPolygons

Proposed Geo-Probe
- PA-5,6,7 Work Plan

Proposed Water Forensics Sample at Existing Location
- PA-5,6,7 Work Plan

Existing Monitoring Location (TDS in mg/L - 2013 Q3 GMR)[3,4]
- Deep or Medium
- Shallow
- To Be Abandoned
- To Be Replaced

Existing Surface Water Monitoring Location
- Surface Water Sampling

Groundwater Elevation Contour (ft) 2013-Q3
Muddy River Transect
Muddy River Cross-Section (Existing)
Muddy River Cross-Section (Proposed by NDEP)[2]
CSM Workshop Cross-Section (Existing)
Background Report Cross Section (Existing)
Muddy River
Parcel Boundary (March 2012)

Proposed Soil Surface Sample
- PA-5,6,7 Work Plan

Proposed HPT
- MRI Work Plan
- PA-5,6,7 Work Plan

225 112.5 0 225 450 Feet

Notes:
1. Aerial imagery provided by Clark County Assessor Office; photographs taken Spring 2013
2. Muddy River cross-section lines (proposed by NDEP) to be created after work plan implementation
3. **TDS values in units mg/L from 1999-Q4 figure (AOC-109)
4. ***HP-X sampling locations from 1999-Q4 figure (AOC-109)

Stanley Consultants INC.

August 2015

PA5, PA6, PA7 (HIDDEN VALLEY RANCH)
PROPOSED SAMPLING
Ponds D/E/F/G Groundwater and Soil
Characterization Work Plan
NV Energy
Reid Gardner Station
Moapa, NV
Figure 1B

REV	No.	REVISION DESCRIPTION	DATE	DRWN	CHKD	APVD
4		Submittal to NDEP (revised report)	8/06/15	CC	JS	RLS
3		Submittal to NDEP	5/12/15	CC	JS	RLS
2		Submittal to NDEP	3/12/15	CC	JS	RLS
1		Submittal to NDEP	1/09/15	CC	AE	RLS
0		Submittal to NDEP	12/01/14	JS/CC	TK/AE	RLS

0 1in.
At full size
1 inch = 225 feet

NV Energy

20618.09.38

REV. 4

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Appendix B

ASTM Standards

Designation: D 5092 – 04$^{\epsilon 1}$

Standard Practice for Design and Installation of Ground Water Monitoring Wells[1]

This standard is issued under the fixed designation D 5092; 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.

ϵ[1] NOTE—Editorial changes were made throughout in June 2004.

1. Scope

1.1 This practice describes a methodology for designing and installing conventional (screened and filter-packed) ground-water monitoring wells suitable for formations ranging from unconsolidated aquifers (i.e., sands and gravels) to granular materials having grain-size distributions with up to 50 % passing a #200 sieve and as much as 20 % clay-sized material (i.e., silty fine sands with some clay). Formations finer than this (i.e., silts, clays, silty clays, clayey silts) should not be monitored using conventional monitoring wells, as representative ground-water samples, free of artifactual turbidity, cannot be assured using currently available technology. Alternative monitoring technologies (not described in this practice) should be used in these formations

1.2 The recommended monitoring well design and installation procedures presented in this practice are based on the assumption that the objectives of the program are to obtain representative ground-water samples and other representative ground-water data from a targeted zone of interest in the subsurface defined by site characterization.

1.3 This practice, in combination with proper well development (D 5521), proper ground-water sampling procedures (D 4448), and proper well maintenance and rehabilitation (D 5978), will permit acquisition of ground-water samples free of artifactual turbidity, eliminate siltation of wells between sampling events, and permit acquisition of accurate ground-water levels and hydraulic conductivity test data from the zone screened by the well. For wells installed in fine-grained formation materials (up to 50 % passing a #200 sieve), it is generally necessary to use low-flow purging and sampling techniques (D 6771) in combination with proper well design to collect turbidity-free samples.

1.4 This practice applies primarily to well design and installation methods used in drilled boreholes. Other Standards, including Guide D 6724 and Practice D 6725, cover installation of monitoring wells using direct-push methods.

1.5 The values stated in inch-pound units are to be regarded as standard. The values in parentheses are for information only.

1.6 *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.*

1.7 *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. Nat 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 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]

C 150 Specification for Portland Cement
C 294 Descriptive Nomenclature of Constituents of Natural Mineral Aggregates
D 421 Practice for Dry Preparation of Soil Samples for Particle Size Analysis and Determination of Soil Constants
D 422 Test Method for Particle Size Analysis of Soils
D 653 Terminology Relating to Soil, Rock, and Contained Fluids
D 1452 Practice for Soil Investigation and Sampling by Auger Borings
D 1586 Method for Penetration Test and Split-Barrel Sampling of Soils
D 1587 Practice for Thin-Walled Tube Sampling of Soils
D 2113 Practice for Rock Core Drilling and Sampling of Rock for Site Investigation
D 2217 Practice for Wet Preparation of Soil Samples for Particle Size Analysis and Determination of Soil Constants

[1] This practice is under the jurisdiction of ASTM Committee D18 on Soil and Rock and is the direct responsibility of Subcommittee D18.21.05 on Design and Installation of Ground-Water Monitoring Wells.

Current edition approved Jan. 1, 2004. Published March 2004. Originally approved in 1990. Last previous edition approved in 2002 as D 5092 – 02.

[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.

D 2487 Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System)
D 2488 Practice for Description and Identification of Soils (Visual-Manual Procedure)
D 3282 Practice for Classification of Soils and Soil Aggregate Mixtures for Highway Construction Purposes
D 3441 Test Method for Deep, Quasi-Static, Cone and Friction Cone Penetration Tests of Soil
D 3550 Practice for Ring Lined Barrel Sampling of Soils
D 4220 Practice for Preserving and Transporting Soil Samples
D 4700 Guide for Soil Sampling from the Vadose Zone
D 4750 Test Method for Determining Subsurface Liquid Levels in a Borehole or Monitoring Well (Observation Well)
D 5079 Practices for Preserving and Transporting Rock Core Samples
D 5088 Practice for Decontamination of Field Equipment Used at Nonradioactive Waste Sites
D 5254 Practice for Minimum Set of Data Elements to Identify a Ground-Water Site
D 5299 Guide for Decommissioning of Ground-Water Wells, Vadose Zone Monitoring Devices, Boreholes, and Other Devices for Environmental Activities
D 5434 Guide for Field Logging of Subsurface Explorations of Soil and Rock
D 5518 Guide for Acquisition of File Aerial Photography and Imagery for Establishing Historic Site Use and Surficial Conditions
D 5521 Guide for Development of Ground-Water Monitoring Wells in Granular Aquifers
D 5608 Practice for Decontamination of Field Equipment Used at Low-Level Radioactive Waste Sites
D 5730 Guide to Site Characterization for Environmental Purposes with Emphasis on Soil, Rock, the Vadose Zone, and Ground Water
D 5753 Guide for Planning and Conducting Borehole Geophysical Logging
D 5777 Guide for Using the Seismic Refraction Method for Subsurface Investigation
D 5781 Guide for Use of Dual-Wall Reverse-Circulation Drilling for Geoenvironmental Exploration and Installation of Subsurface Water-Quality Monitoring Devices
D 5782 Guide for Use of Direct Air-Rotary Drilling for Geoenvironmental Exploration and Installation of Subsurface Water-Quality Monitoring Devices
D 5783 Guide for Use of Direct Rotary Drilling with Water-Based Drilling Fluid for Geoenvironmental Exploration and Installation of Subsurface Water-Quality Monitoring Devices
D 5784 Guide for Use of Hollow Stem Augers for Geoenvironmental Exploration and Installation of Subsurface Water-Quality Monitoring Devices
D 5787 Practice for Monitoring Well Protection
D 5872 Guide for the Use of Casing Advancement Drilling Methods for Geoenvironmental Exploration and Installation of Subsurface Water-Quality Monitoring Devices
D 5875 Guide for the Use of Cable Tool Drilling and Sampling Methods for Geoenvironmental Exploration and Installation of Subsurface Water-Quality Monitoring Devices
D 5876 Guide for the Use of Direct Rotary Wireline Casing Advancement Drilling Methods for Geoenvironmental Exploration and the Installation of Subsurface Water-Quality Monitoring Devices
D 5978 Guide for Maintenance and Rehabilitation of Ground-Water Monitoring Wells
D 5979 Guide for Conceptualization and Characterization of Ground-Water Systems
D 6001 Guide for Direct-Push Water Sampling for Geoenvironmental Investigations
D 6067 Guide for Using the Electronic Cone Penetrometer for Environmental Site Characterization
D 6167 Guide for Conducting Borehole Geophysical Logging
D 6169 Guide to the Selection of Soil and Rock Sampling Devices Used With Drilling Rigs for Environmental Investigations
D 6235 Practice for Expedited Site Characterization of Vadose Zone and Ground-Water Contamination at Hazardous Waste Contaminated Sites
D 6274 Guide for Conducting Borehole Geophysical Logging—Gamma
D 6282 Guide for Direct-Push Soil Sampling for Environmental Site Characterization
D 6286 Guide to the Selection of Drilling Methods for Environmental Site Characterization
D 6429 Guide for Selecting Surface Geophysical Methods
D 6430 Guide for Using the Gravity Method for Subsurface Investigation
D 6431 Guide for Using the Direct Current Resistivity Method for Subsurface Investigation
D 6432 Guide for Using the Surface Ground Penetrating Radar Method for Subsurface Investigation
D 6519 Practice for Sampling of Soil Using the Hydraulically Operated Stationary Piston Sampler
D 6639 Guide for Using the Frequency Domain Electromagnetic Method for Subsurface Investigations
D 6640 Guide for Collection and Handling of Soils Obtained in Core Barrel Samplers for Environmental Investigations
D 6724 Guide for the Installation of Direct-Push Ground-Water Monitoring Wells
D 6725 Practice for the Installation of Prepacked Screen Monitoring Wells in Unconsolidated Aquifers
D 6771 Practice for Low-Flow Purging and Sampling for Wells and Devices Used for Ground-Water Quality Investigations
F 480 Specification for Thermoplastic Well Casing and Couplings Made in Standard Dimension Ratios (SDR), Schedule 40 and Schedule 80

3. Terminology

3.1 *Definitions:*

3.1.1 *annular space; annulus*—the space between two concentric strings of casing, or between the casing and the borehole wall. This includes the space(s) between multiple strings of casing in a borehole installed either concentrically or adjacent to one another.

3.1.2 *artifactual turbidity*—particulate matter that is not naturally mobile in the ground-water system and that is produced in some way by the ground-water sampling process. May consist of particles introduced to the subsurface during drilling or well construction, sheared from the target monitoring zone during pumping or bailing the well, or produced by exposure of ground water to atmospheric conditions.

3.1.3 *assessment monitoring*—an investigative monitoring program that is initiated after the presence of a contaminant in ground water has been detected. The objective of this program is to determine the concentration of constituents that have contaminated the ground water and to quantify the rate and extent of migration of these constituents.

3.1.4 *ballast*—materials used to provide stability to a buoyant object (such as casing within a water-filled borehole).

3.1.5 *borehole*—an open or uncased subsurface hole, generally circular in plan view, created by drilling.

3.1.6 *borehole log*—the record of geologic units penetrated, drilling progress, depth, water level, sample recovery, volumes, and types of materials used, and other significant facts regarding the drilling and/or installation of an exploratory borehole or well.

3.1.7 *bridge*—an obstruction within the annulus that may prevent circulation or proper placement of annular fill materials.

3.1.8 *casing*—pipe, finished in sections with either threaded connections or beveled edges to be field welded, which is installed temporarily or permanently either to counteract caving, to advance the borehole, or to isolate the zone being monitored, or any combination of these.

3.1.9 *casing, protective*—a section of larger diameter pipe that is placed over the upper end of a smaller diameter monitoring well riser or casing to provide structural protection to the well, to prevent damage to the well, and to restrict unauthorized access into the well.

3.1.10 *casing, surface*—pipe used to stabilize a borehole near the surface during the drilling of a borehole that may be left in place or removed once drilling is completed.

3.1.11 *caving; sloughing*—the inflow of unconsolidated material into a borehole that occurs when the borehole walls lose their cohesiveness.

3.1.12 *cement*—commonly known as Portland cement. A mixture that consists of calcareous, argillaceous, or other silica-, alumina-, and iron-oxide-bearing materials that is manufactured and formulated to produce various types which are defined in Specification C 150. Portland cement is considered a hydraulic cement because it must be mixed with water to form a cement-water paste that has the ability to harden and develop strength even if cured under water.

3.1.13 *centralizer*—a device that assists in the centering of a casing or riser within a borehole or another casing.

3.1.14 *confining unit*—a body of relatively low hydraulic conductivity formation material stratigraphically adjacent to one or more aquifers. Synonymous with "aquiclude,"" aquitard," and "aquifuge."

3.1.15 *detection monitoring*—a program of monitoring for the express purpose of determining whether or not there has been a contaminant release to ground water.

3.1.16 *d-10*—the diameter of a soil particle (preferably in mm) at which 10 % by weight (dry) of the particles of a particular sample are finer. Synonymous with the effective size or effective grain size.

3.1.17 *d-60*—the diameter of a soil particle (preferably in mm) at which 60 % by weight (dry) of the particles of a particular sample are finer.

3.1.18 *flush joint or flush coupled*—casing or riser with ends threaded such that a consistent inside and outside diameter is maintained across the threaded joints or couplings.

3.1.19 *gravel pack*—common term used to refer to the primary filter pack of a well (see *primary filter pack*).

3.1.20 *grout (monitoring wells)*—a low-permeability material placed in the annulus between the well casing or riser and the borehole wall (in a single-cased monitoring well), or between the riser and casing (in a multi-cased monitoring well), to prevent movement of ground water or surface water within the annular space.

3.1.21 *hydrologic unit*—geologic strata that can be distinguished on the basis of capacity to yield and transmit fluids. Aquifers and confining units are types of hydrologic units. Boundaries of a hydrologic unit may not necessarily correspond either laterally or vertically to lithostratigraphic formations.

3.1.22 *multi-cased well*—a well constructed by using successively smaller diameter casings with depth.

3.1.23 *neat cement*—a mixture of Portland cement (Specification C 150) and water.

3.1.24 *packer (monitoring wells)*—a transient or dedicated device placed in a well that isolates or seals a portion of the well, annulus, or borehole at a specific level.

3.1.25 *piezometer*—a small-diameter well with a very short screen that is used to measure changes in hydraulic head, usually in response to pumping a nearby well. Synonymous with observation well.

3.1.26 *primary filter pack*—a clean silica sand or sand and gravel mixture of selected grain size and gradation that is installed in the annular space between the borehole wall and the well screen, extending an appropriate distance above the screen, for the purpose of retaining and stabilizing the particles from the adjacent formation(s). The term is used in place of *gravel pack*.

3.1.27 *PTFE tape*—joint sealing tape composed of polytetrafluoroethylene.

3.1.28 *riser*—the pipe or well casing extending from the well screen to just above or below the ground surface.

3.1.29 *secondary filter pack*—a clean, uniformly graded sand that is placed in the annulus between the primary filter pack and the overlying seal, or between the seal and overlying grout backfill, or both, to prevent intrusion of the seal or grout, or both, into the primary filter pack.

3.1.30 *sediment sump*—a blank extension of pipe or well casing, closed at the bottom, beneath the well screen used to collect fine-grained material from the filter pack and adjacent formation materials during the process of well development. Synonymous with rat trap or tail pipe.

3.1.31 *single-cased well*—a monitoring well constructed with a riser but without an exterior casing.

3.1.32 *static water level*—the elevation of the top of a column of water in a monitoring well or piezometer that is not influenced by pumping or conditions related to well installation, or hydraulic testing.

3.1.33 *tamper*—a heavy cylindrical metal section of tubing that is operated on a wire rope or cable. It either slips over the riser and fits inside the casing or borehole annulus, or fits between the riser and annulus. It is generally used to tamp annular sealants or filter pack materials into place and to prevent bridging or break bridges that form in the annular space.

3.1.34 *target monitoring zone*—the ground-water flow path from a particular area or facility in which monitoring wells will be screened. The target monitoring zone should be an interval in subsurface materials in which there is a reasonable expectation that a monitoring well will intercept ground water moving beneath an area or facility and any migrating contaminants that may be present.

3.1.35 *tremie pipe*—a small-diameter pipe or tube that is used to transport filter pack materials and annular seal materials from the ground surface into an annular space.

3.1.36 *uniformity coefficient*—the ratio of d-60/d-10, where d-60 and d-10 are particle diameters corresponding to 60 % and 10 % finer on the cumulative particle size curve, respectively.

3.1.37 *uniformly graded*—a quantitative definition of the particle size distribution of a soil that consists of a majority of particles being of approximately the same diameter. A granular material is considered uniformly graded when the uniformity coefficient is less than about five (Test Method D 2487). Comparable to the geologic term *well sorted.*

3.1.38 *vented cap*—a cap with a small hole that is installed on top of the riser.

3.1.39 *weep hole*—a small-diameter hole (usually ¼ in.) drilled into the protective casing above the ground surface that serves to drain out water that may enter the annulus between the riser and the protective casing.

3.1.40 *well completion diagram*—a record that illustrates the details of a well installation.

3.1.41 *well screen*—a device used to retain the primary or natural filter pack; usually a cylindrical pipe with openings of a uniform width, orientation, and spacing.

4. Significance and Use

4.1 This practice for the design and installation of ground-water monitoring wells will promote *(1)* efficient and effective site hydrogeological characterization; *(2)* durable and reliable well construction; and *(3)* acquisition of representative ground-water quality samples, ground-water levels, and hydraulic conductivity testing data from monitoring wells. The practices established herein are affected by governmental regulations and by site-specific geological, hydrogeological, climatological, topographical, and subsurface geochemical conditions. To meet these geoenvironmental challenges, this practice promotes the development of a conceptual hydrogeologic model prior to monitoring well design and installation.

4.2 A properly designed and installed ground water monitoring well provides essential information on one or more of the following subjects:

4.2.1 Formation geologic and hydraulic properties;

4.2.2 Potentiometric surface of a particular hydrologic unit(s);

4.2.3 Water quality with respect to various indicator parameters; and

4.2.4 Water chemistry with respect to a contaminant release.

5. Site Characterization

5.1 *General*—A thorough knowledge of site-specific geologic, hydrologic and geochemical conditions is necessary to properly apply the monitoring well design and installation procedures contained within this practice. Development of a conceptual site model, that identifies potential flow paths and the target monitoring zone(s), and generates a 3-D picture of contaminant distribution and contaminant movement pathways, is recommended prior to monitoring well design and installation. Development of the conceptual site model is accomplished in two phases -- an initial reconnaissance, after which a preliminary conceptual model is created, and a field investigation, after which a revised conceptual model is formulated. When the hydrogeology of a project area is relatively uncomplicated and well documented in the literature, the initial reconnaissance may provide sufficient information to identify flow paths and the target monitoring zone(s). However, where limited or no background data are available or where the geology is complex, a field investigation will be required to develop the necessary conceptual site model.

5.2 *Initial Reconnaissance of Project Area*—The goal of the initial reconnaissance of the project area is to identify and locate those zones or preferential flow pathways with the greatest potential to transmit fluids from the project area. Identifying these flow pathways is the first step in selecting the target ground-water monitoring zone(s).

5.2.1 *Literature Search*—Every effort should be made to collect and review all applicable field and laboratory data from previous investigations of the project area. Information such as, but not limited to, topographic maps, aerial imagery (see Guide D 5518), site ownership and utilization records, geologic and hydrogeologic maps and reports, mineral resource surveys, water well logs, information from local well drillers, agricultural soil reports, geotechnical engineering reports, and other engineering maps and reports related to the project area should be reviewed to locate relevant site information.

5.2.2 *Field Reconnaissance*—Early in the investigation, the soil and rocks in open cut areas (e.g., roadcuts, streamcuts) in the vicinity of the project should be studied, and various soil and rock profiles noted. Special consideration should be given to soil color and textural changes, landslides, seeps, and springs within or near the project area.

5.2.3 *Preliminary Conceptual Model*—The distribution of the predominant soil and rock units likely to be found during subsurface exploration may be hypothesized at this time in a preliminary conceptual site model using information obtained in the literature search and field reconnaissance. In areas where the geology is relatively uniform, well documented in the literature, and substantiated by the field reconnaissance, further refinement of the conceptual model may not be necessary unless anomalies are discovered in the well drilling stage.

5.3 *Field Investigation*—The goal of the field investigation is to refine the preliminary conceptual site model so that the target monitoring zone(s) is (are) identified prior to monitoring well installation.

5.3.1 *Exploratory Borings and Direct-Push Methods*—Characterization of the flow paths conceptualized in the initial reconnaissance involves defining the porosity (type and amount), hydraulic conductivity, stratigraphy, lithology, gradation and structure of each hydrologic unit encountered beneath the site. These characteristics are defined by conducting an exploratory program which may include drilled soil borings (see Guide D 6286 for selection of drilling methods) and direct-push methods (e.g., cone penetrometers [see Test Method D 3441 or Guide D 6067] or direct-push machines using soil sampling, ground-water sampling and/or electrical conductivity measurement tools [see Guides D 6282 and D 6001]). Exploratory soil borings and direct-push holes should be deep enough to develop the required engineering and hydrogeologic data for determining the preferential flow pathway(s), target monitoring zone(s), or both.

5.3.1.1 *Sampling*—Soil and rock properties should not be predicted wholly on field description or classification, but should be confirmed by laboratory and/or field tests made on samples or in boreholes or wells. Representative soil or rock samples of each material that is significant to the design of the monitoring well system should be obtained and evaluated by a geologist, hydrogeologist, soil scientist or engineer trained and experienced in soil and rock analysis. Soil sample collection should be conducted according to Practice D 1452, Test Method D 1586, Practice D 3550, Practice D 6519 or Practice D 1587, whichever is appropriate given the anticipated characteristics of the soil samples (see Guide D 6169 for selection of soil sampling methods). Rock samples should be collected according to Practice D 2113. Soil samples obtained for evaluation of hydraulic properties should be containerized and identified for shipment to a laboratory. Special measures to preserve either the continuity of the sample or the natural moisture are not usually required. However, soil and rock samples obtained for evaluation of chemical properties often require special field preparation and preservation to prevent significant alteration of the chemical constituents during transportation to a laboratory (see Practice D 6640). Rock samples for evaluation of hydraulic properties are usually obtained using a split-inner-tube core barrel. Evaluation and logging of the core samples is usually done in the field before the core is removed from the core barrel.

5.3.1.2 *Boring Logs*—Care should be taken to prepare and retain a complete boring log and sampling record for each exploratory soil boring or direct-push hole (see Guide D 5434).

NOTE 1—Site investigations conducted for the purpose of generating data for the installation of ground-water monitoring wells can vary greatly due to the availability of reliable site data or the lack thereof. The general procedure would be as follows: *(1)* gather factual data regarding the surficial and subsurface conditions, *(2)* analyze the data, *(3)* develop a conceptual model of the site conditions, *(4)* locate the monitoring wells based on the first three steps. Monitoring wells should only be installed with sufficient understanding of the geologic, and hydrologic and geochemical conditions present at the site. Monitoring wells often serve as part of an overall site investigation for a specific purpose, such as determining the extent of contamination present, or for predicting the effectiveness of aquifer remediation. In these cases, extensive additional geotechnical and hydrogeologic information may be required that would go beyond the Section 5 Site Characterization description.

Boring logs should include the location, geotechnical data (that is, penetration rates or blow counts), and sample description information for each material identified in the borehole either by symbol or word description, or both. Description and identification of soils should be in accordance with Practice D 2488; classification of soils should be in accordance with either Practice D 2487 or Practice D 3282. Identification of rock material should be based on Nomenclature C 294 or by an appropriate geologic classification system. Observations of seepage, free water, and water levels should also be noted. The boring logs should be accompanied by a report that includes a description of the area investigated; a map illustrating the vertical and horizontal location (with reference to either North American Vertical Datum of 1988 [NAVD 88] or to a standardized survey grid) of each exploratory soil boring or test pit, or both; and color photographs of rock cores, soil samples, and exposed strata labeled with a date and identification.

5.3.2 *Geophysical Exploration*—Geophysical surveys may be used to supplement soil boring and outcrop observation data and to aid in interpretation between soil borings. Appropriate surface and borehole geophysical methods for meeting site-specific project objectives can be selected by consulting Guides D 6429 and D 5753 respectively. Surface geophysical methods such as seismic (Guide D 5777), electrical-resistivity (Guide D 6431), ground-penetrating radar (Guide D 6432), gravity (Guide D 6430) and electromagnetic conductance surveys (Guide D 6639) can be particularly valuable when distinct differences in the properties of contiguous subsurface materials are indicated. Borehole methods such as resistivity, gamma, gamma-gamma, neutron, and caliper logs (see Guide D 6167) can be useful to confirm specific subsurface geologic conditions. Gamma logs (Guide D 6274) are particularly useful in existing cased wells.

5.3.3 *Ground-Water Flow Direction*—Ground-water flow direction is generally determined by measuring the vertical and horizontal hydraulic gradient within each conceptualized flow pathway. However, because water will flow along the pathways of least resistance (within the highest hydraulic conductivity formation materials at the site), actual flow direction may be oblique to the hydraulic gradient (within buried stream channels or glacial valleys, for example). Flow direction is determined by first installing piezometers in the exploratory soil borings that penetrate the zone(s) of interest at the site. The depth and location of the piezometers will depend upon anticipated hydraulic connections between conceptualized flow pathways and their respective lateral direction of flow. Following careful evaluation, it may be possible to utilize existing private or public wells to obtain water-level data. The construction integrity of such wells should be verified to ensure that the water levels obtained from the wells are representative only of the zone(s) of interest. Following water-level data acquisition, a potentiometric surface map should be prepared. Flow pathways are ordinarily determined to be at right angles, or nearly so, to the equipotential lines, though consideration of complex geology can result in more complex interpretations of flow

5.4 *Completing the Conceptual Model*—A series of geologic and hydrogeologic cross sections should be developed to refine the conceptual model. This is accomplished by first plotting logs of soil and rock observed in the exploratory soil borings or test pits, and interpreting between these logs using the geologic and engineering interrelationships between other soil and rock data observed in the initial reconnaissance or with geophysical techniques. Extrapolation of data into adjacent areas should be done only where geologically uniform subsurface conditions are known to exist. The next step is to integrate the geologic profile data with the potentiometric data for both vertical and horizontal hydraulic gradients. Plan view and cross-sectional flow nets should be constructed. Following the analysis of these data, conclusions can be made as to which flow pathway(s) is (are) the appropriate target monitoring zone(s).

NOTE 2—UUse of ground-water monitoring wells is difficult and may not be a reliable technology in fine-grained, low hydraulic conductivity formation materials with primary porosity because of *(1)* the disproportionate influence that microstratigraphy has on ground-water flow in fine-grained strata; *(2)* the proportionally higher vertical flow component in low hydraulic conductivity strata; and *(3)* the presence of indigenous metallic and inorganic constituents in the matrix that make water-quality data evaluation difficult.

6. Monitoring Well Construction Materials

6.1 *General*—The materials that are used in the construction of a monitoring well that come in contact with water samples should not alter the chemical quality of the sample for the constituents being examined. The riser, well screen, and annular seal installation equipment should be cleaned immediately prior to well installation (see either Practice D 5088 or D 5608) or certified clean from the manufacturer and delivered to the site in a protective wrapping. Samples of the riser and screen material, cleaning water, filter pack, annular seal, bentonite, and mixed grout should be retained to serve as quality control until the completion of at least one round of ground- water quality sampling and analysis has been completed.

6.2 *Water*—Water used in the drilling process, to prepare grout mixtures and to decontaminate the well screen, riser, and annular sealant injection equipment, should be obtained from a source of known chemistry that does not contain constituents that could compromise the integrity of the well installation.

6.3 *Primary Filter Pack*:

6.3.1 *General*—The purposes of the primary filter pack are to act as a filter that retains formation material while allowing ground water to enter the well, and to stabilize the formation to keep it from collapsing on the well. The design of the primary filter pack is based on the grain-size distribution of the formation material (as determined by sieve analysis—see Test Method D 422) to be retained. The grain size distribution of the primary filter pack must be fine enough to retain the formation, but coarse enough to allow for unrestricted movement of ground water into and through the monitoring well. The design of the well screen (see 6.4.3) must be done in concert with the design of the filter pack. After development, a monitoring well with a correctly designed and installed filter pack and screen combination should produce samples free of artifactual turbidity.

6.3.2 *Materials*—The primary filter pack should consist of an inert granular material (generally ranging from gravel to very fine sand, depending on formation grain size distribution) of selected grain size and gradation that is installed in the annulus between the well screen and the borehole wall. Washed and screened silica sands and gravels, with less than 5 % non-siliceous materials, should be specified.

6.3.3 *Design*—The design theory of filter pack gradation is based on mechanical retention of formation materials.

6.3.3.1 1 For formation materials that are relatively coarse-grained (i.e., fine, medium and coarse sands and gravels), the grain size distribution of the primary filter pack is determined by calculating the d-30 (30 % finer) size, the d-60 (60 % finer) size, and the d-10 (10 % finer) size of the filter pack. The first point on the filter pack grain-size distribution curve is the d-30 size. The primary filter pack is usually selected to have a d-30 grain size that is about 4 to 6 times greater than the d-30 grain size of the formation material being retained (see Fig. 1). A multiplication factor of 4 is used if the formation material is relatively fine-grained and well sorted or uniform (small range in grain sizes); a multiplication factor of 6 is used if the formation is relatively coarse grained and poorly sorted or non-uniform (large range in grain sizes). Thus, 70 % of the filter pack will have a grain size that is 4 to 6 times larger than the d-30 size of the formation materials. This ensures that the filter pack is coarser (with a higher hydraulic conductivity) than the formation material, and allows for unrestricted ground-water flow from the formation into the monitoring well.

The next 2 points on the filter pack grain-size distribution curve are the d-60 and d-10 grain sizes. These are chosen so that the ratio between the two grain sizes (the uniformity coefficient) is less than 2.5. This ensures that the filter pack has a small range in grain sizes and is uniform (see technical Note 5). The d-60 and d-10 grain sizes of the filter pack are calculated by a trial and error method using grain sizes that are close to the d-30 size of the filter pack. After the d-30, d-60 and d-10 sizes of the filter pack are determined, a smooth curve is drawn through these points. The final step in filter pack design is to specify the limits of the grain size envelope, which defines the permissible range in grain sizes for the filter pack. The permissible range on either side of the grain size curve is 8 %. The boundaries of the grain size envelope are drawn on either side of the filter pack grain-size distribution curve, and filter pack design is complete. A filter medium having a grain-size distribution as close as possible to this curve is then obtained from a local sand supplier.

6.3.3.2 In formation materials that are predominantly fine-grained (finer than fine to very fine sands), soil piping can occur when a hydraulic gradient exists between the formation and the well (as would be the case during well development and sampling). To prevent soil piping in these materials, the following criteria are used for designing granular filter packs:

$$\frac{\text{d-15 of filter}}{\text{d-85 of formation}} \leq 4 \text{ to } 5 \quad \text{and} \quad \frac{\text{d-15 of filter}}{\text{d-15 of formation}} \geq 4 \text{ to } 5$$

The left half of this equation is the fundamental criterion for the prevention of soil piping through a granular filter, while the right half of the equation is the hydraulic conductivity criterion. This latter criterion serves the same purpose as multiplying the d-30 grain size of the formation by a factor of between 4 and 6 for coarser formation materials. Filter pack materials suitable for retaining formation materials in formations that are predominantly fine-grained are themselves, by necessity, relatively fine-grained (e.g., fine to very fine sands), presenting several problems for well designers and installers. First, well screen slot sizes suitable for retaining such fine-grained filter pack materials are not widely available (the smallest commercially available slotted well casing is 0.006 in. [6 slot]; the smallest commercially available continuous-slot wire-wound screen is 0.004 in. [4 slot]). Second, the finest filter pack material practical for conventional (tremie tube) installation is a 40 by 70 (0.008 by 0.018 in.) sand, which can be used with a well screen slot as small as 0.008-in. (8 slot). Finer grained filter pack materials cannot be placed practically by either tremie tubes or pouring down the annular space or down augers. Thus, the best method for ensuring proper installation of filter packs in predominantly fine-grained formation materials is to use pre-packed or sleeved screens, which are described in detail in Practice D 6725. A 50 by 100 (0.011 by 0.006 in.) filter-pack sand can be used with a 0.006-in. slot size pre-packed or sleeved screen, and a 60 by 120 (0.0097 by 0.0045 in.) filter-pack sand can be used with a 0.004-in. (4 slot) slot size pre-packed or sleeved screen. Filter packs that are finer than these (e.g., sands as fine as 100 by 120 [0.006 by 0.0045 in.], or silica flour as fine as 200 mesh [0.003 in.]) can only be installed within stainless steel mesh sleeves that can be placed over pipe-based screens. While these sleeves, or the space between internal and external screens in a pre-packed well screen may be as thin as 1/2-in. (1.27 cm), the basis for mechanical retention dictates that a filter-pack thickness of only two or three grain diameters is needed to contain and control formation materials. Laboratory tests have demonstrated that a properly sized filter pack material with a thickness of less than 1/2-in. (1.27 cm) successfully retains formation particles regardless of the velocity of water passing through the filter pack [3].

[3] (1) Driscoll, F.G., 1986, Groundwater and Wells, Johnson Division, St. Paul, MN, pg.443

6.3.3.3 The limit of mechanical filtration for monitoring wells is defined by the finest filter pack material that can be practically installed via a pre-packed or sleeved screen—silica flour with a grain size of 0.003 in. (200 mesh), encased within a very fine mesh screen of stainless steel or other suitable material. This fine a filter pack material will retain formation material as fine as silt, but not clay. Formations with a small fraction of clay (up to about 20 %) can be successfully monitored, as long as the wells installed in these formations are properly developed (see Guide D 5521). For mechanical filtration to be effective in formations with more than 50 % fines, the filter pack design would have to include silt-sized particles in the filter pack in order to meet the design criteria, which is impractical, as placement would be impossible and screen mesh fine enough to retain the material is not commercially available. Therefore, formations with more than 50 % passing a #200 sieve, and having more than 20 % clay-sized material, should not be monitored using conventional well designs. Alternative monitoring technologies should be used in these formations..

NOTE 3—When installing a monitoring well in solution-channeled limestone or highly fractured bedrock, the borehole configuration of void spaces within the formation surrounding the borehole is often unknown. Therefore, the installation of a filter pack becomes difficult and may not be possible.

NOTE 4—This practice presents a design for monitoring wells that will be effective in the majority of formations. Applicable state guidance may differ from the designs contained in this practice.

NOTE 5—Because the well screen slots have uniform openings, the filter pack should be composed of particles that are as uniform in size as is practical. Ideally, the uniformity coefficient (the quotient of the 60 % passing, D-60 size divided by the 10 % passing D-10 size [effective size]) of the filter pack should be 1.0 (that is, the D-60 % and the D-10 % sizes should be identical). However, a more practical and consistently achievable uniformity coefficient for all ranges of filter pack sizes is 2.5. This value of 2.5 should represent a maximum value, not an ideal.

NOTE 6—Although not recommended as standard practice, often a project requires drilling and installing the well in one phase of work. Therefore, the filter pack materials must be ordered and delivered to the drill site before soil samples can be collected. In these cases, the suggested well screen slot size and filter pack material combinations are presented in Table 1.

NOTE 7—Silica flour can alter water chemistry, particularly for transuranics, and its use should be evaluated against the monitoring program analytes

6.4 *Well Screen:*

6.4.1 *General*—The purposes of the well screen are to provide designed openings for ground-water flow through the well, and to prevent migration of filter pack and formation

TABLE 1 Recommended (Achievable) Filter Pack Characteristics for Common Screen Slot Sizes

Size of Screen Opening, mm (in.)	Slot No.	Sand Pack Mesh Size Name(s)	1 % Passing Size (D-1), mm	Effective Size, (D-10), mm	30 % Passing Size (D-30), mm	Range of Uniformity Coefficient	Roundness (Powers Scale)
0.125 (0.005)	5[A]	100	0.09 to 0.12	0.14 to 0.17	0.17 to 0.21	1.3 to 2.0	2 to 5
0.25 (0.010)	10	20 to 40	0.25 to 0.35	0.4 to 0.5	0.5 to 0.6	1.1 to 1.6	3 to 5
0.50 (0.020)	20	10 to 20	0.7 to 0.9	1.0 to 1.2	1.2 to 1.5	1.1 to 1.6	3 to 6
0.75 (0.030)	30	10 to 20	0.7 to 0.9	1.0 to 1.2	1.2 to 1.5	1.1 to 1.6	3 to 6
1.0 (0.040)	40	8 to 12	1.2 to 1.4	1.6 to 1.8	1.7 to 2.0	1.1 to 1.6	4 to 6
1.5 (0.060)	60	6 to 9	1.5 to 1.8	2.3 to 2.8	2.5 to 3.0	1.1 to 1.7	4 to 6
2.0 (0.080)	80	4 to 8	2.0 to 2.4	2.4 to 3.0	2.6 to 3.1	1.1 to 1.7	4 to 6

[A] A 5-slot (0.152-mm) opening is not currently available in slotted PVC but is available in Vee wire PVC and Stainless; 6-slot opening may be substituted in these cases.

material into the well. The well screen design is based on either the grain-size distribution of the formation (in the case of a well with a naturally developed filter pack), or the grain-size distribution of the primary filter pack material (in the case of a filter-packed well). The screen openings must be small enough to retain most if not all of the formation or filter-pack materials, yet large enough to maintain ground-water flow velocities, from the well screen/filter pack interface back to the natural formation materials, of less than 0.10 ft/s (0.03 m/s). If well screen entrance velocities exceed 0.10 ft/s (0.03 m/s), turbulent flow conditions can occur, resulting in mobilization of sediment from the formation and reductions in well efficiency.

6.4.2 *Materials*—TThe well screen should be new, machine-slotted casing or continuous wrapped wire-wound screen composed of materials compatible with the monitoring environment, as determined by the site characterization program. The screen should be plugged at the bottom (unless a sediment sump is used), and the plug should generally be of the same material as the well screen. This assembly must have the capability to withstand well installation and development stresses without becoming dislodged or damaged. The length of the well screen open area should reflect the thickness of the target monitoring zone. Immediately prior to installation, the well screen should be cleaned (see either Practice D 5088 or Practice D 5608) with water from a source of known chemistry, if it is not certified clean by the manufacturer, and delivered, and maintained in a clean environment at the site.

NOTE 8—Well screens are most commonly composed of PVC or stainless steel. Stainless steel may be specified based on knowledge of the occurrence of microbially influenced corrosion in formations (specifically reducing or acid-producing conditions).

6.4.3 *Diameter*—TThe minimum nominal internal diameter of the well screen should be chosen based on factors specific to the particular application (such as the outside diameter of the purging and sampling device(s) to be used in the well). Well screens as small as 1/2-in. (1.27 cm) nominal diameter are available for use in monitoring well applications.

6.4.4 *Design*—The design of the well screen should be determined based on the grain size analysis (per Test Method D 422) of the interval to be monitored and the gradation of the primary filter pack material. In granular, non-cohesive formation materials that will fall in easily around the screen, filter packs can be developed from the native formation materials—filter pack materials foreign to the formation are not necessary. In these cases of naturally developed filter packs, the slot size of the well screen is determined using the grain size of the materials in the surrounding formation. The well screen slot size selected for this type of well completion should retain at least 70 % of formation materials—the finest 30 % of formation materials will be brought into the well during development, and the objectives of filter packing (to increase hydraulic conductivity immediately surrounding the well screen, and to promote easy flow of ground water into and through the screen) will be met. In wells in which a filter pack material of a selected grain size distribution is introduced from the surface, the screen slot size selected should retain at least 90 %, and preferably 99 %, of the primary filter pack materials. The method for determining the primary filter pack design is described in 6.3.3.

6.4.5 *Prepacked or Sleeved Well Screens*—An alternative to designing and installing filter pack and well screens separately is to use a pre-packed or sleeved screen assembly. A pre-packed well screen consists of an internal well screen, an external screen or filter medium support structure, and the filter medium contained between the screens, which together comprise an integrated structure. The internal and external screens are constructed of materials compatible with the monitored environment, and are usually of a common slot size specified by the well designer to retain the filter pack material. The filter pack is normally an inert (e.g., siliceous) granular material that has a grain-size distribution chosen to retain formation materials. A sleeved screen consists of a slotted pipe base over which a sleeve of stainless steel mesh filled with selected filter media is installed. Pre-packed or sleeved screens may be used for any formation conditions, but they are most often used where heaving, running or blowing sands make accurate placement of conventional well screens and filter packs difficult, or where predominantly fine-grained formation materials are encountered. In the latter case, using pre-packed or sleeved screens is the only practical means of ensuring that filter pack materials of the selected grain-size distribution (generally fine to very fine sands) are installed to completely surround the screen.

NOTE 9—The practice of using a single well screen/filter pack combination (e.g., 0.010 in. [0.254 mm]) well screen slot size with a 20/40 sand) for all wells, regardless of formation grain-size distribution, will result in siltation of the well and significant turbidity in samples when applied to formations finer than the recommended design. It will also result in the loss of filter pack, possible collapse of the screen, and invasion of overlying well construction materials (e.g., secondary filter pack, annular seal materials, grout) when applied to formations coarser than the recommended design. For these reasons, the universal application of a single well screen/filter pack combination to all formations is not recommended, and should be avoided.

6.5 *Riser*:

6.5.1 *Materials*—TThe riser should be new pipe composed of materials that will not alter the quality of water samples for the constituents of concern and that will stand up to long-term exposure to the monitoring environment, including potential contaminants. The riser should have adequate wall thickness and coupling strength to withstand the stresses imposed on it during well installation and development. Each section of riser should be cleaned (see either Practice D 5088 or Practice D 5608) using water from a source of known chemistry immediately prior to installation.

NOTE 10—Risers are generally constructed of PVC, galvanized steel or stainless steel.

6.5.2 *Diameter*—The minimum nominal internal diameter of the riser should be chosen based on the particular application. Risers as small as ½-in. (1.25-cm) in diameter are available for applications in monitoring wells.

6.5.3 *Joints (Couplings)*—Threaded joints are recommended. Glued or solvent-welded joints of any type are not recommended because glues and solvents may alter the chemistry of water samples. Because square profile flush joint threads (Specification F 480) are designed to be accompanied by O-ring seals at the joints, they do not require PTFE taping. However, tapered threaded joints should be PTFE taped to prevent leakage of water into the riser.

6.6 *Casing*—Where conditions warrant, the use of permanent casing installed to prevent communication between water-bearing zones is encouraged. The following subsections address both temporary and permanent casings.

6.6.1 *Materials*—The material type and minimum wall thickness of the casing should be adequate to withstand the forces of installation. All casing that is to remain as a permanent part of the installation (that is, in multi-cased wells) should be new and cleaned to be free of interior and exterior protective coatings.

NOTE 11—The exterior casing (temporary or permanent multi-cased) is generally composed of steel, although other appropriate materials may be used.

6.6.2 *Diameter*—Several different casing sizes may be required depending on the geologic formations penetrated. The diameter of the borehole and the well casing for conventionally filter packed wells should be selected so that a minimum annular space of 2 in. (5 cm) is maintained between the inside diameter of the casing and outside diameter of the riser to provide working space for a tremie pipe. For naturally developed wells and pre-packed or sleeved screen completions, this annular space requirement need not be met. In addition, the diameter of the casings in multi-cased wells should be selected so that a minimum annular space of 2 in. (5 cm) is maintained between the casing and the borehole (that is, a 2-in. [5 cm] diameter screen will require first setting a 6-in. [15.2 cm] diameter casing in a 10-in. [25.4 cm] diameter boring).

NOTE 12—Under difficult drilling conditions (collapsing soils, rock, or cobbles), it may be necessary to advance temporary casing. Under these conditions, a smaller annular space may be maintained.

6.6.3 *Joints (Couplings)*—The ends of each casing section should be either flush-threaded or beveled for welding.

6.7 *Sediment Sump*—A sediment sump, a length of blank pipe, generally of the same diameter and made of the same material as the riser and well screen -- may be affixed to the bottom of the screen, and capped with a bottom plug, to collect fine-grained material brought into the well by the process of well development. A drainage hole may be drilled in the bottom of the sump to prevent the sump from retaining water in the event that the water level outside the well falls below the bottom of the well screen. Because the sediment that collects in the sump may harbor geochemistry-altering microflora and reactive metal oxides, this sediment must be removed periodically to minimize the potential for sample chemical alteration.

6.8 *Protective Casing*:

6.8.1 *Materials*—Protective casings may be made of aluminum, mild steel, galvanized steel, stainless steel, cast iron, or structural plastic pipe. The protective casing should have a lid capable of being locked shut by a locking device or mechanism.

6.8.2 *Diameter*—The inside dimensions of the protective casing should be a minimum of 2 in. (5 cm) and preferably 4 in. (10 cm) larger than the nominal diameter of the riser to facilitate the installation and operation of sampling equipment.

6.9 *Annular Sealants*—TThe materials used to seal the annulus may be prepared as a slurry or used un-mixed in a dry pellet, granular, or chip form. Sealants should be selected to be compatible with ambient geologic, hydrogeologic, geochemical and climatic conditions and any man-induced conditions (e.g., subsurface contamination) anticipated during the life of the well.

6.9.1 *Bentonite*—Bentonite should be powdered, granular, pelletized, or chipped sodium montmorillonite from a commercial source, free of impurities that may adversely impact the water quality in the well. Pellets consist of roughly spherical units of moistened, compressed bentonite powder. Chips are large, irregularly shaped, and coarse granular units of bentonite free of additives. The diameter of pellets or chips selected for monitoring well construction should be less than one fifth the width of the annular space into which they are placed to reduce the potential for bridging. Granules consist of coarse to fine particles of unaltered bentonite, typically smaller than 0.2 in. (5.0 mm). It is recommended that the water chemistry of the formation in which the bentonite is intended for installation be evaluated to ensure that it is suitable to hydrate the bentonite. Some water-quality conditions (e.g., high chloride content, high concentrations of certain organic solvents or petroleum hydrocarbons) may inhibit the hydration of bentonite and result in an ineffective seal.

6.9.2 *Cement*—Each type of cement has slightly different characteristics that may be appropriate under various physical and chemical conditions. Cement should be one of the five Portland cement types that are specified in Specification C 150. The use of quick-setting cements containing additives is not recommended for use in monitoring well installation. Additives may leach from the cement and influence the chemistry of water samples collected from the monitoring well.

6.9.3 *Grout*—The grout backfill that is placed above the bentonite annular seal and secondary filters (see Fig. 1) is ordinarily a thick liquid slurry consisting of either a bentonite (powder or granules, or both) base and water, or a Portland cement base and water. Often, bentonite-based grouts are used when it is desired that the grout remain workable for extended periods of time during well construction or flexible (that is, to accommodate freeze-thaw cycles) during the life of the well. Cement-based grouts are often used when filling cracks in the surrounding geologic material, adherence to rock units, or a rigid setting is desired.

6.9.3.1 *Mixing*—The mixing (and placing) of a grout backfill should be performed with precisely recorded weights and volumes of materials, and according to procedures stipulated by the manufacturer that often include the order of component mixing. The grout should be thoroughly mixed with a paddle-type mechanical mixer or by recirculating the mix through a pump until all lumps are disintegrated. Lumpy grout should not be used in the construction of a monitoring well to prevent bridging within the tremie pipe.

NOTE 13—Lumps do not include lost circulation materials that may be added to the grout if excessive grout losses occur.

6.9.3.2 *Typical Bentonite-Based Grout*—When a bentonite-based grout is used, bentonite, usually unaltered, should be placed in the water through a venturi device. A typical

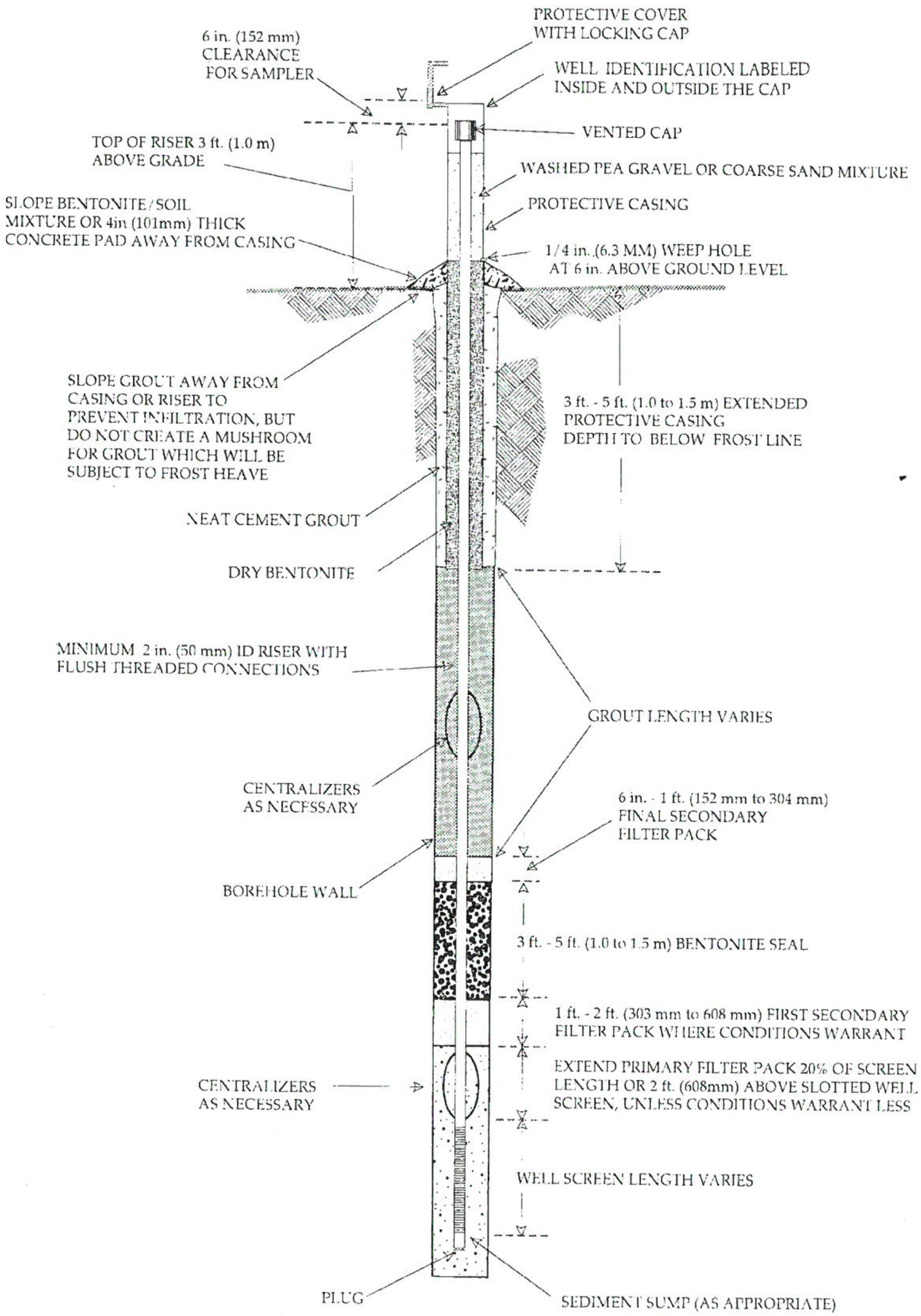

FIG. 1 Monitoring Well Design—Single–Cased Well

unbeneficiated bentonite-based grout consists of about 1 to 1.25 lb (0.57 kg) of unaltered bentonite to each 1 gal (3.8 L) of water. 100 % bentonite grouts should not be used for monitoring well annular sealants in the vadose zone of arid regions because of the possibility that they may desiccate. This could result in migration of water into the screened portion of the well from zones above the target monitoring zone.

NOTE 14—High solids bentonite grouts (minimum 20 % by weight with water) and other bentonite-based grouts may contain granular bentonite to increase the solids content and other components added under manufacturer's directions to either stiffen or retard stiffening of the mix. All additives to grouts should be evaluated for their effects on subsequent water samples.

6.9.3.3 *Typical Cement-Based Grout*—A typical cement-based grout consists of about 6 gal. (23 L) of water per 94-lb. (43-kg) bag of Type I Portland cement. Though not recommended because of the chemical incompatability of bentonite with cement (2, 3), from 3 to 8 % (by dry weight) of unaltered bentonite powder is often added after the initial mixing of cement and water to retard shrinkage and provide plasticity..

6.10 *Secondary Filter Packs*:

6.10.1 *Materials*—A secondary filter pack is a layer of material placed in the annulus between the primary filter pack and the bentonite seal, and/or between the bentonite seal and the grout backfill (see Fig. 1 and Fig. 2).

6.10.2 *Gradation*—The secondary filter pack should be uniformly graded fine sand with 100 % by weight passing the #30 U.S. Standard sieve, and less than 2 % by weight passing the #200 U.S. Standard sieve.

6.11 *Annular Seal and Filter Pack Installation Equipment*—The equipment used to install the annular seals and filter pack materials should be cleaned (if appropriate for the selected material) using water from a source of known quality prior to use. This procedure is performed to prevent the introduction of materials that may ultimately alter water quality samples.

7. Drilling Methods

7.1 The type of equipment required to create a stable, open, vertical borehole for installation of a monitoring well depends upon the site geology, hydrology, and the intended use of the data. Engineering and geological judgment and some knowledge of subsurface geological conditions at the site is required for the selection of the appropriate drilling method(s) utilized for drilling the exploratory soil borings and monitoring wells (see Guide D 6286). Appropriate drilling methods for investigating and installing monitoring wells at a site may include any one or a combination of several of the following methods: hollow-stem auger (Guide D 5784); direct (mud) rotary (Guide D 5783); direct air-rotary (Guide D 5782); direct rotary wireline casing advancement (Guide D 5876); dual-wall reverse-circulation rotary (Guide D 5781); cable-tool (Guide D 5875); or various casing advancement methods (Guide D 5872). Whenever feasible, it is advisable to utilize drilling procedures that do not require the introduction of water or drilling fluids into the borehole, and that optimize cuttings control at ground surface. Where the use of water or drilling fluid is unavoidable, the selected fluid should have as little impact as possible on the water samples for the constituents of interest. The chemistry of the fluid to be used should be evaluated to determine the potential for water quality sample alteration. In addition, care should be taken to remove as much drilling fluid as possible from the well and the surrounding formation during the well development process. It is recommended that if an air compressor is used, it should be equipped with an oil air filter or oil trap to minimize the potential for chemical alteration of ground-water samples collected after the well is installed. 8. Monitoring Well Installation

8. Monitoring Well Installation

8.1 *Stable Borehole*—A stable borehole must be constructed prior to attempting the installation of monitoring well screen and riser. Steps must be taken to stabilize the borehole before attempting installation if the borehole tends to cave or blow in, or both. Boreholes that are not straight or are partially obstructed should be corrected prior to attempting the installation procedures described herein.

8.2 *Assembly of Well Screen and Riser*:

8.2.1 *Handling*—TThe well screen, sediment sump, bottom plug and riser should be either certified clean from the manufacturer or steam-cleaned or high-pressure hot-water washed (whichever is appropriate for the selected material) using water from a source of known chemistry immediately prior to assembly. Personnel should take precautions to assure that grease, oil, or other contaminants that may ultimately alter the water sample do not contact any portion of the well screen and riser assembly. As one precaution, for example, personnel should wear a clean pair of cotton, nitrile or powder-free PVC (or equivalent) gloves while handling the assembly..

8.2.2 *Riser Joints (Couplings)*—Flush joint risers with square profile (Specification F 480) threads do not require PTFE taping to achieve a water tight seal; these joints should not be taped. O-rings made of a material of known chemistry, selected on the basis of compatibility with contaminants of concern and prevailing environmental conditions, should be used to assure a tight seal of flush-joint couplings. Couplings are often tightened by hand; however, if necessary, steam-cleaned or high-pressure water-cleaned wrenches may be utilized. Precautions should be taken to prevent damage to the threaded joints during installation, as such damage may promote leakage past the threads.

8.3 *Setting the Well Screen and Riser Assembly*—When the well screen and riser assembly is lowered to the predetermined level in the borehole and held in position, the assembly may require ballast to counteract the tendency to float in the borehole. Ballasting may be accomplished by filling the riser with water from a source of known and acceptable chemistry or, preferably, using water that was previously removed from the borehole. Alternatively, the riser may be slowly pushed into the fluid in the borehole with the aid of hydraulic rams on the drill rig and held in place as additional sections of riser are added to the column. Care must be taken to secure the riser assembly so that personnel safety is assured during the installation. The assembly must be installed straight and plumb, with centralizers installed at appropriate locations (typically every 20 to 30 ft [6 to 9 m]). Difficulty in maintaining a straight installation may be encountered where the weight of the well screen and riser assembly is significantly less than the buoyant force of the fluid in the borehole. The riser should extend above grade and be capped temporarily to deter entrance of foreign materials during final completion.

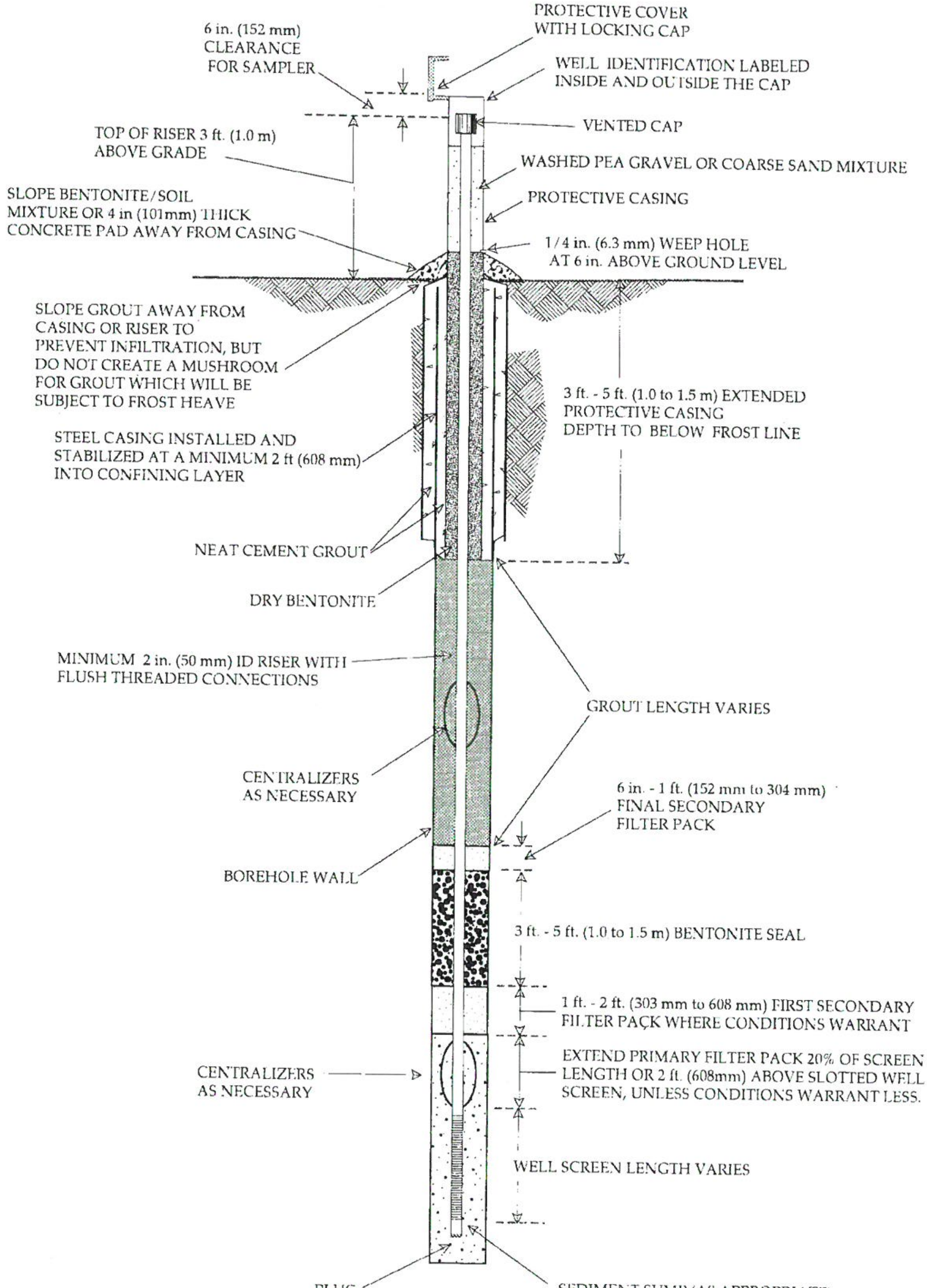

FIG. 2 Monitoring Well Design—Multi–Cased Well

8.4 *Installation of the Primary Filter Pack:*

8.4.1 *Volume of Filter Pack*—TThe volume of filter pack required to fill the annular space between the well screen and borehole should be calculated, measured, and recorded on the well completion diagram during installation. To be effective, the filter pack should extend above the screen for a distance of about 20 % of the length of the well screen but not less than 2 ft. (0.6 m) (see Figs. 1 and 2). Where there is hydraulic connection between the zone to be monitored and the overlying strata, this upward extension should be gauged to prevent seepage from overlying hydrologic units into the filter pack. Seepage from other units may alter hydraulic head measurements or the chemistry of water samples collected from the well.

8.4.2 *Placement of Primary Filter Pack*—Placement of the well screen is preceded by placing no less than 2 % and no more than 10 % of the primary filter pack into the bottom of the borehole using a decontaminated, flush threaded, 1-in. (25-mm) minimum internal diameter tremie pipe. Alternatively, the filter pack may be added directly between the riser pipe and the auger or drive/temporary casing and the top of the filter pack located using a tamper or a weighted line. The well screen and riser assembly is then centered in the borehole. This can be done using one or more centralizer(s) or alternative centering devices located not more than 10 ft (3 m) above the bottom of the well screen (see Figs. 1 and 2). Centralizers should not be located in the well screen. The remaining primary filter pack is then placed in increments as the tremie is gradually raised or as the auger or drive/temporary casing is removed from the borehole. As primary filter pack material is poured into the tremie pipe, water from a source of known and acceptable chemistry may be added to help deliver the filter pack to the intended interval in the borehole. The tremie pipe or a weighed line can be used to measure the top of the primary filter pack as work progresses. If bridging of the primary filter pack material occurs, the bridged material should be broken mechanically prior to proceeding with the addition of more filter pack material. The elevation (or depth below ground surface), volume, and gradation of primary filter pack should be recorded on the well completion diagram (see Fig. 2 for an example).

8.4.3 *Withdrawal of the Temporary Casing/Augers*—If used, the drive/temporary casing or hollow stem auger is withdrawn, usually in stipulated increments. Care should be taken to avoid lifting the riser with the withdrawal of the temporary casing/augers. To limit borehole collapse in stable formations, the temporary casing or hollow stem auger is usually withdrawn until the lower-most point on the temporary casing or hollow stem auger is at least 2 ft (0.6 m), but no more than 5 ft (1.5 m) above the filter pack for unconsolidated materials; or at least 5 ft (1.5 m), but no more than 10 ft (3.0 m), for consolidated materials. In highly unstable formations, withdrawal intervals may be much less. After each increment, it should be ascertained that the primary filter pack has not been displaced during the withdrawal operation (using a weighed measuring device).

8.5 *Placement of First Secondary Filter*—A secondary filter pack may be installed above the primary filter pack to prevent the intrusion of the bentonite grout seal into the primary filter pack (see Figs. 1 and 2). To be effective, a measured and recorded volume of secondary filter material should be added to extend 1 to 2 ft (0.3 to 0.6 m) above the primary filter pack. As with the primary filter, a secondary filter must not extend into an overlying hydrologic unit (see 8.4.1). The well designer should evaluate the need for this filter pack by considering the gradation of the primary filter pack, the hydraulic heads between adjacent units, and the potential for grout intrusion into the primary filter pack. The secondary filter material is poured into the annular space through a decontaminated, flush threaded, 1-in. (25-mm) minimum internal diameter tremie pipe lowered to within 3 ft (1.0 m) of the placement interval. Water from a source of known and acceptable chemistry may be added to help deliver the filter pack to its intended location. The tremie pipe or a weighed line can be used to measure the top of the secondary filter pack as work progresses. The elevation (or depth below ground surface), volume, and gradation of the secondary filter pack should be recorded on the well completion diagram.

8.6 *Installation of the Bentonite Seal*—A bentonite pellet or a slurry seal is placed in the annulus between the borehole and the riser pipe on top of the secondary or primary filter pack (see Figs. 1 and 2). This seal retards the movement of cement-based grout backfill into the primary or secondary filter packs. To be effective, the bentonite seal should extend above the filter packs approximately 3 to 5 ft (1.0 to 1.5 m), depending on local conditions. The bentonite slurry seal should be installed using a positive displacement pump and a side-discharge tremie pipe lowered to the top of the filter pack. The tremie pipe should be raised slowly as the bentonite slurry fills the annular space. Bentonite pellets or chips may be poured from the surface and allowed to free-fall into the borehole. As a bentonite pellet or chip seal is poured into the borehole, a tamper may be necessary to tamp pellets or chips into place or to break bridges formed as the pellets or chips stick to the riser or the walls of the water-filled portion of the borehole. If the bentonite seal is installed above the water level in the borehole, granular bentonite should be used as the seal material – *bentonite pellets or chips should not be used in the unsaturated zone.* Granular bentonite should be poured into the borehole and installed in lifts of 2 in., then hydrated with water from a source of known chemistry. The tremie pipe or a weighed line can be used to measure the top of the bentonite seal as the work progresses. Sufficient time should be allowed for the bentonite pellet seal to hydrate or the slurry annular seal to expand prior to grouting the remaining annulus. The volume and elevation (or depth below ground surface) of the bentonite seal material should be measured and recorded on the well completion diagram.

8.7 *Final Secondary Filter Pack*—A 6-in. to 1-ft (0.15 to 0.3-m) secondary filter may be placed above the bentonite seal in the same manner described in 8.5 (see Figs. 1 and 2). This secondary filter pack will provide a layer over the bentonite seal to limit the downward movement of cement-based grout backfill into the bentonite seal. The volume, elevation (or depth below ground surface), and gradation of this final secondary filter pack should be documented on the well completion diagram.

8.8 *Grouting the Annular Space*:

8.8.1 *General*—Grouting procedures vary with the type of well design. The following procedures will apply to both single- and multi-cased monitoring wells. Paragraphs 8.8.2 and 8.8.3 detail those procedures unique to single- and multi-cased installations, respectively.

8.8.1.1 *Volume of Grout*—An ample volume of grout should be mixed on site to compensate for unexpected losses to the formation. The use of alternate grout materials, including grout containing gravel, may be necessary to control zones of high grout loss. The volume and location of grout used to backfill the remaining annular space is recorded on the well completion diagram.

8.8.1.2 *Grout Installation Procedures*—The grout should be pumped down hole through a side-discharge tremie pipe using a positive displacement pump (e.g., a diaphragm pump, moyno pump, or similar pump) to reduce the chance of leaving voids in the grout, and to displace any liquids and drill cuttings that may remain in the annulus. In very shallow wells, grouting may be accomplished by gravity feeding grout through a tremie pipe. With either method, grout should be introduced in one continuous operation until full-strength grout flows out of the borehole at the ground surface without evidence of drill cuttings, drilling fluid, or water.

8.8.1.3 *Grout Setting and Curing*—The riser should not be disturbed until the grout sets and cures for the amount of time necessary to prevent a break in the seal between the grout and riser. The amount of time required for the grout to set or cure will vary with the grout mix and ambient temperature and should be documented on the well completion diagram.

8.8.2 *Specific Procedures for Single-Cased Wells*—Grouting should begin at a level directly above the final secondary filter pack (see Fig. 1) if used, or above the bentonite pellet, chip or slurry seal. Grout should be pumped using a side-discharge tremie pipe to dissipate the fluid-pumping energy against the borehole wall and riser, reducing the potential for infiltration of grout into the primary filter pack. The tremie pipe should be kept full of grout from start to finish, with the discharge end of the pipe completely submerged as it is slowly and continuously lifted. Approximately 5 to 10 ft (1.5 to 3.0 m) of tremie pipe should remain submerged until grouting is complete. For deep installations or where the joints or couplings of the selected riser cannot withstand the collapse stress exerted by a full column of grout as it is installed, a staged grouting procedure may be used. If used, the drive/temporary casing or hollow-stem auger should be removed in increments immediately following each increment of grout installation and before the grout begins to set. If casing removal does not commence until grout pumping is completed, then, after the casing is removed, additional grout may be periodically pumped into the annular space to maintain a continuous column of grout up to the ground surface.

8.8.3 *Specific Procedures for Multi-Cased Wells*—If the outer casing of a multi-cased well cannot be driven to form a tight seal between the surrounding stratum (strata) and the casing, it should be installed in a pre-drilled borehole. After the borehole has penetrated not less than 2 ft. (0.6 m) of the first targeted confining stratum, the outer casing should be lowered to the bottom of the boring and the annular space pressure grouted. Pressure grouting requires the use of a grout shoe or packer installed at the end of the outer casing to prevent grout from moving up into the casing. The grout must be allowed to cure and form a seal between the casing and the borehole prior to advancing the hole to the next hydrologic unit. This procedure is repeated as necessary to advance the borehole to the desired depth. Upon reaching the final depth, the riser and screen should be set through the inner casing. After placement of the filter packs and bentonite seal, the remaining annular space is grouted as described in 8.8.2 (see Fig. 2).

NOTE 15—When using a packer, pressure may build up during grout injection and force grout up the sides of the packer and into the casing.

8.9 *Well Protection*—Well protection refers specifically to installations made at the ground surface to deter unauthorized entry to the monitoring well, to prevent damage to or destruction of the well, and to prevent surface water from entering the annulus. The methods described in Practice D 5787 should be used for well protection.

8.9.1 *Protective Casing*—Protective casing should be used for all monitoring well installations. In areas that experience frost heaving, the protective casing should extend from below the depth of frost penetration (3 to 5 ft [1.0 to 1.5 m] below grade, depending on local conditions), to slightly above the top of the well casing. The protective casing should be initially placed before final set of the grout. The protective casing should be sealed and immobilized in concrete placed around the outside of the protective casing above the set grout. The protective casing should be stabilized in a position concentric with the riser (see Figs. 3 and 1). Sufficient clearance, usually 6 in. (0.15 m) should be maintained between the lid of the protective casing and the top of the riser to accommodate sampling equipment. A ¼-in. (6.3-mm) ddiameter weep hole should be drilled in the protective casing approximately 6 in. (15 cm) above ground surface to permit water to drain out of the annular space between the protective casing and the riser. In cold climates, this hole will also prevent water freezing between the protective casing and the well casing. Dry bentonite pellets, granules, or chips should then be placed in the

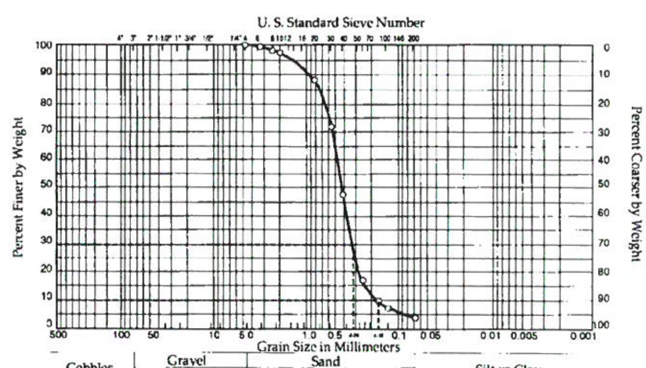

FIG. 3 Example Grading Curve for Design of Monitoring Well Screens

annular space below ground level within the protective casing. Coarse sand or pea gravel or both should be placed in the annular space above the dry bentonite pellets and to just above the weep hole to prevent entry of insects. All materials chosen should be documented on the well completion diagram. The monitoring well identification number should be clearly visible on the inside and outside of the protective casing.

8.9.2 *Completion of Surface Installation*—The well protection installation may be completed in one of three ways:

8.9.2.1 In areas subject to frost heave, place a soil or bentonite/sand layer adjacent to the protective casing sloped to direct water drainage away from the well.

8.9.2.2 In regions not subject to frost heave, a concrete pad, sloped slightly to provide water drainage away from the well, should be placed around the installation.

8.9.2.3 Where monitoring well protection must be installed flush with the ground, an internal cap should be fitted on top of the riser within the manhole or vault. This cap should be leak-proof so that if the vault or manhole should fill with water, the water will not enter the well casing. Ideally, the manhole cover cap should also be leak-proof..

8.9.3 *Additional Protection*—In areas where there is a high probability of damaging the well (high traffic, heavy equipment, poor visibility), it may be necessary to enhance the normal protection of the monitoring well through the use of posts, markers, signs, or other means, as described in Practice D 5787. The level of protection should meet the damage threat posed by the location of the well.

9. Well Development

9.1 *General*—Well development serves to remove fine-grained material from the well screen and filter pack that may otherwise interfere with water quality analyses, to restore the formation properties disturbed during the drilling process, and to improve the hydraulic characteristics of the filter pack and hydraulic communication between the well and the hydrologic unit adjacent to the well screen. Methods of well development vary with the physical characteristics of hydrologic units in which the monitoring well is screened and with the drilling method used.

9.2 *Development Methods and Procedures*—The methods and procedures for well development described in Guide D 5521 should be followed to ensure a proper well completion.

9.3 *Timing and Duration of Well Development*—Well development should begin either after the riser, well screen and filter pack are installed and before the bentonite seal and grout are installed (the preferred time), or after the monitoring well is completely installed and the grout has cured or set. In the former case, the installer may add filter pack material to the borehole before the bentonite seal is installed to compensate for settlement that typically occurs during the development process. This allows the installer to maintain the desired separation between the top of the screen and the bentonite seal. In the latter case, the possibility exists that settlement of the filter pack may result in the bentonite seal settling into the top of the screen. Development should be continued until representative water, free of the drilling fluids, cuttings, or other materials introduced or produced during well construction, is obtained. Representative water is assumed to have been obtained when turbidity readings stabilize and the water is visually clear of suspended solids. The minimum duration of well development will vary with the method used to develop the well. The timing and duration of well development and the turbidity measurements should be recorded on the well completion diagram.

9.4 *Well Recovery Test*—A well recovery test should be performed immediately after and in conjunction with well development. The well recovery test provides an indication of well performance and provides data for estimating the hydraulic conductivity of the screened hydrologic unit. Readings should be taken at intervals suggested in Table 2 until the well has recovered to 90 % of its static water level.

NOTE 16—If a monitoring well does not recover sufficiently for sampling within a 24-hr period and the well has been properly developed, the installation should not generally be used as a monitoring well for detecting or assessing low level organic constituents or trace metals. The installation may, however, be used for long-term water-level monitoring if measurements of short-frequency water-level changes are not required.

10. Installation Survey

10.1 *General*—The vertical and horizontal position of each monitoring well in the monitoring system should be surveyed and subsequently mapped by a licensed surveyor. The well location map should include the location of all monitoring wells in the system and their respective identification numbers, elevations of the top of riser position to be used as the reference point for water-level measurements, and the elevations of the ground surface protective installations. The locations and elevations of all permanent benchmark(s) and pertinent boundary marker(s) located on-site or used in the survey should also be noted on the map.

10.2 *Water-Level Measurement Reference*—The water-level measurement reference point should be permanently marked, for example, by cutting a V-notch into the top edge of the riser pipe. This reference point should be surveyed in reference to the nearest NAVD reference point.

10.3 *Location Coordinates*—The horizontal location of all monitoring wells (active or decommissioned) should be surveyed by reference to a standardized survey grid or by metes and bounds.

10.4 *Borehole Deviation Survey*—A borehole deviation survey, to determine the direction and distance of the bottom of the well relative to the top of the well and points in between, should be completed in wells deeper than 100 feet and in wells installed in dipping formations.

11. Monitoring Well Network Report

11.1 TTo demonstrate that the goals set forth in the Scope have been met, a monitoring well network report should be prepared. This report should:

TABLE 2 Suggested Recording Intervals for Well Recovery Tests

Time Since Starting Test	Time Interval
0 to 15 min	1 min
15 to 50 min	5 min
50 to 100 min	10 min
100 to 300 min (5 h)	30 min
300 to 1440 min (24 h)	60 min

11.1.1 Locate the area investigated in terms pertinent to the project. This should include sketch maps or aerial photos on which the exploratory borings, piezometers, sample areas, and monitoring wells are located, as well as topographic items relevant to the determination of the various soil and rock types, such as contours, streambeds, etc. Where feasible, include a geologic map and geologic cross sections of the area being investigated.

11.1.2 Include copies of all well boring test pits and exploratory borehole logs, initial and post-completion water levels, all laboratory test results, and all well completion diagrams.

11.1.3 Include the well installation survey.

11.1.4 Describe and relate the findings obtained in the initial reconnaissance and field investigation (Section 5) to the design and installation procedures selected (Sections 7-9) and the surveyed locations (Section 10).

11.1.5 This report should include a recommended decommissioning procedure that is consistent with those described in Guide D 5299 and/or with applicable regulatory requirements.

12. Keywords

12.1 aquifer; borehole drilling; geophysical exploration; ground water; monitoring well; site investigation

Standard Guide for Direct-Push Groundwater Sampling for Environmental Site Characterization[1]

This standard is issued under the fixed designation D6001; 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 covers a review of methods for sampling groundwater at discrete points or in increments by insertion of sampling devices by static force or impact without drilling and removal of cuttings. By directly pushing the sampler, the soil is displaced and helps to form an annular seal above the sampling zone. Direct-push water sampling can be one time, or multiple sampling events. Methods for obtaining water samples for water quality analysis and detection of contaminants are presented.

1.2 Direct-push methods of water sampling are used for groundwater quality studies. Water quality may vary at different depths below the surface depending on geohydrologic conditions. Incremental sampling or sampling at discrete depths is used to determine the distribution of contaminants and to more completely characterize geohydrologic environments. These investigations are frequently required in characterization of hazardous and toxic waste sites.

1.3 Direct-push methods can provide accurate information on the distribution of water quality if provisions are made to ensure that cross-contamination or linkage between water bearing strata are not made. Discrete point sampling with a sealed (protected) screen sampler, combined with on-site analysis of water samples, can provide the most accurate depiction of water quality conditions at the time of sampling. Direct-push water sampling with exposed-screen sampling devices may be useful and are considered as screening tools depending on precautions taken during testing. Exposed screen samplers may require development or purging depending on sampling and quality assurance plans. Results from direct-push investigations can be used to guide placement of permanent groundwater monitoring wells and direct remediation efforts. Multiple sampling events can be performed to depict conditions over time. Use of double tube tooling, where the outer push tube seals the hole, prevents the sampling tools from coming in contact with the formation, except at the sampling point.

1.4 Field test methods described in this guide include installation of temporary well points, and insertion of water samplers using a variety of insertion methods. Insertion methods include: *(1)* soil probing using combinations of impact, percussion, or vibratory driving with or without additions of smooth static force; *(2)* smooth static force from the surface using hydraulic cone penetrometer (Guide D6067) or drilling equipment (Guide D6286), and incremental drilling combined with direct-push water sampling events. Under typical incremental drilling operations, samplers are advanced with assistance of drilling equipment by smooth hydraulic push, or mechanical impacts from hammers or other vibratory equipment. Direct-push water sampling maybe combined with other sampling methods (Guide D6169) in drilled holes. Methods for borehole abandonment by grouting are also addressed.

1.5 Direct-push water sampling is limited to soils that can be penetrated with available equipment. In strong soils damage may result during insertion of the sampler from rod bending or assembly buckling. Penetration may be limited, or damage to samplers or rods can occur in certain ground conditions, some of which are discussed in 5.6. Information in this procedure is limited to sampling of saturated soils in perched or saturated groundwater conditions. Some soil formations do not yield water in a timely fashion for direct-push sampling. In the case of unyielding formations direct-push soil sampling can be performed (Guide D6282).

1.6 This guide does not address installation of permanent water sampling systems such as those presented in Practice D5092. Direct-push monitoring wells for long term monitoring are addressed in Guide D6724 and Practice D6725.

1.7 Direct-push water sampling for geoenvironmental exploration will often involve safety planning, administration, and documentation.

1.8 *This guide does not purport to address all aspects of exploration and site safety. It is the responsibility of the user of this guide to establish appropriate safety and health practices and determine the applicability of regulatory limitations before its use.*

[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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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 or 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]

D653 Terminology Relating to Soil, Rock, and Contained Fluids
D2488 Practice for Description and Identification of Soils (Visual-Manual Procedure)
D4448 Guide for Sampling Ground-Water Monitoring Wells
D4750 Test Method for Determining Subsurface Liquid Levels in a Borehole or Monitoring Well (Observation Well) (Withdrawn 2010)[3]
D5088 Practice for Decontamination of Field Equipment Used at Waste Sites
D5092 Practice for Design and Installation of Ground Water Monitoring Wells
D5254 Practice for Minimum Set of Data Elements to Identify a Ground-Water Site
D5314 Guide for Soil Gas Monitoring in the Vadose Zone
D5434 Guide for Field Logging of Subsurface Explorations of Soil and Rock
D5474 Guide for Selection of Data Elements for Groundwater Investigations
D5521 Guide for Development of Ground-Water Monitoring Wells in Granular Aquifers
D5730 Guide for Site Characterization for Environmental Purposes With Emphasis on Soil, Rock, the Vadose Zone and Groundwater
D5778 Test Method for Electronic Friction Cone and Piezocone Penetration Testing of Soils
D5903 Guide for Planning and Preparing for a Groundwater Sampling Event
D6067 Practice for Using the Electronic Piezocone Penetrometer Tests for Environmental Site Characterization
D6089 Guide for Documenting a Ground-Water Sampling Event
D6235 Practice for Expedited Site Characterization of Vadose Zone and Groundwater Contamination at Hazardous Waste Contaminated Sites
D6452 Guide for Purging Methods for Wells Used for Groundwater Quality Investigations
D6517 Guide for Field Preservation of Groundwater Samples
D6564 Guide for Field Filtration of Groundwater Samples
D6634 Guide for the Selection of Purging and Sampling Devices for Ground-Water Monitoring Wells
D6724 Guide for Installation of Direct Push Groundwater Monitoring Wells
D6725 Practice for Direct Push Installation of Prepacked Screen Monitoring Wells in Unconsolidated Aquifers
D6771 Practice for Low-Flow Purging and Sampling for Wells and Devices Used for Ground-Water Quality Investigations (Withdrawn 2011)[3]
D6911 Guide for Packaging and Shipping Environmental Samples for Laboratory Analysis

2.2 *Drilling Methods:*[2]

D5781 Guide for the Use of Dual-Wall Reverse-Circulation Drilling for Geoenvironmental Exploration and the Installation of Subsurface Water-Quality Monitoring Devices
D5782 Guide for the Use of Direct Air-Rotary Drilling for Geoenvironmental Exploration and the Installation of Subsurface Water-Quality Monitoring Devices
D5783 Guide for the 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 the Use of Hollow-Stem Augers for Geoenvironmental Exploration and the Installation of Subsurface Water-Quality Monitoring Devices
D5875 Guide for the Use of Cable-Tool Drilling and Sampling Methods for Geoenvironmental Explorations and Installation of Subsurface Water-Quality Monitoring Devices
D5876 Guide for the Use of Direct Rotary Wireline Casing Advancement Drilling Methods for Geoenvironmental Exploration and the Installation of Subsurface Water-Quality Monitoring Devices
D6286 Guide to the Selection of Drilling Methods for Environmental Site Characterization

2.3 *Soil Sampling:*[2]

D4700 Guide for Soil Sampling from the Vadose Zone
D6169 Guide to the Selection of Soil and Rock Sampling Devices Used With Drilling Rigs for Environmental Investigations
D6282 Guide for Direct-Push Soil Sampling for Environmental Site Characterization

3. Terminology

3.1 Terminology used within this guide is in accordance with Terminology D653 with the addition of the following:

3.2 *Definitions in Accordance with Practice D5092:*

3.2.1 *bailer*—a hollow tubular receptacle used to facilitate removal of fluid from a well or borehole.

3.2.2 *borehole*—a circular open or uncased subsurface hole created by drilling.

3.2.3 *casing*—pipe, finished in sections with either threaded connections or beveled edges to be field welded, which is installed temporarily or permanently to counteract caving, to

[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.

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

advance the borehole, or to isolate the interval being monitored, or combination thereof.

3.2.4 *caving; sloughing*—the inflow of unconsolidated material into a borehole that occurs when the borehole walls lose their cohesive strength.

3.2.5 *centralizer*—a device that helps in the centering of a casing or riser within a borehole or another casing.

3.2.6 *jetting*—when applied as a drilling method, water is forced down through the drill rods or riser pipe and out through the end openings. The jetting water then transports the generated cuttings to the ground surface in the annulus of the drill rods or casing and the borehole. The term jetting may also refer to a well development technique.

3.2.7 *PTFE tape*—joint sealing tape composed of polytetrafluorethylene.

3.2.8 *well screen*—a filtering device used to retain the primary or natural filter pack; usually a cylindrical pipe with openings of uniform width, orientation, and spacing.

3.3 *Definitions of Terms Specific to This Standard:*

3.3.1 *assembly length*—length of sampler body and riser pipes.

3.3.2 *bentonite*—the common name for drilling fluid additives and well construction products consisting mostly of naturally occurring sodium montmorillonite. Some bentonite products have chemical additives that may affect water quality analyses (see 9.3.3).

3.3.3 *direct-push sampling*—sampling devices that are directly inserted into the soil to be sampled without drilling or borehole excavation.

3.3.4 *drill hole*—a cylindrical hole advanced into the subsurface by mechanical means; also, known as borehole or boring.

3.3.5 *effective screen length*—the length of a screen open or exposed to water bearing strata.

3.3.6 *effective seal length*—the length of soil above the well screen that is in intimate contact with the riser pipe and prevents connection of the well screen with groundwater from other zones.

3.3.7 *grab sampling*—the process of collecting a sample of fluid exposed to atmospheric pressure through the riser pipe with bailers or other methods that may include pumping; also known as batch sampling.

3.3.8 *incremental drilling and sampling*—insertion method where rotary drilling and sampling events are alternated for incremental sampling. Incremental drilling is often needed to penetrate harder or deeper formations.

3.3.9 *percussion driving*—insertion method where rapid hammer impacts are performed to insert the sampling device. The percussion is normally accompanied with application of static down force.

3.3.10 *push depth*—the depth below a ground surface datum that the end or tip of the direct-push water sampling device is inserted.

4. Summary of Guide

4.1 Direct-push water sampling consists of pushing a protected well screen to a known depth, opening the well screen over a known interval, and sampling water from the interval. A well point with an exposed screen can also be pushed with understanding of potential cross-contamination effects and purging requirements considered. A sampler with constant outside diameter is inserted directly into the soil by hydraulic jacking or hammering until sufficient riser pipe is seated into the soil to ensure a seal. Protected well screens can be exposed by retraction of riser pipes. While the riser is seated in the soil, water samples can be taken, and water injection or pressure measurements may be performed.

5. Significance and Use

5.1 Direct-push water sampling is an economical method for obtaining discrete groundwater samples without the expense of permanent monitoring well installation **(1-6)**.[4] This guide can be used to profile potential groundwater contamination with depth by performing repetitive sampling events. Direct-push water sampling is often used in expedited site characterization (Practice D6235). Soils to be sampled must be permeable to allow filling of the sampler in a relatively short time. The zone to be sampled can be isolated by matching well screen length to obtain discrete samples of thin aquifers. Use of these sampling techniques will result in more detailed characterization of sites containing multiple aquifers. By inserting a protected sampling screen in direct contact with soil and with watertight risers, initial well development (Guide D5521) and purging of wells (Guide D6452) may not be required for the first sampling event. Discrete water sampling, combined with knowledge of location and thickness of target aquifers, may better define conditions in thin multiple aquifers than monitoring wells with screened intervals that can intersect and allow for intercommunication of multiple aquifers **(4,6,7,9,13)**. Direct-push sampling performed without knowledge of the location and thickness of target aquifers can result in sampling of the wrong aquifer or penetration through confining beds.

5.2 For sites that allow surface push of the sampling device, discrete water sampling is often performed in conjunction with the cone penetration test (Test Method D6067) **(4-9)**, which is often used for stratigraphic mapping of aquifers, and to delineate high-permeability zones. In such cases, direct-push water sampling is normally performed close to cone holes. In complex alluvial environments, thin aquifers may vary in continuity such that water sampling devices may not intersect the same layer at equivalent depths as companion cone penetrometer holes.

5.3 Water sampling chambers may be sealed to maintain in situ pressures and to allow for pressure measurements and permeability testing **(6,9,12)**. Sealing of samples under pressure may reduce the possible volatilization of some organic compounds. Field comparisons may be used to evaluate any systematic errors in sampling equipments and methods. Comparison studies may include the need for pressurizing samples,

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

or the use of vacuum to extract fluids more rapidly from low hydraulic conductivity soils (8.1.5.3).

5.4 Degradation of water samples during handling and transport can be reduced if discrete water sampling events with protected screen samplers are combined with real time field analysis of potential contaminants. In limited studies, researchers have found that the combination of discrete protected screen sampling with onsite field analytical testing provide accurate data of aquifer water quality conditions at the time of testing (**4,6**). Direct-push water sampling with exposed screen sampling devices, which may require development or purging, are considered as screening tools depending on precautions that are taken during testing.

5.5 A well screen may be pushed into undisturbed soils at the base of a drill hole and backfilled to make permanent installed monitoring wells. Procedures to complete direct-push wells as permanent installations are given in Practice D6725 and Guide D6724.

5.6 In difficult driving conditions, penetrating to the required depth to ensure sealing of the sampler well screen may not be possible. If the well screen cannot be inserted into the soil with an adequate seal, the water-sampling event would require sealing in accordance with Practice D5092 to isolate the required aquifer. Selection of the appropriate equipment and methods to reach required depth at the site of concern should be made in consultation with experienced operators or manufacturers. If there is no information as to the subsurface conditions, initial explorations consisting of penetration-resistance tests, such as Test Method D6067, or actual direct-push testing trials can be performed to select the appropriate testing system.

5.6.1 Typical penetration depths for a specific equipment configuration depend on many variables. Some of the variables are the driving system, the diameter of the sampler and riser pipes, and the resistance of the materials.

5.6.2 Certain subsurface conditions may prevent sampler insertion. Penetration is not possible in hard rock and usually not possible in softer rocks such as claystones and shales. Coarse particles such as gravels, cobbles, and boulders may be difficult to penetrate or cause damage to the sampler or riser pipes. Cemented soil zones may be difficult to penetrate depending on the strength and thickness of the layers. If layers are present that prevent direct-push from the surface, the rotary or percussion drilling methods (Guide D6286) can be employed to advance a boring through impeding layers to reach testing zones.

5.6.3 Driving systems are generally selected based on required testing depths and the materials to be penetrated. For systems using primarily static reaction force to insert the sampler, depth will be limited by the reaction weight of the equipment and penetration resistance of the material. The ability to pull back the rod string is also a consideration. Impact or percussion soil probing has an advantage of reducing the reaction weight required for penetration. Penetration capability in clays may be increased by reducing rod friction by enlarging tips or friction reducers. However, over reaming of the hole may increase the possibility of rod buckling and may allow for communication of differing groundwater tables. Hand-held equipment is generally used on very shallow investigations, typically less than 5-m depth, but depths on the order of 10 m have been reached in very soft lacustrine clays. Intermediate size driving systems, such as small truck-mounted hydraulic-powered push and impact drivers, typically work within depth ranges from 5 to 30 m. Heavy static-push cone penetrometer vehicles, such as 20-ton trucks, typically work within depth ranges from 15 to 45 m, and also reach depth ranges on the order of 10^2 m in soft ground conditions. Drilling methods (Guide D6286) using drilling and incremental sampling are frequently used in all depth ranges and can be used to reach depths on the order of 103 m.

NOTE 1—Users and manufacturers cannot agree on depth ranges for different soil types. Users should consult with experienced producers and manufacturers to determine depth capability for their site conditions.

5.7 Combining multiple-sampling events in a single-sample chamber without decontamination (Practices D5088) is generally unacceptable. In this application, purging of the chamber should be performed to ensure isolation of the sampling event. Purging should be performed by removing several volumes of fluid until new chemical properties have been stabilized or elements are flushed with fluid of known chemistry. Purging requirements may depend upon the materials used in the sampler and the sampler design (Guide D6634).

6. Apparatus

6.1 *General*—A direct-push sampling system consists of a tip; well screen; chambers, if present; and riser pipes extending to the surface. Direct-push water sampling equipment can be grouped into two classes, either with a sealed protected screen or exposed screen (see 6.2). There are also two types of drive systems, single tube and double tube (see 6.4).

6.2 Samplers with sealed screens depend on the seal to avoid exposure of the sampling interval to soil or water from other layers. They can be considered as accurate point-source detectors. They are normally decontaminated between sampling events. Exposed-screen samplers may require purging and development and as such are considered as screening devices for profiling relative degrees of contamination.

6.2.1 *Exposed-Screen Samplers*—Some direct-push samplers may consist of a simple exposed well screen and riser pipe that allows grab sampling with bailers or pumps. An example of this arrangement is the simple push or well point shown in Fig. 1 (**14**). The practice of jetting well points is often not acceptable due to the large quantities of water used for insertion and the resulting potential for disturbance and dilution in the aquifer. If water is used for insertion, knowing the chemical constituents in the water may be necessary. Bias may be possible if an exposed-screen sampler is pushed through multiple contaminated layers. If exposed-screen well points are pushed through predrilled holes the screen and riser may fill with water present in the drill hole and require purging before sampling. One form of exposed screen sampler has been developed for multiple sampling events as an exposed tip is advanced (**18,19**). This multiple event "groundwater profiler" injects distilled water out of the ports in between sampling

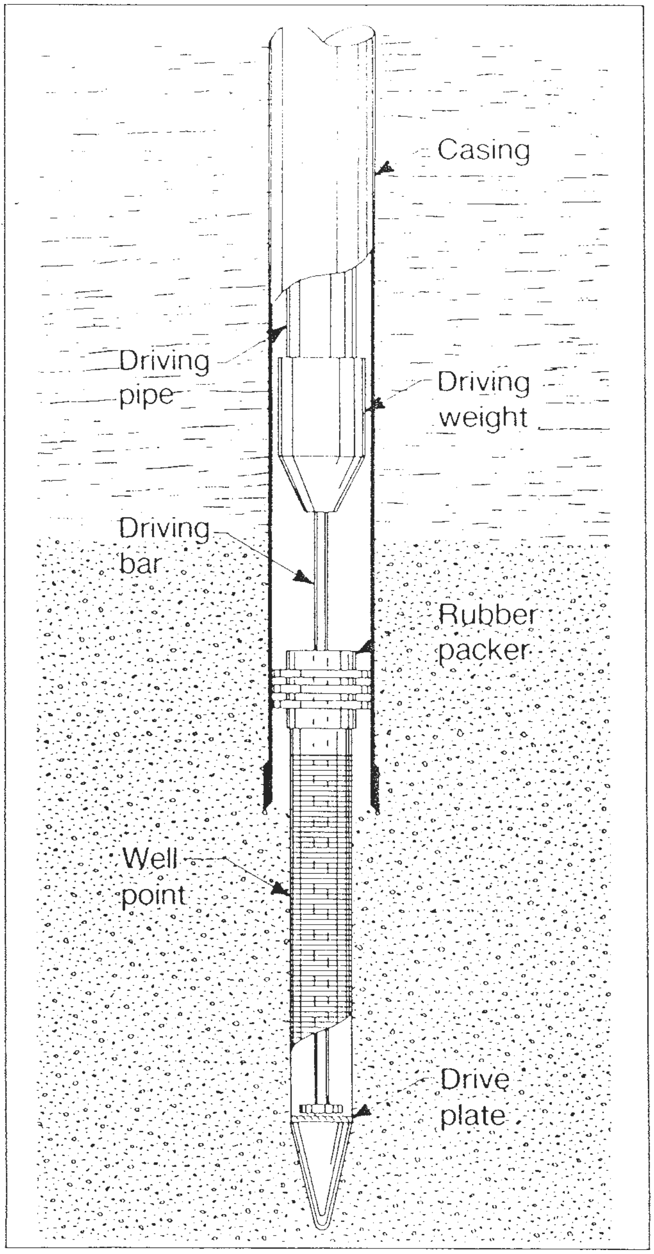


FIG. 1 Exposed-Screen Sampler—Well Point Driven Below the Base of a Borehole (12)

events which keep the port from clogging and purges the sampling line between sampling events.

6.2.1.1 Another form of an exposed-screen sampler has been incorporated into cone penetrometer bodies (**8**). The cone penetrometers have sample chambers with measurement devices such as temperature and conductivity. Some cone penetrometers have been equipped with pumps for drawing in water samples into sample chambers or to the surface. Samplers equipped with chambers and subjected to multiple sampling events may require purging between sampling events.

6.2.2 *Sealed-Screen Samplers*—Protected well screen and simple riser pipes for grab sampling are also deployed. An example is shown in Fig. 2 (**15**). This simple well screen arrangement allows for grab sampling through the riser pipe without purging or development if there is no leakage at the screen seals and riser pipes. Fig. 3 shows a schematic of a direct-push water sampler with a protected screen and with the ability to work in the grab sampling mode or by allowing water to enter a sample chamber in the sampler body (**5**). Most simple sample chambers allow for flow through the chamber. When flow through chambered samplers is opened, it is possible that the groundwater from the test interval can fill into the rods above the chamber. In those cases, it may be advisable to add water of known chemistry into the rods prior to opening the screen. Some protected-screen samplers have sample chambers designed to reduce volume and pressure changes in the sample to avoid possible volatilization of volatile compounds (**6**,**9**,**12**). The need for pressurization is dependent on the requirements of the investigation program and should be evaluated by comparison studies in the field with simpler systems allowing the sample to equalize at atmospheric pressure. There are different approaches to pressurizing the sample chamber including use of inert gas pressure or using sealed systems. An example of a sealed vial-septum system is shown in Fig. 4 (**6**). In the sealed vial system, a septum is punctured with a hypodermic needle connected to a sealed vial. With this approach the vial will contain both a liquid and gas at aquifer pressure. The sealed vial-septum system has been used in an exposed-screen mode.

6.2.3 *Materials of Manufacture*—The choice of materials used in the construction of direct-push water sampling devices should be based on the knowledge of the geochemical environment to be sampled and how the materials may interact with the sample by means of physical, chemical, or biological processes. Due to the nature of insertion of these devices, the sampler body is typically comprised of steel, stainless steel, or metals of other alloys. The type of metal should be selected based on possible interaction effects with the fluid to be sampled. Well-screen materials can be selected from a variety of materials. Materials commonly used for well-screen elements include steel, stainless steel, rigid polyvinyl chloride (PVC), polytetrafluorethylene (PTFE), polyethylene (PE), polypropylene (PP), and brass. Sample chambers, pumps, and connector lines are also constructed with a variety of materials. Evaluating the possible interaction of materials that will be exposed to the water during the sampling event is important.

6.3 *Sampler Body*—The sampler body consists of a tip, and a barrel that consists of well screen, a protective sleeve if used, and a sampling chamber if used, with a connector assembly to attach to riser pipes or tubing. The sampler is normally constructed of steel to withstand insertion forces. The sampler barrel should be of constant outside diameter to ensure intimate contact with the soil to be tested. Protective sleeves shall be equipped with O-rings to prevent the ingress of water before the sampling event.

6.3.1 *Expendable Sampler Tips*—Some sampler tips are expendable and are left in the ground after the sampling event. The tip should be equipped with an O-ring seal to the sampler sleeve to prevent leakage into the riser pipe until the sampling depth is reached.

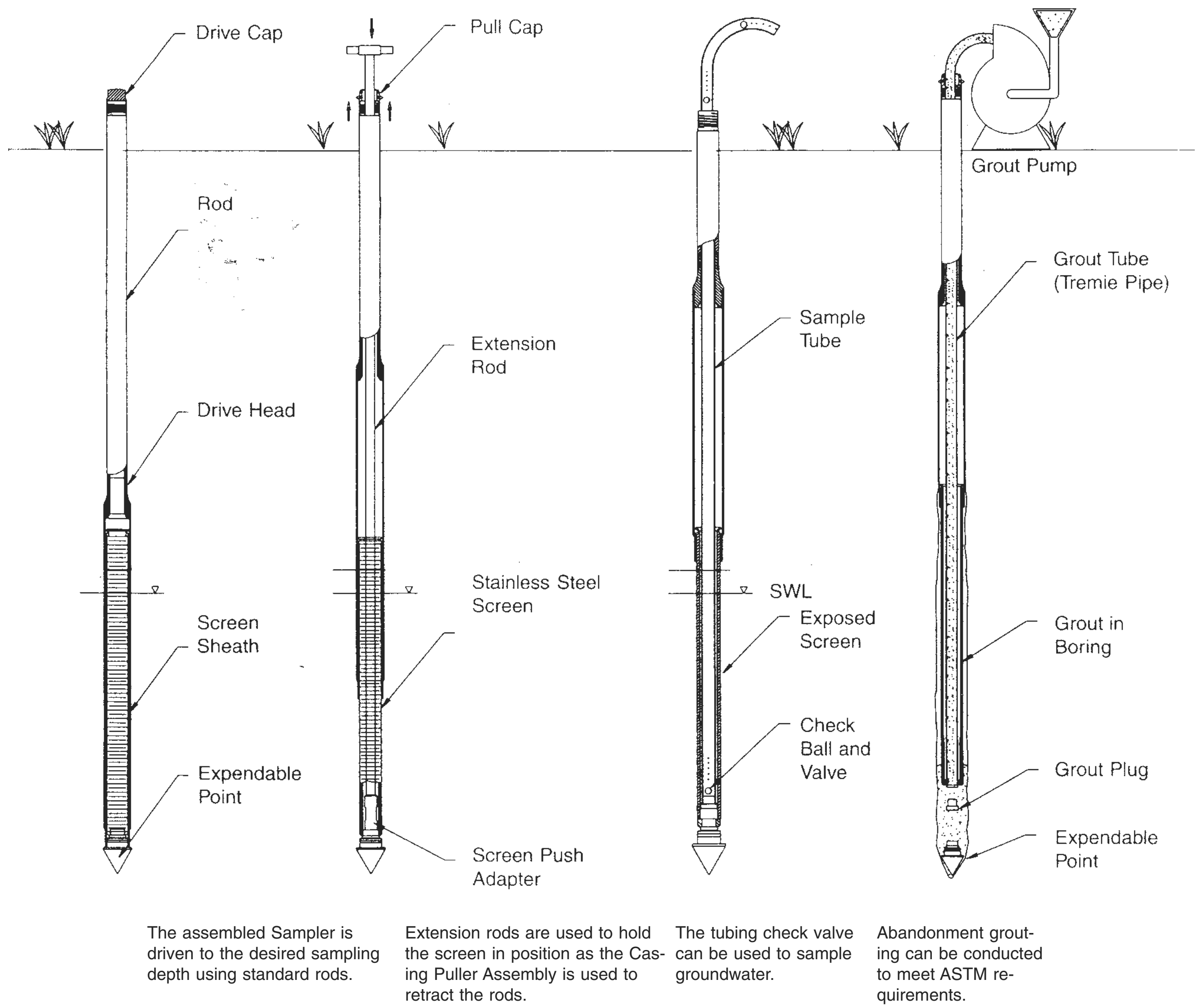
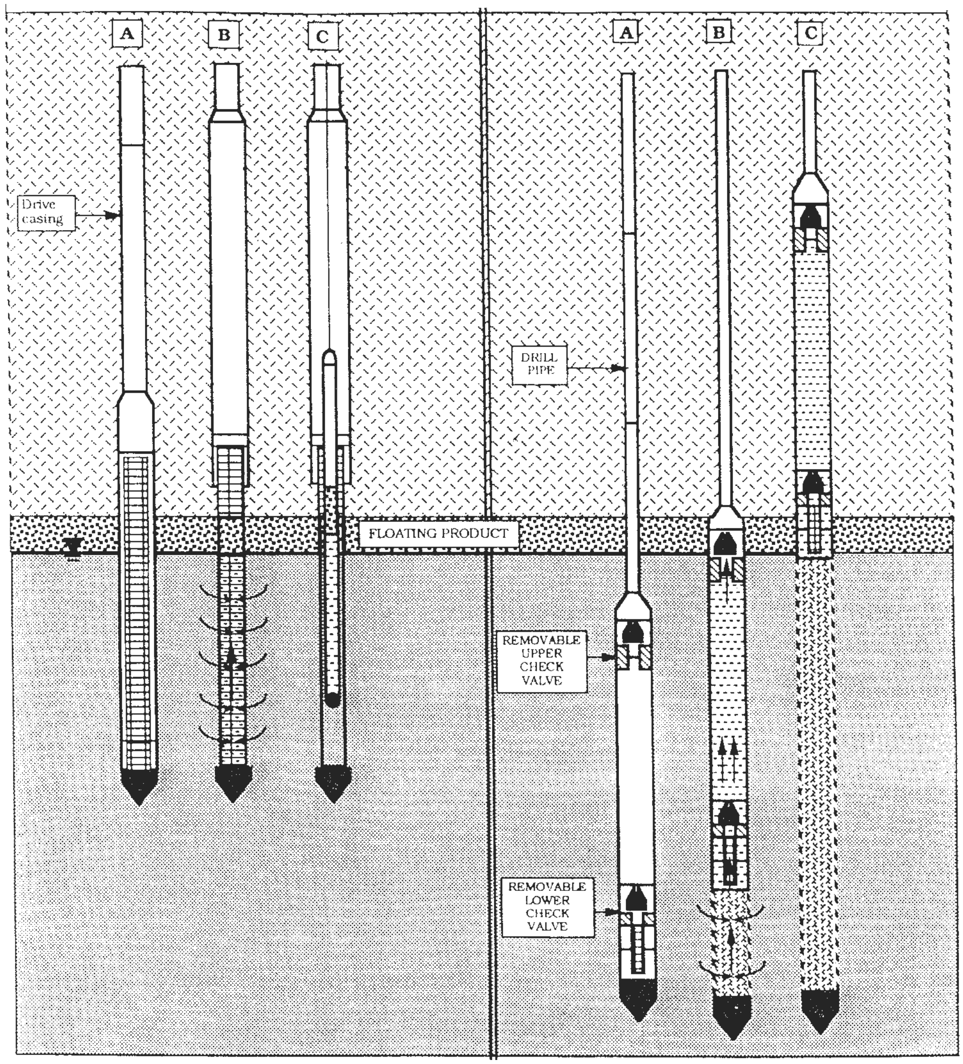


FIG. 2 Simple Protected Screen Sampler (13)

6.3.1.1 Sampler tips are designed so that upon pull back of the sampler body and riser pipe, the tip is disconnected from the sampler. The required diameter, and the ability to expend the tip successfully, depends on the soils to be penetrated. The tip diameter can be set equal to, or slightly less than, the sampler body. If there are problems with tip retraction, tips can be designed with a diameter of 1 to 3 mm (1⁄8 to 1⁄16 in.) larger than the sampler body. The use of an enlarged diameter with a larger shoulder or tip may help in reaching greater depths because it acts as a friction reducer. An enlarged tip should not leave too large an annulus above the sampler body and riser pipes as to maintain a seal above the well screen and to prevent potential cross contamination.

6.3.1.2 Most sampler tips are made of steel to withstand pushing forces. With some samplers, after the sampling event, the tip may remain in the ground and the hole may be grouted. The user should consider if leaving the tips below the ground will adversely affect surrounding groundwater chemistry depending on site conditions.

6.3.2 *Well Screen*—Many materials for well screens are available for direct-push samplers. The material of manufacture should be selected with consideration of chemical composition of the groundwater to be sampled and possible interactive effects (see 6.2.3). Some samplers use simple mill slotted steel, or PVC tube. Steel or brass screen formed into a cylinder can be used to cover inlets. Continuous-wrapped, wire-wound well points are also commonly used. The effective opening size of the well screen material should be selected based on the material to be sampled, the time required to sample, and soil sediment that can be tolerated in the water sample. Methods to size well-screen and filter-pack materials are given in Practice D5092. Clean sands and gravels can be sampled with a screen with larger openings without producing excessive sediment. Clayey and silty soils containing fines may require finer openings. Typical openings of 10 to 60 µm are used. Finer openings will reduce sediment but may also slow ingress of fluid.



Legend: Grab Sampling

A Penetrometer closed while being driven into position.
B Tool opened and 5 foot screen telescopes into position for collection of hydrocarbon or water sample at the very top of the aquifer.
C Hydrocarbon sample being collected using bailer lowered through drive casing.

Legend: Water Sampling in Chamber

A Penetrometer closed while being driven into position.
B Cone separated and tool open to collect sample.
C Check valves closed as sample is retrieved within body of the tool.

FIG. 3 Protected Screen Sampler Capable of Working in Grab or Chamber Sampling Modes (1)

6.3.3 Some sampler inlets are not protected by well screen or slotting. The simplest form of sampler can be an open riser pipe with an expendable tip. The use of unprotected inlets has sometimes been useful to sample groundwater at soil/bedrock interface. If unprotected inlets are used, one must consider the amount of soil sediment that can be tolerated in the sample.

6.4 *Push Rod, Single Tube and Double Tube Systems and Riser Pipes*—Also commonly referred to as "push rods" or "extension rods," drive tubes are normally constructed of steel to withstand pushing and impactforces. Most double tube systems use an outer casing and inner drive rods. The inner drive rods are removed when ready for sampling (Fig. 5). Double-tube systems are advantageous if multiple sampling events are required in a single push. The outer casing of a double tube system prevents cross contamination from different aquifers. Some systems may use a double-tube system with a small-diameter PVC riser pushed by the steel tube (Fig. 6) **(14)**. Other temporary systems may use a flexible tubing system connected to the well point (Fig. 7) **(14)**. Most double tube systems have larger outside diameter and required more driving power. Single rod systems (Fig. 2) sometime have a larger diameter sampling body in front of smaller diameter drive rods and can cause concern if the sampler has to be driven through multiple aquifers. The single rod system is generally used for one time sampling events in the same hole. The maximum rod diameter that can be used depends on the material to be penetrated and the driving system. Increased rod diameter causes increase in the required driving force required

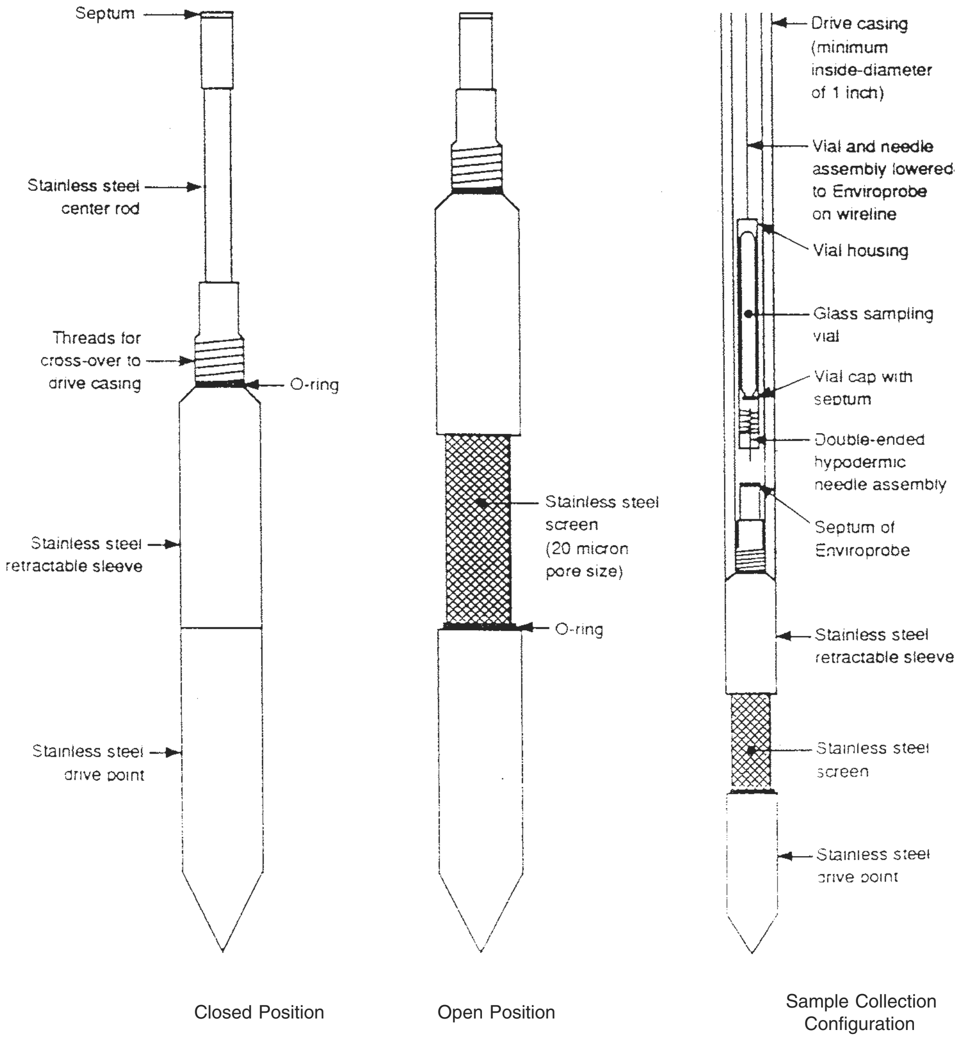


FIG. 4 Protected Screen Sampler with Sealed Vial System (4)

to penetrate a sufficient distance. Most surface direct-push riser pipes are less than 50 mm (2 in.) in diameter.

6.4.1 Cone penetrometer rods as specified in Test Method D5778 are sometimes used in sampling systems deployed with cone penetrometer equipment. Larger diameter rods, typically 45 mm (1.75 in.), are sometimes used with cone penetrometer equipment.

6.4.2 Standard drilling rods used for rotary drilling are normally used when sampling is done at the base of drill holes. Many drill rods are available (see Guide D6286).

6.4.3 For direct-push sampling systems that depend on the riser pipe for sampling within the riser, ensuring that joints are watertight will be necessary such that water enters through the well screen interval to be sampled. Rods should be wrench-tightened, and PFTE tape can be used on the threads to stop leakage. The quality checks discussed in Section 8 can be performed to evaluate possible leakage. Sometimes it may be necessary to equip rod joint shoulders with O-rings to prevent leakage. Cone penetrometer rods with precision tapered threads are normally watertight during short sampling events lasting up to 1 h if they are not damaged.

6.4.4 *Friction Reducers*—Friction reducers that have enlarged outside diameters of the riser pipe are sometimes employed to reduce thrust capacity needed to advance the well point or sampler. If friction reducers are used, they must be a sufficient distance above the sampling location to ensure that fluids from overlying layers cannot enter the sampling zone. If cross-contamination is possible, use of friction reducers should be avoided. In some cases the use of friction reducers can help in forming an annular seal. Donut-type reducers ream the hole smoothly. Lug-type reducers rip and remold the soil and may provide a better annular seal. The type and location of friction reducers should be documented in the project report.

6.4.5 *Mud Injection*—Some direct-push systems inject bentonite drill fluid along the drill rods to reduce friction. These systems normally inject the fluid behind friction reducers. These systems may provide better sealing above the sampler for the sampling process but are also more difficult to operate.

6.5 *Sampling Devices*—Consult Guide D6634 for selection of sampling devices. Due to the small diameter of most direct-push equipment, pump selection is limited. Bladder

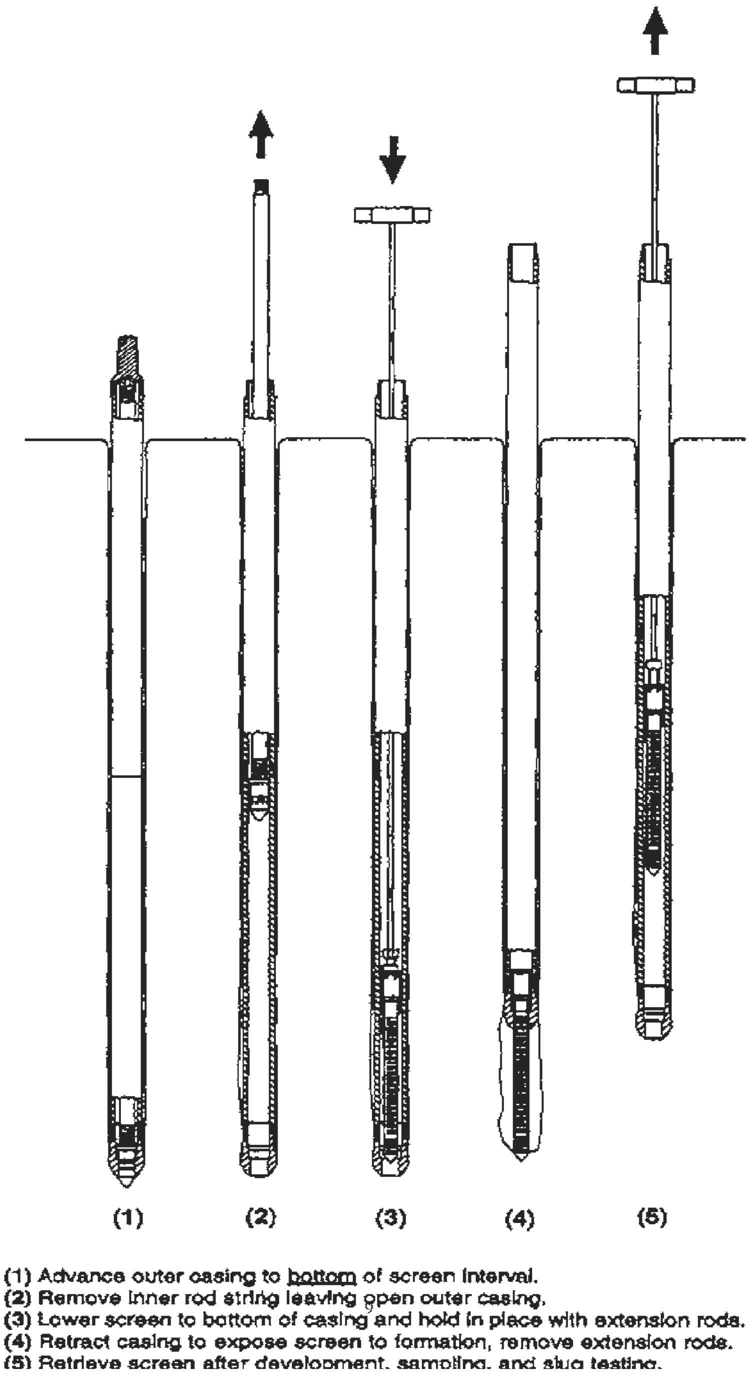


FIG. 5 Double Tube Sealed Screen Sampler

pumps, gas-displacement pumps, peristaltic pumps, and inertial lift (tubing check valve) pumps may all be used for sampling.

6.6 *Sample Containers*—Sample containers for sampling groundwater are addressed in Guide D6911.

6.7 *Driving or Pushing Equipment*—Soil probing (percussion driving) systems, penetrometer systems, and rotary drilling equipment are used for inserting direct-push water sampling devices. The equipment should be capable of applying sufficient mechanical force or have sufficient reaction weight, or both, to advance the sampler or screen to a sufficient depth to ensure an effective seal above the area to be sampled. The advancement system must also have sufficient retraction force to remove the rods, which is often a more difficult task than advancing the rods. Simple advancement systems include hand-held rotary-impact hammers with mechanical-extraction jacks. Many systems use hydraulic- or vibratory-impact hammers operating at high frequency to drive rods into the

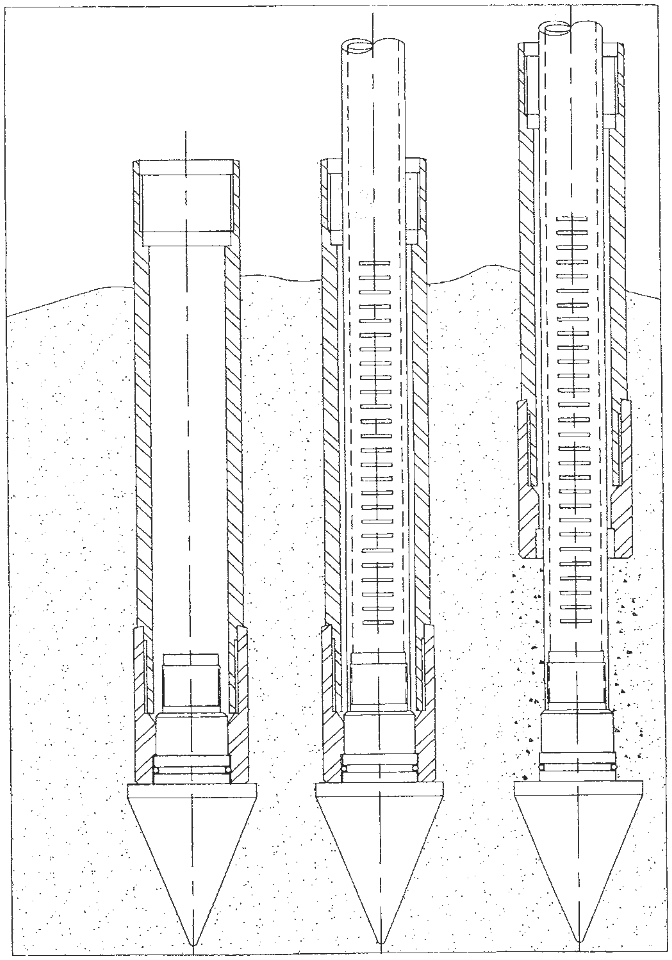


FIG. 6 Double-Tube Temporary Well Point System (14)

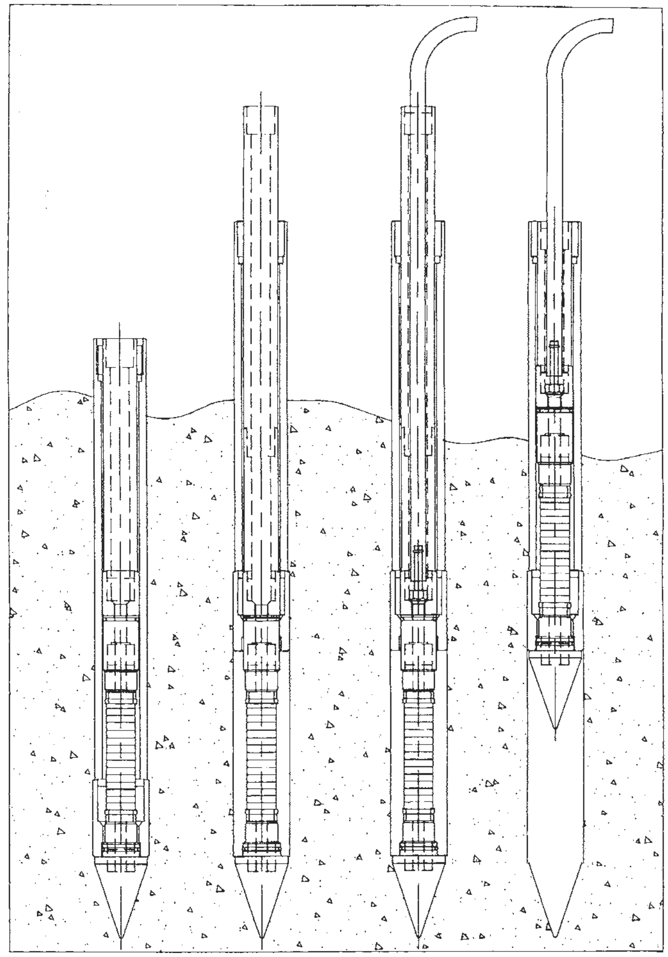


FIG. 7 Protected Screen Sampler with Sample Tubing (14)

sampling interval. Reaction force can be reduced if impact hammers are employed. Multipurpose driving systems such as those commonly deployed for soil gas sampling (Guide D5314) are frequently used in shallow explorations. Some vibratory drilling systems can provide vibration to the rods and easily penetrate cohesionless soils. On soft ground sites, cone penetrometer systems use hydraulic rams to push the sampler and riser pipe into the ground. Conventional rotary drilling rigs can use either hydraulic pull-down capability or hammers to drive the sampler to the required depth. Rotary drilling rigs are often used with the incremental drilling and sampling method. A140-lb SPT hammer (Test Method D1586) is available on most rotary drilling rigs and can be used to advance the sampler. Use of impact or vibration may allow for penetration of harder soils. If a significant length of rods whip during driving, they should be restrained to prevent damaging of the annular seal at the base of a borehole from lateral movement.

7. Conditioning

7.1 *Decontamination*—Sampling equipment that contacts groundwater to be sampled before and after the sampling event may require decontamination. Decontamination should be performed following the procedures outlined in Practices D5088 and the site-sampling plan. The sampler body normally requires complete decontamination before sampling. Well-screen components are sometimes expendable. Newly manufactured screens and sampler components may contain residues from manufacture and should be cleaned before the sampling event. Riser pipes should be decontaminated if sampling will be performed within the tube. In many cases it's advantageous to have several samplers on hand so one can be cleaned while the other is being used.

7.2 *Purging*—For exposed-screen sampling devices and sampling systems open to overlying groundwater, purging may be required before the sampling event. With both protected- and exposed-screen samplers, purging may be required if groundwater from overlying sources infiltrates into the riser pipes into the sampling area. Purging should consist of removal of overlying groundwater from the sampling system prior to the sampling event. Purging requirements are outlined in Guides D6452 and D6771.

8. Procedure

8.1 Two procedures are outlined depending on whether the sampling device is pushed directly from the surface or whether drilling is used to advance an open hole close to the sampling interval. In either event, the sampling screen should be advanced into undisturbed soil a sufficient distance to ensure that the sampling depth cannot be exposed to overlying groundwater, if present. Consult Guide D5903 prior to performing a groundwater sampling event.

8.1.1 *Incremental Drilling and Sampling*—In this method, advance a drill hole close to the sampling interval using drilling methods listed in 2.2. Of the drilling methods listed, the most commonly employed is rotary hollow-stem auger drilling because fluids are not introduced during the drilling process. If a rotary drilling method using drilling fluid or air is employed, the impact of the fluid or air to the sample quality and quality of the surrounding aquifer should be considered. If caving or sloughing occurs the use of protective casings may be required.

8.1.1.1 Stabilize the drill rig and erect the drill rig mast. Establish and document a datum for measuring hole depth. This datum may consist of a stake driven into a stable ground surface, the top of the surface casing, or the drilling deck. If the hole is to be later surveyed for elevation, record and report the elevation difference between the datum and the ground surface. Proceed with drilling until a depth is reached above the target sampling interval. Check and document the depth of the borehole and condition of the base of the hole. Establish the depth and condition of the base of the boring by resting the sampler at the base of the boring and checking depth to the sampler tip. If casing is used and heave occurs into the casing, remove this material and advance the hole deeper. Heave of soil into the casing may make it impossible to drive the water sampler without it carrying the casing along with the well point or sampler. If excessive heave, caving, or sloughing of soil occurs, consider using an alternative drilling method capable of maintaining stable soil conditions.

8.1.2 If the sampling event is to occur at the groundwater table and equipment depends on a dry-hole condition, that is, an exposed screen sampler with no purging requirements, test the drill hole to confirm that groundwater has not entered the hole. Water levels can be determined using Test Method D4750.

8.1.3 Attach the well point or sampler to riser pipes and lower into the borehole. Carefully record the assembly length as rod sections are added to the assembly. Centralizers may be used to maintain verticality of the assembly and to reduce rod whip. Rest the assembly on the base of the borehole. Determine and record the depth to the tip of the assembly.

8.1.4 Either push or drive the well point or sampler a sufficient distance below the base of the boring. This distance should be at least 1 m (3 ft), or the minimum to ensure an effective seal. For protected-screen samplers where a protective screen is exposed by pulling back the riser pipe, the withdrawal action may shear or crack soil, allowing connection to the base of the borehole. In these cases, adjust the insertion and retraction lengths according to soil conditions. In general, the sampler should be inserted at least three times the effective screen length from retraction. To check the seal in fluid filled holes, tracers can be introduced into the fluid in the base of the borehole. Document the final depth of insertion to the tip of the sampler and midpoint of the well screen. If the sampler is driven with hammer blows, accomplish the penetration without excessive vibrations that could reduce the effective seal of the riser pipe above the well screen. Normally, if smooth penetration is accomplished with each hammer blow, the seal should be intact.

8.1.4.1 The process of jetting well points is not preferred because of the addition of water, disturbance to the sampling zone, and lack of an effective seal above the screen. These installations are usually intended for permanent installations with the drill hole completed as a monitoring well. If jetting is used, document the approximate volume and chemical quality of water.

8.1.5 *Sampling*—The sampling process depends on the type of the sampling equipment used, that is, exposed- or protected-screen samplers.

8.1.5.1 *Sampling of Exposed-Screen Samplers*—Exposed-screen samplers can be sampled after fluids have been purged from the screen and riser pipes. Purge these systems in accordance with Guides D4448, D6452, and D6771.

8.1.5.2 *Sampling of Protected-Screen Samplers*—Test protected-screen samplers that are open to the surface through the riser for grab sampling for system leakage before exposing the screen for sampling. Before screen exposure, test the riser for presence of water that may have leaked through joints and connections using Test Method D4750. If water is present from unknown sources, this should be noted and either purging or abandoning of the test should be considered. After quality checks for leakage, the riser pipes may be pulled or twisted to expose the well screen to the aquifer.

8.1.5.3 Several methods for sampling water are available. If the sampling device uses head pressure available in the aquifer, sufficient time should be allowed for water to fill the sampling chamber or riser pipes. Some systems allow for connection of a sealed sampling chamber, or tubing, to a port in the sampler body after the screen is opened, allowing direct connections to the screened sampling area. By using these systems, one may avoid the necessity to check inside the riser pipes for leakage water. Use of sampling pumps to draw in the sample may be allowed, but consideration should be given to the changes in ambient pressures and temperatures that may change chemical compositions. With an open tube well screen using grab or pump sampling in low permeability soils, a vacuum is sometimes applied to the top of the riser pipe to accelerate groundwater inflow. The use of a vacuum and its effect on chemical composition should be considered and evaluated if site requirements dictate.

8.1.5.4 After a sufficient volume of the sample is obtained, place the samples in suitable containers for analysis and preserve them if required (Guides D6517 and D6911). The volume of a sample to obtained depends on the chemical composition of groundwater, testing protocols, and the data-quality objectives. Depending on the screen or porous filter used, samples may contain turbidity and/or sediment and may require filtering before placement of samples in containers. Certain testing procedures or regulations may require filtration of water samples. Consult Guide D6564 for filtering groundwater samples.

8.1.6 After sampling, either retrieve the sampler or leave it in place for permanent installation in accordance with Practice D5092 and Guide D6724. Some retrievable samplers leave a tip or a well screen element, or both, below the bottom of the boring. If repeated sampling events are to be performed in the same drill hole, drilling it through these pieces if present will be necessary. Depending on the drilling method, a pilot bit should be reinserted in the drill string and drilling continued to a depth exceeding the depth of the previous sampling event. Tips or screens from the previous sampling event, will be drilled through or moved to the side of the drill hole by drilling action before the next sampling event. Sometimes the presence of a tip or element, or both, can be detected by drilling action. If drilling action detects these pieces, note the location. Drilling continues to the next depth of concern and sampling may be repeated. The depth of the extended drill hole should equal or exceed the depth to the sampling tip of the previous interval.

8.1.7 After the drilling is completed, the drill hole should be completed following guidelines in drilling methods (Guide D6286) or those given in Section 9.

8.2 *Direct-Push from the Surface*—Well points and samplers may be advanced directly from the surface with multipurpose percussion driving systems, hand-held rotary percussion drills, cone penetrometer systems, or any other systems capable of supplying sufficient force to reach the depths of concern.

8.2.1 Stabilize and level the rig for testing. For some tire-mounted equipment, the rig can be raised off the ground and leveled with hydraulic rams to lift the rig from the tires to avoid shifting during difficult driving conditions. Establish and document a datum for measuring hole depth. If the hole is to be later surveyed for elevation, record and report the height of the datum to the ground surface.

8.2.2 The sampler body is connected to riser pipes along with any subassemblies such as friction reducers. Prior to driving, measure the length of the sampler assembly and riser pipes to determine the depth of sampling. Some temporary well systems drive a double tube or cased system, where riser pipe and casing are added as it is advanced. This allows for easy annulus grouting as the casing is retracted. The rods are then pushed using smooth quasi static push or impacts, or both. Additional riser pipes are added as pushing progresses. As driving progresses, operators should carefully record the rods added to ensure that sampling occurs at the correct depth.

8.2.3 *Sampling of Exposed-Screen Samplers*—Use the same procedures in accordance with 8.1.5.1.

8.2.4 *Sampling of Protected-Screen Samplers*—Use the procedure in accordance with 8.1.5.2 with the addition that the riser pipes should be periodically checked for leakage using Test Method D4750.

8.2.5 After sufficient volume of a sample is procured, place the samples in suitable containers and preserve them if required (Guides D6517 and D6911). The volume of the sample to obtained depends on the chemical composition of groundwater, testing protocols, and the data-quality objectives. Depending on the screen used, samples may contain turbidity and/or sediment and may require filtering before placement of samples in containers (Guide D6564).

8.3 After sampling, the sampler is either retrieved or left in place for permanent installation (Section 9). Some retrievable samplers leave a tip or a well-screen element, or both, at the bottom of the sounding. If repeated sampling events are to be done in the same hole, they must be done with samplers pushed to greater depths.

8.4 After the testing is finished, complete the borehole following the guidelines in Section 9.

9. Completion and Abandonment

9.1 *Permanent or Temporary Well Installations*—Wells inserted by either drilling methods or direct-push from the surface may be left in the ground as permanent or temporary installations. Refer to Guide D6724 for direct-push well installation. For wells inserted in drill holes, the drill hole will require completion with sealing materials to ensure a seal between the hole wall and riser pipes. Sealing procedures are given in Practice D5092.

NOTE 2—For wells installed by direct push from the surface, the need for sealing depends on the size of the annulus, groundwater quality, and the ability for cross-contaminating or accelerating contamination movements among aquifer(s). Temporary well points installed into the top of the first groundwater layer may only require surface sealing. If the annulus is very small, soil cave and squeeze may reduce effective vertical hydraulic conductivity. If the well riser intersects perched aquifers, cross-communication of aquifers may be possible if too large an annulus is left open. Communication can be evaluated by performing tracer tests, if necessary. Friction reducers used on cone penetrometer equipments may only increase hole diameters by 6 to 13 mm (¼ to ½ in.) of that of the steel pipes for pushing.

9.2 *Other Completion Methods*—Performing special completions with protective casings or other sealing methods may be necessary depending on the investigation requirements. For holes using rotary drilling methods and incremental sampling, the hole could be completed as a monitoring well (Practice D5092) or with grouted casings for other testing such as geophysical tests. Several methods are available for grouting of casings. The most desirable method is injection grouting, where injection is done at the base of the boring is most desirable and grouts are pumped up the annulus until they reach the surface showing a continuous seal.

9.3 *Hole Abandonment*—For test holes where there are no installations or other completion methods, the hole should be abandoned following program requirements. The need for and the method of sealing for abandonment depends on state and local regulations, site conditions, groundwater quality, and the ability for cross-contaminating or accelerating contamination movements among aquifer(s).

9.3.1 Large-diameter drill holes from rotary drill operation which intersect the groundwater often require sealing. State, federal, and local regulations may dictate abandonment requirements for boreholes intersecting the water table.

9.3.1.1 The need for sealing of holes is also dependent on geohydrologic conditions. If the hole intersects the top of the first groundwater table, complete sealing may not be required. Under a homogeneous single aquifer system, where there are no perched water table or artesian conditions, there will be little hydraulic gradient to move potential contaminants at differing elevations. The worst case for possible cross-communication of aquifers occurs under perched or confined groundwater conditions.

9.3.1.2 In most cases, direct-push holes intersecting groundwater tables will require complete sealing. In cases where the hole is to be backfilled completely, the condition of the hole should be evaluated and documented. Any zones of caving or blocking which preclude complete sealing should be documented. Displacement grouting may displace groundwater from the hole to the surface. If this water is considered contaminated then provisions must be made to collect these fluids at the surface. A minimum requirement for sealing should be that the surface of the hole is sealed to prevent hazards to those at the surface and to eliminate direct movement of surface contaminants to the water table through the hole.

9.3.2 *Completion of Drill Holes*—Completion of boreholes using drilling methods are addressed in Guides D5781, D5782, D5783, D5784, D5875, D5876, and also see 2.2.

9.3.3 *Completion of Surface Direct-Push Holes*—Several methods have been used successfully for sealing or grouting of surface direct-push holes (**17**). The method of grouting depends on the types of equipment deployed and the subsurface conditions encountered.

9.3.3.1 *Retraction Grouting*—One method of grouting is retraction grouting directly through the sampler tip or friction reducer as the sampler is withdrawn after the sampling event. Tip retraction grouting is normally performed through small diameter tubes and a knockoff tip. Tip retraction grouting is the least frequently used due to difficulty in pumping grout mixtures without significant head loss through the tubing. Cement grouts for tip retraction grouting may require higher water content or additives to reduce viscosity.

(1) Retraction grouting is sometimes performed through grouting points above the sampler tip. This is normally accomplished using an enlarged diameter grouting port above the sampler as shown in Fig. 8.

9.3.3.2 *Reentry Grouting*—Reentry grouting may have an advantage of freeing pushing equipments for production while grouting operations follow. Reentry grouting allows temporary connection of aquifers between the removal and reinsertion process but is normally acceptable if grouting follows promptly minimizing exposure. The selection of retraction or reentry grouting is an economic decision and it depends on site conditions and depth of soundings.

(1) In reentry grouting, Figs. 9 and 10, the test string is completely withdrawn from the hole and a secondary grouting tube or tubing is reinserted to the complete depth of the hole. If the hole remains open after retraction of the test string, inserting flexible tubing or small-diameter PVC into the hole by hand directly after testing may be possible. In this case, reinserting the grout line is desirable close to the original depth of the hole. In some cases, depending on project needs, locations of water bearing strata, and soil stratigraphy, it may be acceptable if the grout line does not reach the bottom of the hole.

(2) Usually, with squeezing clays or caving sands, reaction equipment may be required to push rigid tubing of steel or plastic with a sacrificial or grouting tip to the complete depth of the hole (Figs. 9 and 10). The reentry string should follow the original hole alignment because it is the path of least

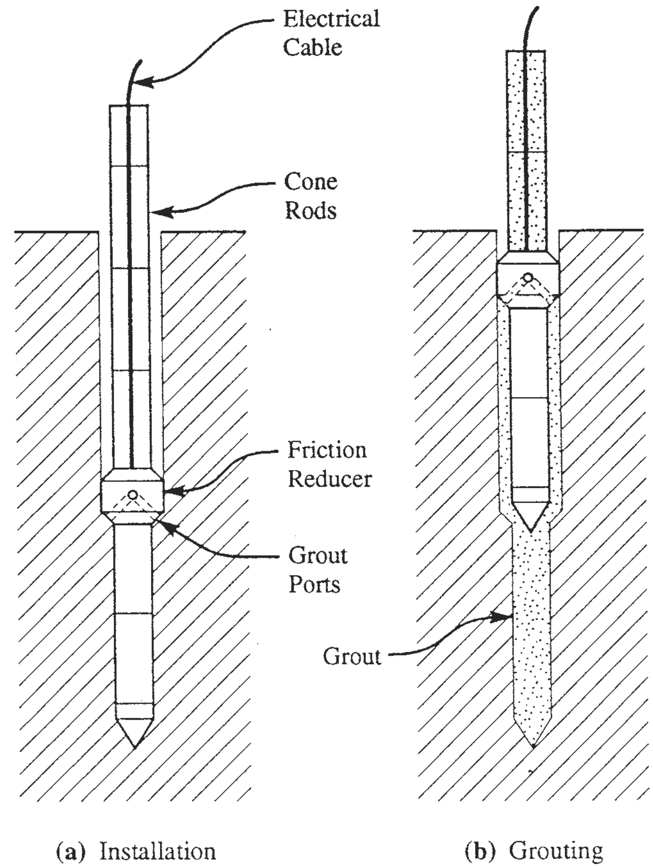


FIG. 8 Grouting Through Ports in Friction Reducers (15)

resistance. If deviation is suspected, it should be reported. If a knockoff tip is to be retracted in high hydraulic conductivity sands it may be necessary to add grout into rods prior to tip retraction to avoid water filling the rods. Grout is then pumped through the hole until it rises to the surface, or tremie grouting is performed by maintaining a grout column in the rods as they are removed. Grouting is continued to maintain a full hole as tubing is withdrawn.

9.3.3.3 Direct-push water sampling holes can be grouted with either cement or bentonite grouts. The grout consistency may have to be wetter than standard mixes used for sealing boreholes (Practice D5092). There has been no research to confirm the best proportions. A typical mixture is 1 sack of Portland cement to 19 to 22 L (5 to 8 gal) of water. Bentonite is added in a small percentage, 2 to 5 %, to reduce shrinkage. Typical bentonite-based mixtures consist of 22.7 kg of dry powered bentonite to 50 to 200 L (24 to 55 gal) of water. It is difficult to mix dry high-yield bentonite without good circulation equipment and time to allow for mixing and hydration. Pre-hydrated bentonite is easier to mix. Some bentonites contain additives that may not be acceptable for grouting use and the user should check with regulators to ensure sealing products are acceptable.

9.3.3.4 Record the volumes of grout injected and compare them with theoretical hole volumes. Often the grouting pressure at depth is unknown due to head losses through pipes, grout tubing, and connections. Pressure grouting equipments should at a minimum include a pressure gage at the surface. To

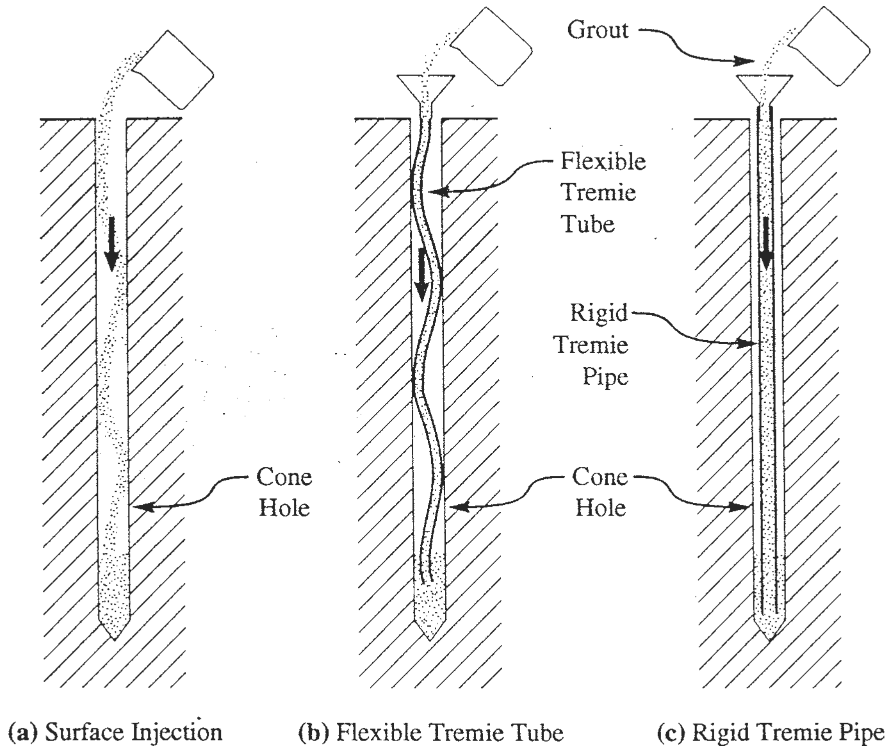


FIG. 9 Rigid Pipe with Internal Flexible Tremie Tube (15)

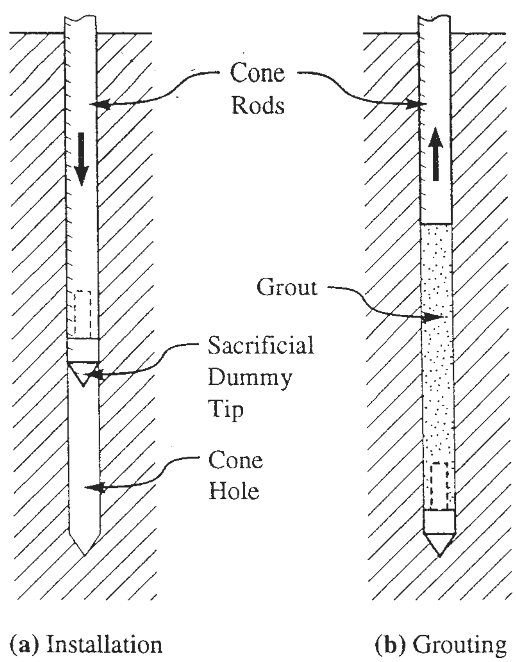


FIG. 10 Reentry with CPT Rods and Sacrificial Tip (15)

avoid excessive hydraulic fracturing of the units, downhole pressures should be restricted to ½ psi per foot of hole depth. Record any unusual changes in grouting pressures that may suggest the presence of obstructions, caved zones, or occurrence of fracturing.

9.3.3.5 *Dry Granular Bentonite*—The simplest method of sealing a direct-push hole in stable materials is to place dry materials by pouring or placing directly into the open hole after testing. This method is normally only acceptable in stable clay soils above the water table where the hole remains open after testing. This method is not acceptable if there are zones of hole caving or squeezing or there is appreciable presence of groundwater in the hole. The holes can be probed with small-diameter rods to evaluate these conditions. Small diameter granular bentonite is normally used in this application.

10. Field Report and Project Control

10.1 Report information recommended in Guide D5434 and Test Method D6034 and identified as necessary and pertinent to the needs of the exploration program. Information is normally required for the project, exploration type and execution, drilling equipment and methods, subsurface conditions encountered, groundwater conditions, sampling events, and installations. Some of the data collected during these investigations may be reported as data elements for describing groundwater sites (Practice D5254, and Guide D5474).

10.2 Other information besides that mentioned in Guide D5434 and Test Method D6034 should be considered if deemed appropriate and necessary to the needs of the exploration program. Additional information should be considered as follows:

10.2.1 *Drilling Methods*—If rotary drilling methods are used for predrilling holes, report information particular to the drilling methods as outlined in Guides D5781, D5782, D5783, D5784, D5875, D5876, and also see 2.2.

10.2.2 *Percussion Driving and Penetrometer Equipment*—For equipment used for surface direct-push, report the equipment type, make, model, and manufacturers. Report conditions during push of the sampler such as the occurrence of hard layers. Report datums established for monitoring depth of penetration. For combined cone penetrometers and water-sampling devices, report cone-penetration information in accordance with Test Methods D3441 and D5778.

10.3 *Sampling:*

10.3.1 *Equipment*—Report the types of sampling equipment used including materials of manufacture of the components. Provide dimensions of the equipment including outside diameter, screen length and diameter, and friction reducers. Report methods for cleaning of the equipment before and after sampling. Note materials left in the hole or discarded between sampling events. Report any purging or development actions taken before the sampling event.

10.3.2 When water sampling is performed at the base of the borehole, report the condition of the base of the hole before sampling, and report any slough or cuttings present in the recovered sample.

10.3.3 During insertion of the sampler or well point, note any difficulties in advancing the point and retraction of a protective sleeve. Report the retraction distance for protected-screen samplers. If the sampler cannot be advanced more than the minimum required distance of the sampler given in 8.1.4, report the distance driven. Note and record sampling depths including depths to the tip and midpoint of the well screen. Note any unusual occurrence during sampling such as fluid exposure, or evidence of cross-contamination contained in the samples recovered. Note and record the volume of the sample taken and other sample handling and preservation methods taken.

10.3.4 Report any measurements of water samples routinely performed in the field. These measurements may include temperature, PH, and conductivity. Report methods of testing, calibrations, and equipment used.

10.4 *Completion and Installations*—A description of completion materials and methods of placement, approximate volumes placed, intervals of placement, methods of confirming placement, and areas of difficulty or unusual occurrences.

11. Precision and Bias

11.1 The precision and bias of this method have not been established. Due to variability of subsurface conditions, comparative studies of differing approaches to direct-push sampling have not been statistically significant, because site spatial variability exceeded differences between methods (**2**). Comparisons between water samples obtained from direct-push samples and standard-monitoring wells have been favorable (**11**). Additional studies are needed and are actively pursued by Subcommittee D18.21.

12. Keywords

12.1 direct-push; groundwater; groundwater sampling; site characterization; well point

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Designation: D6282/D6282M – 14

Standard Guide for Direct Push Soil Sampling for Environmental Site Characterizations[1]

This standard is issued under the fixed designation D6282/D6282M; 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 addresses direct push soil samplers, which may also be driven into the ground from the surface or through prebored holes. The samplers can be continuous or discrete interval units. Samplers are advanced by static push, or impacts from hammers, or vibratory methods, or a combination thereof, to the depth of interest. Both single tube and dual (double) tube systems may be advanced for soil sampling with direct push methods. Direct push methods are most often used to collect geo-environmental soil samples. These soil samples are used for soil classification (Practice D2488) and lithologic/hydrostratigraphic logging as well as being sub-sampled for contaminant and chemical analyses.

1.2 Other drilling and sampling methods may apply for samples needed for engineering and construction applications. This guide does not address single sampling events in the immediate base of the drill hole using rotary drilling equipment that employ cuttings removal as the sampler is advanced. Other sampling standards, such as Test Method D1586, Practices D1587 and D3550, and summarized in Guide D6169 apply to rotary drilling activities (Guide D6286). The guide does not cover open chambered samplers operated by hand such as augers, agricultural samplers operated at shallow depths, or side wall samplers.

1.2.1 While Sonic Drilling is considered a direct push method this standard may not apply to larger equipment addressed in Practice D6914.

1.3 Guidance on collection and handling of samples, are given in Practices D4220 and D6640. Samples for chemical analysis often must be subsampled and preserved for chemical analysis using special techniques such as Practice D4547, D6418, and D6640. Additional information on environmental sample preservation and transportation is available in other references **(1, 2, 3, 4, 5, 6)**[2]. Samples for soil classification may be preserved using procedures given in Practice D4220 similar to Class A. In most cases, a direct push sample is considered as Class B in Practice D4220 but is protected, representative, and suitable for chemical analysis. The samples taken with this practice do not usually produce Class C and D (with exception of thin wall samples of standard size) samples for laboratory testing for engineering properties, such as shear strength and compressibility. If sampling is for chemical evaluation in the Vadose Zone, consult Guide D4700 for any special considerations.

1.4 Insertion methods described include static push, impact, percussion, other vibratory/sonic driving, and combinations of these methods using direct push equipment adapted to drilling rigs, cone penetrometer units, and specially designed percussion/direct push combination machines. Hammers providing the force for insertion include drop style, hydraulically activated, air activated and mechanical lift devices.

1.5 Direct push soil sampling is limited to soils and unconsolidated materials that can be penetrated with the available equipment. The ability to penetrate strata is based on hammer energy, carrying vehicle weight, compactness of soil, and consistency of soil. Penetration may be limited or damage to samplers and conveying devices can occur in certain subsurface conditions, some of which are discussed in 5.6. Successful sample recovery also may be limited by the ability to retrieve tools from the borehole. Sufficient retract force must be available when attempting difficult or deep investigations.

1.6 This guide does not address the installation of any temporary or permanent soil, groundwater, vapor monitoring, or remediation devices.

1.7 The practicing of direct push techniques may be controlled by local regulations governing subsurface penetration. Certification, or licensing requirements, or both, may need to be considered in establishing criteria for field activities.

1.8 The values stated in either SI units or inch-pound units 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.

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

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.*

1.10 *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 or 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 projects'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:*

D653 Terminology Relating to Soil, Rock, and Contained Fluids

D1452 Practice for Soil Exploration and Sampling by Auger Borings

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

D2488 Practice for Description and Identification of Soils (Visual-Manual Procedure)

D3550 Practice for Thick Wall, Ring-Lined, Split Barrel, Drive Sampling of Soils

D3694 Practices for Preparation of Sample Containers and for Preservation of Organic Constituents

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

D4220 Practices for Preserving and Transporting Soil Samples

D4547 Guide for Sampling Waste and Soils for Volatile Organic Compounds

D4700 Guide for Soil Sampling from the Vadose Zone

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

D5434 Guide for Field Logging of Subsurface Explorations of Soil and Rock

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

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

D6169 Guide for Selection of Soil and Rock Sampling Devices Used With Drill Rigs for Environmental Investigations

D6286 Guide for Selection of Drilling Methods for Environmental Site Characterization

D6418 Practice for Using the Disposable En Core Sampler for Sampling and Storing Soil for Volatile Organic Analysis

D6640 Practice for Collection and Handling of Soils Obtained in Core Barrel Samplers for Environmental Investigations

D6724 Guide for Installation of Direct Push Groundwater Monitoring Wells

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

D6914 Practice for Sonic Drilling for Site Characterization and the Installation of Subsurface Monitoring Devices

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

D7648 Practice for Active Soil Gas Sampling for Direct Push or Manual-Driven Hand-Sampling Equipment

3. Terminology

3.1 *Definitions*—For definitions of common terminology terms used within this guide refer to Terminology D653. Definitions for additional terms related to direct push water sampling for geoenvironmental investigations are in accordance with Guide D6001.

3.1.1 *assembly length, n*—length of sampler body and riser pipes.

3.1.2 *direct push sampler, n*—sampling devices that are advanced into the soil to be sampled without drilling or borehole excavation.

3.1.3 *extension rod, n*—hollow steel rod, threaded, in various lengths, used to advance and remove samplers and other devices during direct pushing boring. Also known as drive rod. In some applications, small diameter solid extension rods are used through hollow drive rods to activate closed samples at depth.

3.1.4 *incremental drilling and sampling, n*—insertion method where rotary drilling and sampling events are alternated for incremental sampling. Incremental drilling often is needed to penetrate harder or deeper formations.

3.1.5 *push depth, n*—the depth below a ground surface datum to which the lower end, or tip, of the direct-push sampling device is inserted.

3.1.6 *sample interval, n*—defined zone within a subsurface strata from which a sample is gathered.

3.1.7 *sample recovery, n*—the length of material recovered divided by the length of sampler advancement and stated as a percentage.

3.1.8 *soil core, n*—cylindrical shaped specimen recovered from a soil sampler of soil, sediments, or other unconsolidated accumulations of solid particles produced by deposition or the physical and chemical disintegration of rocks and which may or may not contain organic matter.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *closed barrel sampler, n*—a sampling device with a piston or other secured device that is held to block the movement of material into the barrel until the blocking device is removed or released. Liners are required in closed barrel samplers. Also may be referred to as a protected type sampler.

3.2.2 *impact heads/drive heads, n*—pieces or assemblies that fit to top of the above ground portion of the direct push tool assembly to receive the impact of the hammering device and transfer the impact energy to sampler extensions or drive rods.

3.2.3 *open barrel sampler, n*—sampling barrel with open end allowing material to enter at any time or depth. Also may be referred to as an unprotected type sampler.

3.2.4 *piston lock, n*—device to lock the sampler piston in place to prevent any entry of a foreign substance into the sampler chamber prior to sampling.

3.2.5 *single tube system, n*—a system whereby single extension/drive rods with sampler attached are advanced into the subsurface strata to collect a soil sample.

3.2.6 *solid barrel sampler, n*—a soil sampling device consisting of a continuous or segmented tube with a wall thickness sufficient to withstand the forces necessary to penetrate the strata desired and gather a sample. A cutting shoe and a connecting head are attached to the barrel.

3.2.7 *split barrel sampler, n*—a soil sampling device consisting of the two half circle tubes manufactured to matching alignment, held together on one end by a shoe and on the other by a connecting head.

3.2.8 *dual tube systems, n*—a system whereby inner and outer tubes are advanced simultaneously into the subsurface strata to collect a soil sample. The outer tube is used for borehole stabilization. The inner tube for is used sampler recovery and insertion.

4. Summary of Guide

4.1 Direct push soil sampling consists of advancing a sampling device into subsurface soils by applying static pressure, by applying impacts, or by applying vibration, or any combination thereof, to the above ground portion of the sampler extensions until the sampler has been advanced to the desired sampling depth. The sampler is recovered from the borehole and the sample removed from the sampler. The sampler is cleaned and the procedure repeated for the next desired sampling interval. Sampling can be continuous for full depth borehole logging or incremental for specific interval sampling. Samplers used can be protected type for controlled specimen gathering or unprotected for general soil specimen collection.

5. Significance and Use

5.1 Direct Push Soil Sampling is used extensively in environmental site characterization of soils below ground surface and can also be used for subsurface geotechnical site characterization (**3, 7, 8, 9-12, 13**). Limited early studies have been done using Direct Push Soil Sampling for environmental investigations (**14, 15, 16**). These methods are preferred for environmental site characterization over rotary drilling sampling methods (D6169, D6286) because they are minimally intrusive (less disruptive to the soil column) and they do not generate soil cuttings which could be contaminated and require characterization and safe disposal. Direct Push soil samplers are grouped into two categories; Single Tube and Dual (Double) Tube systems.

5.1.1 *Dual Tube Systems*—Dual tube soil sampling systems are preferred for use because the bore hole is protected and sealed by the outer casing during operations. However, in some conditions when sampling below the groundwater, a sealed single tube sampler (5.1.2) must to be used to avoid sample cross contamination. Figure 1 shows how a Double Tube system is used. The outer tube stays in place to protect and seal the borehole and prevents potential cross contamination of the boring and the soil sample. Dual tube systems allow for rapid continuous sampling both above and below the water table. When sampling is not required, a sealed inner drive point can be locked in for driving through zones not targeted for sampling or through obstructions or difficult to sample formations.

5.1.1.1 Dual tube systems facilitate deployment of other testing and sampling systems (Test Method D1586 and Practice D1587) and sensors, groundwater sampling (D6001), water testing (D7242), and even monitoring well installations (D6724, D6725). Well installations may require use of specially designed expendable tips that facilitate well construction.

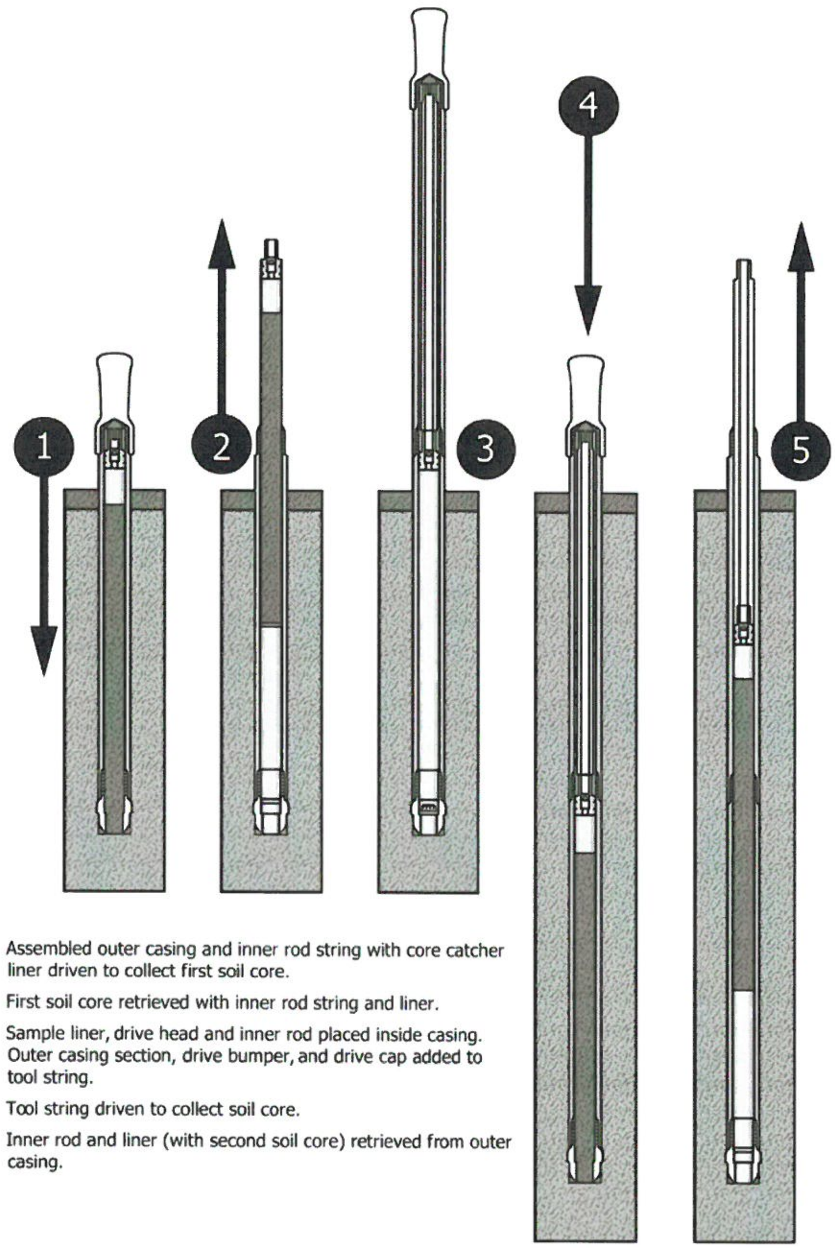
5.1.1.2 In larger Dual Tube systems with inside diameters of at least 75 mm the Standard Penetration Test (D1586) is often conducted in the bottom of the boring. Reliable SPT N values can be obtained in most soil formations that are not disturbed by the driving of the casing. Cohesionless sands and very soft clays may be disturbed during advancement of the Dual System to the test depth and should be evaluated or flagged if suspect. Reliable N values may not be obtained if there is evidence of heave or borehole instability from the base of the borehole to the inside the casing.

5.1.1.3 Dual tube systems are easily grouted and sealed for completion because the outer casing keeps an open sealed borehole for insertion of grout tubes.

5.1.1.4 As shown on Fig. 1, continuous sampling is done with an opening left at the bottom of the outer casing during the sampling process. This is fine as long as the formation is stable between sampling events. If there are heaving conditions into the outer casing the outer casing may be retracted to set the sampler barrel in position. The instability can be improved by maintaining a water level balance in the outer casing and using slower retraction of the sampler string during withdraw. If the material stability ids a problem then one must deploy a sealed single tube piston sampler (5.1.2) into the boring to retrieve samples.

5.1.1.5 A constant outer tube diameter of the Dual Tube system generally has more friction than some Single Tube rod driven samplers so may require larger equipment capable of higher more percussion and push forces. Dual Tube systems approaching 100 to 150 mm outside diameter have been developed and require larger direct push equipment.

5.1.2 *Single Tube Systems*—Sealed single tube samples assure that the soil sample is not cross contaminated by other soils or fluids inside the bore hole so they are preferred sampling method to use below groundwater. Single tube soil



1. Assembled outer casing and inner rod string with core catcher liner driven to collect first soil core.
2. First soil core retrieved with inner rod string and liner.
3. Sample liner, drive head and inner rod placed inside casing. Outer casing section, drive bumper, and drive cap added to tool string.
4. Tool string driven to collect soil core.
5. Inner rod and liner (with second soil core) retrieved from outer casing.

FIG. 1 Dual Tube Direct Push Soil Sampler Operation

sampling systems are most often used for single incremental discrete soil sampling events but can also be used in continuous sampling modes with limitations listed below. Sealed piston type samples assure the best preservation of sample and assure no cross contamination of the soil. Figure 2 shows the basic operation of a single tube sampler. The sampler includes a sealed piston point to prevent soil intrusion during advancement to the target sample depth. The piston is then unlocked using various mechanisms and the sample is pushed to the design length. The complete sampler tube and drive rods are removed from the ground to retrieve the sample leaving an open hole after sampling.

5.1.2.1 The disadvantage to single tube sampling is that the hole left in the ground may not stay open and it would be difficult to grout if required. If positive proof of grouting is required it may be necessary to push a re-entry grout tube to the sample depth to grout the hole (D6001). Another disadvantage is possible travel of contaminants down the open hole. If cross contamination is a concern than a dual tube sampler system should be used.

5.1.2.2 Many single tube systems use drive rods of smaller diameter than the sampler body. The use of smaller diameter drive rods raises two concerns when sampling. First the soil above the sampler body may cave on the sampler and cause

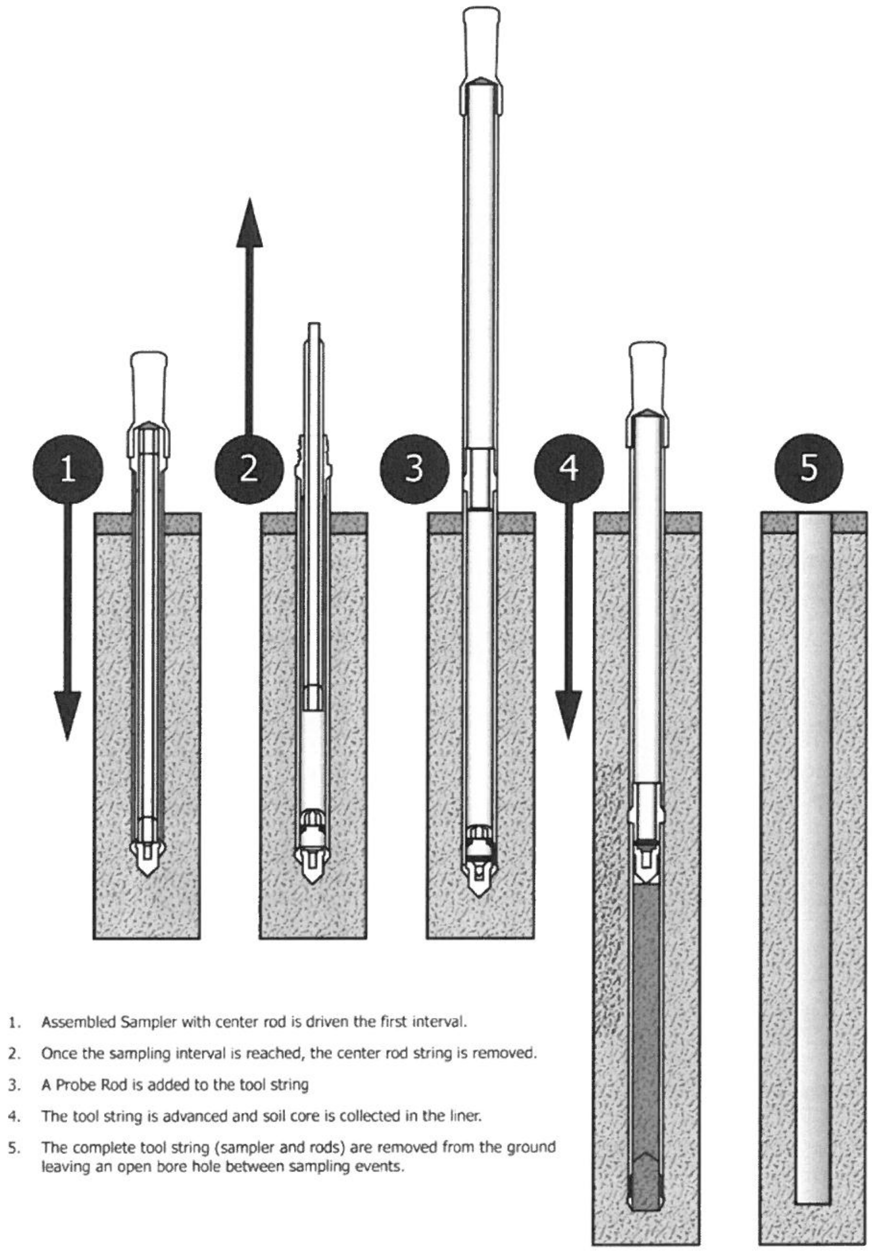


FIG. 2 Single Tube Direct Push Soil Sampler Operation

retraction problems. Second, if chemical analysis is required and the sampler will penetrate and cross contaminated zones there is concern that fluids from layers up above may run down the open annulus above the sampler causing cross contamination.

5.1.2.3 Single tube piston samplers are sometimes used in conjunction with Cone Penetrometer Testing (CPT) (D6067) and can be used in other geotechnical drilling (D6169) in the base of a drill hole.

5.1.2.4 Continuous Sampling operations may be conducted in the same hole with limitations. Using the sealed piston sampler, consecutive samples can be obtained in the same hole by re-driving the sealed piston sampler to a deeper target depths.

5.1.2.5 Open tube samplers without a piston (Fig. 3) should not be used except in rare cases. Use of an unsealed open barrel sampler without a sealed piston multiple times in the same sampling hole will result in cross contamination of samples from the hole wall, cave, and heaving. Continuous soil sampling using an open barrel is sometimes performed above the water table where boreholes are very stable. This sampling mode should never be used below the water table. A sealed sample is required to assure no cross contamination.

5.2 Direct push methods of soil sampling are used for geologic investigations, subsurface soil matrix contamination studies, and water quality investigations. Examples of a few types of investigations in which direct push sampling may be

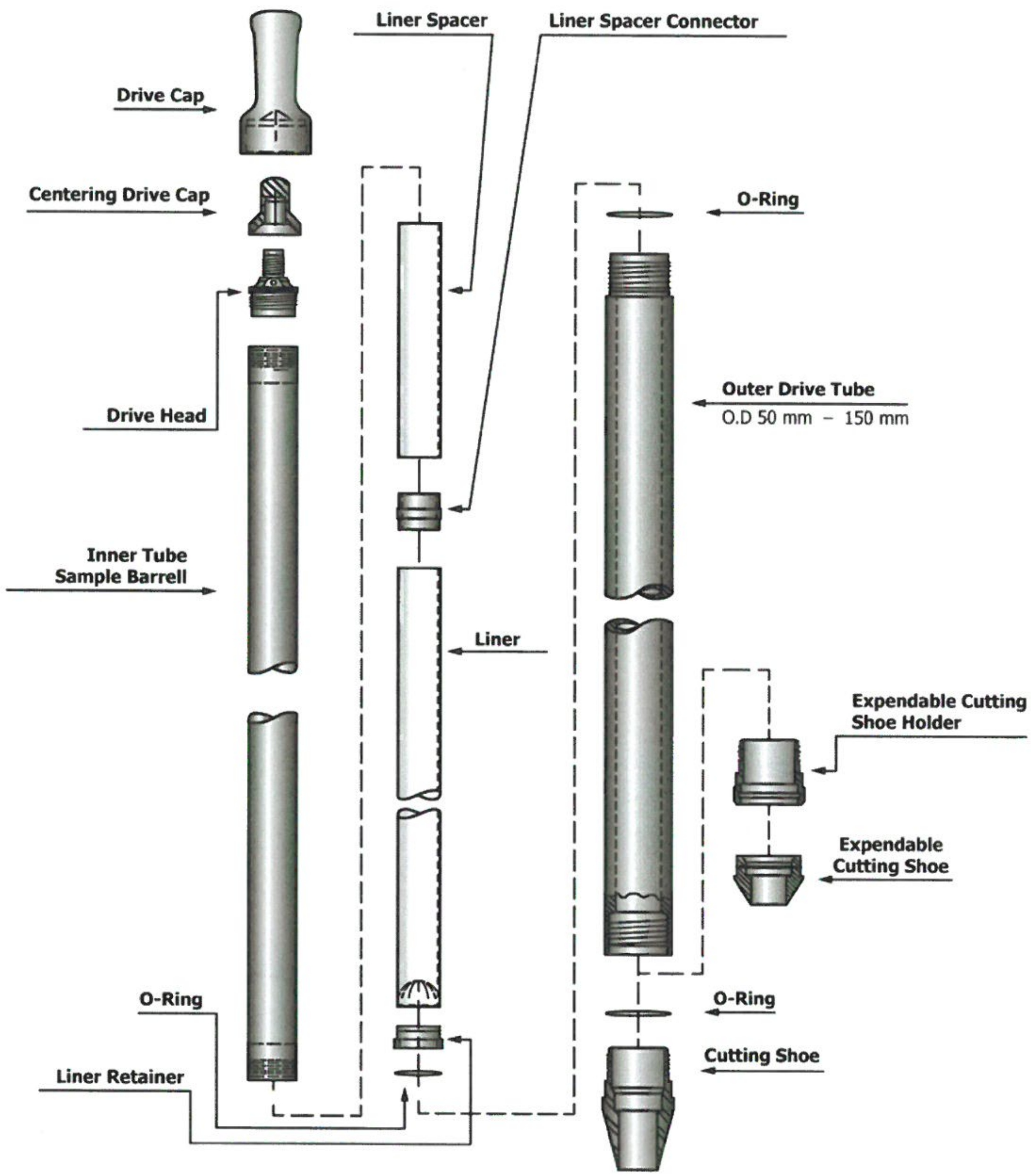


FIG. 3 Dual Tube Soil Sampler with Solid Inner Barrel and Liner

used include site assessments, underground storage tank investigations, and hazardous waste site investigations (17-19). Continuous sampling is used to provide a lithological detail of the subsurface strata and to gather samples for classification and index tests or for chemical testing. These investigations frequently are required in the characterization of hazardous waste sites. Samples, gathered by direct push methods, provide specimens necessary to determine the types and concentration of contaminants in soils and sediments, and in most circumstances, the contained pore fluids (7, 8, 9, 10, 11, 12, 13). Procedures for soil core handling for chemical testing are given standard D6640. Sampling for Volatile Organic Compounds (VOC) is addressed in Guide D4547 and often the core may be rapidly subsampled on site using other methods such as D6418 or other similar small hand core samplers. Samples for other chemical characterization generally require subsampling into glass or plastic jars or vials and preserved with refrigeration (See EPA test methods in SW-846 (4)). Verify containers and preservation requirements meet the data quality objectives as specified by the lead regulatory agency, in the project work plan, and with the selected analytical laboratory.

5.3 Direct push methods can provide accurate information on the characteristics of the soils encountered and of the chemical composition if provisions are made to ensure that discrete samples are collected, that sample recovery is maximized, and that clean decontaminated tools are used in the sample gathering procedure. For purposes of this guide, "soil" shall be defined in accordance with Terminology D653. Using sealed or protected sampling tools, cased boreholes, and proper advancement techniques can assure good representative samples. Direct push boreholes may be considered as a supplementary part of the overall site investigation or may be used for the full site investigation if site conditions permit. As such, they should be directed by the same procedural review and quality assurance standards that apply to other types of subsurface borings. A general knowledge of subsurface conditions at the site is beneficial.

5.4 Soil strata profiling to shallow depths may be accomplished over large areas in less time than with conventional drilling methods because of the rapid sample gathering potential of the direct push method. More site time is available for actual productive investigation as the time required for ancillary activities, such as decontamination, rig setup, tool handling, borehole backfill, and site clean-up is reduced over conventional drilling techniques. Direct push soil sampling has benefits of smaller size tooling, smaller diameter boreholes, and minimal investigative derived waste.

5.5 The direct push soil sampling method may be used as a site characterization tool for subsurface investigation and for remedial investigation and corrective action. The initial direct push investigation program can provide good soil and sediment stratigraphic information depending on the soil density and particle size, determine groundwater depth, and provide samples for field screening and for formal laboratory analysis to determine the types and concentrations of chemical contaminants in the soil or sediments and contained pore fluids. The method does not provide samples for laboratory test if engineering properties (Class C and D D4220).

5.6 This guide may not be the correct method for investigations in all cases. As with all drilling methods, subsurface conditions affect the performance of the sample gathering equipment and methods used. Direct push methods are not effective for solid rock and are marginally effective in partially weathered rock or very dense soils. These methods can be utilized to determine the rock surface depth. The presence or absence of groundwater can affect the performance of the sampling tools. Compact gravelly tills containing boulders and cobbles, stiff clay, compacted gravel, and cemented soil may cause refusal to penetration. Certain cohesive soils, depending on their water content, can create friction on the sampling tools which can exceed the static delivery force, or the impact energy applied, or both, resulting in penetration refusal. Some or all of these conditions may complicate removal of the sampling tools from the borehole as well. Sufficient retract force should be available to ensure tool recovery. As with all borehole advancement methods, precautions must be taken to prevent cross contamination of aquifers through migration of contaminants up or down the borehole. Regardless of the tool size, the moving of drilling and sampling tools through contaminated strata carries risks. Minimization of this risk should be a controlling factor in selecting sampling methods and drilling procedures. The user should take into account the possible chemical reaction between the sample and the sampling tool itself, sample liners, or other items that may come into contact with the sample (3, 4).

5.7 In some cases this guide may combine water sampling, or vapor sampling, or both, with soil sampling in the same investigation. Guides D6001 and D4700, D7648 can provide additional information on procedures to be used in such combined efforts. D3740 provides evaluation factors for the activities in this standard.

NOTE 1—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. Agencies 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.

6. Criteria for Selection

6.1 Important criteria to consider when selecting sampling tools include the following:

6.1.1 Size of sample.

6.1.2 Sample quality (Class A,B,C,D) for physical testing. Refer to Practice D4220.

6.1.3 Sample handling requirements, such as containers, preservation requirements. Refer to Practice D6640.

6.1.4 Soil conditions anticipated.

6.1.5 Groundwater depth anticipated and perched water tables.

6.1.6 Boring depth required.

6.1.7 Types and concentrations of contaminants in the soil or sediments and contained pore fluids.

6.1.8 Probability of cross contamination.

6.1.9 Available funds.

6.1.10 Estimated cost.

6.1.11 Time constraints.

6.1.12 History of tool performance under anticipated conditions (consult experienced users and manufacturers).

6.2 Important criteria to consider when selecting direct push equipment include the following:

6.2.1 Site accessibility.

6.2.2 Site visibility.

6.2.3 Soil conditions anticipated.

6.2.4 Boring depth required.

6.2.5 Borehole sealing requirements.

6.2.6 Equipment performance history.

6.2.7 Personnel requirements.

6.2.8 Decontamination requirements.

6.2.9 Equipment grouting capability.

6.2.10 Local regulatory requirements.

7. Apparatus

7.1 *General*—A direct push soil sampling system consists of a sample collection tool, hollow extension rods for advancement, retrieval, and transmission of energy to the sampler, and an energy source to force sampler penetration. Auxiliary tools are required to handle, assemble and disassemble, clean, and repair the sample collection tools and impact surfaces. Necessary expendable supplies are sample containers, sample container caps, sample liners, sample retainers, appropriate lubricants, and personal safety gear. The following text and subsequent figures tell and show the overall intent of this standard; however, if the exact configuration and dimensions vary in a particular tooling configuration, yet the intent is still met, that particular tooling configuration is acceptable to be used as a part of complying with this standard.

7.2 *Direct Push Tool Soil Sampling Systems*—Direct push soil samplers are described in two groups; Dual Tube and Single Tube Systems.

7.2.1 *Dual Tube System*—Figures 3 and 4 are examples of typical Dual Tube direct push soil samplers. The Outer Drive Tube which is generally the same diameter. Diameters range from 50 to 150 mm [2 to 6 inches]. The outer drive tube is sometimes referred to as Probe rod in the drawings. Outer drive tube friction can be reduced by using oversized cutting shoes or other friction reducers. The Outer drive tube stays in the ground and seals and protects borehole collapse as the sampling progresses to depth.

7.2.1.1 *Sampler*—Figure 3 shows a sampler with a solid inner barrel with a liner inside the barrel. Figure 4 shows just an inner liner without the solid barrel. The solid barrel may be required in situations where liner damage may occur. The length of sample ranges from 2 to 6 ft [0.5 to 1.5 m] and diameters range from 50 to 125 mm [2-5 inches]. The sampler is normally held in place with a series of inner rods that fit inside the outer tube and connect to the drive cap so both the outer rods and inner rods are advanced together. The inner rods are used to place and remove the sampler barrels during sampling events. There are other means of locking the sample barrel in place besides inner rods such as wire line latching systems.

7.2.1.2 The outer drive tube is equipped with a Cutting Shoe on the end the is designed specifically for the sampler system such that the liners, o-rings, and core catchers all fit in place correctly and the shoe cuts the core to slides into the sampler liner with minimal disturbance. There are different cutting

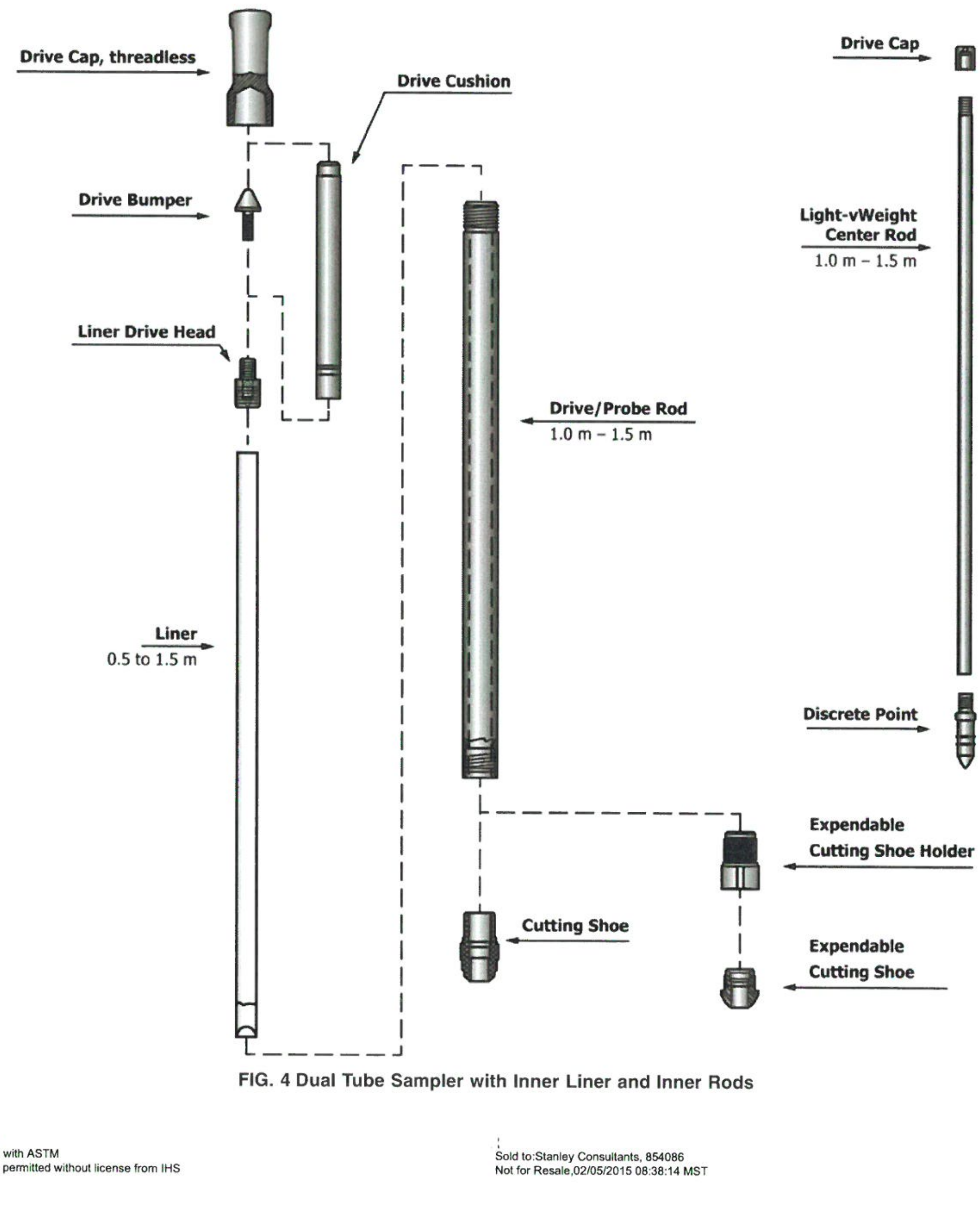


FIG. 4 Dual Tube Sampler with Inner Liner and Inner Rods

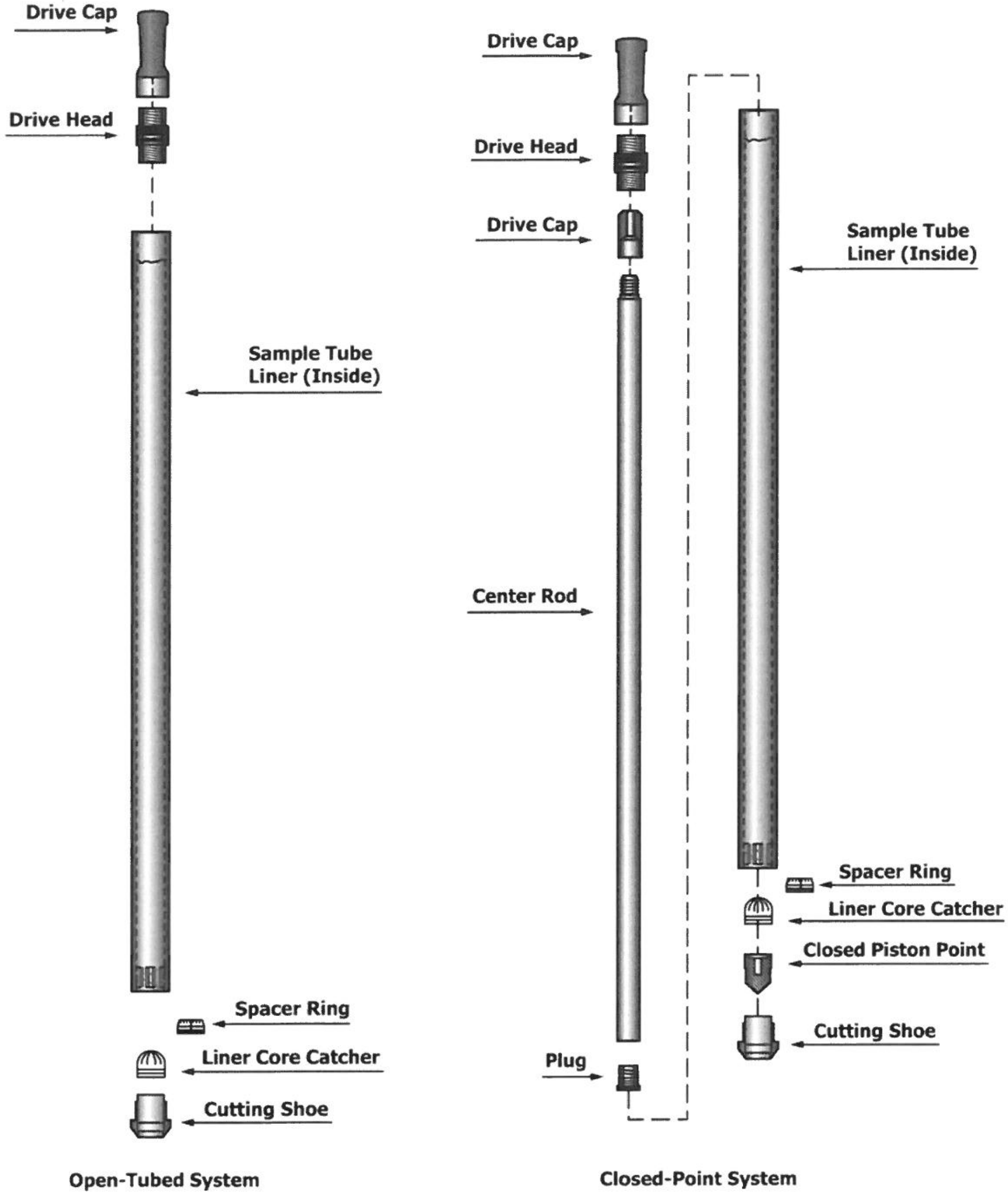


FIG. 5 Typical Single Tube Sampling System Used in Either Open Tube or Sealed (Closed) Piston Point

shoes for differing soil conditions (see Appendix X1) so the correct design must be used in the soils to be sampled. The Cutting Shoe is the most important feature that effects soil core recovery or quality. General purpose cutting shoes are successful in a wide range of soil deposits but if the recover is poor one should change the cutting shoe design for the soils to be sampled. Special expendable cutting shoes (Figs. 4 and 5) can be used when the planned investigation requires post sampling installations such as monitoring wells (D6724, D6725).

7.2.1.3 Core catchers can be used to help the soil recovery by preventing loss of core. Figure 3 shows a core catcher built into the sample liner. Core catchers should be used in most all soil conditions. The catcher does not disturb the soil except in very soft soils. The use of a catcher assures that if clean sands are encountered they can be recovered without running/falling out of the liner.

7.2.1.4 Figure 4 shows a discrete point with inner rods that can be inserted into the dual tube system in place of the sampler barrel to advance the system without sampling. It can be used to drive through difficult formations and intervals where sampling is not required.

7.2.2 *Single Tube Samplers*—Figures 5 and 6 show some single tube sampler systems. Figure 5 shows a Single Tube system used in either an open or sealed mode. Sample lengths

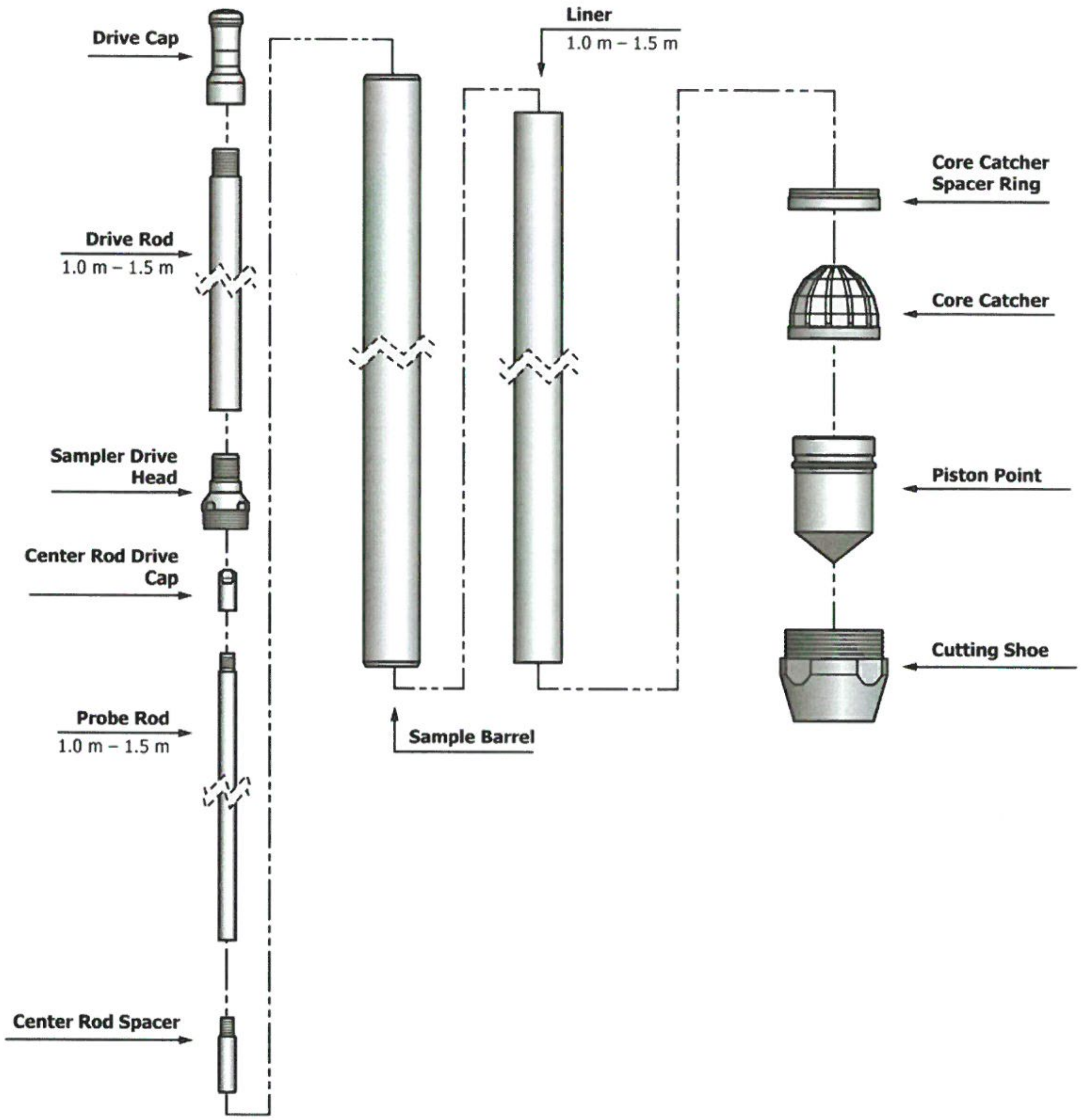


FIG. 6 Sealed Single Tube Piston Sampler

range from 0.5 to 1.5 m [2 to 5 ft]. Typical sample diameters range from 30 to 100 mm [1 to 4 inches]. Figure 6 shows the Sealed single tube sampler with solid barrel, inner liner, piston point, and cutting shoe. The sealed system includes the piston and inner rod are locked inside the liner and the sampler is advanced to the sampling depth. The piston is unlocked using rods or other methods prior to the sampling push. The sample barrel is equipped with a cutting shoe which is specifically designed to cut the core for optimal recovery.

7.2.2.1 Figure 7 shows a typical piston sampler deployed on CPT rigs (D6067) (**20**). It uses a simple ball system to unlock the piston when the sampling depth is reached.

7.2.2.2 A Core Catcher is sometimes used to add in recovery of sands and low plasticity silts. This catcher is reusable and is not built into the liner. In many cases the catcher is not required as the piston system creates a vacuum to hold the sample in the liner.

7.2.2.3 Figure 5 shows the single tube sampler use without the piston in an open sampling mode. As discussed in section 5.1.2.5, the use of an open sampler for consecutive sampling events is extremely limited.

7.3 *Sampler Extension/Drive Rods*—Sampler extension/drive rods are lengths of rod or tube generally constructed of steel to withstand the pushing or percussion forces applied. Inner rods used with Dual Tube systems can be made with thinner walls to provide lightweight tooling to minimize manual effort in sampling. Extension drive rods lengths range from 1.0 to 1.5 m [3 to 5 ft] but are available in various lengths. Rod lengths should be mated with casing and sampling equipment used. Thread types and classes vary between equipment manufacturers. Rod joints can be sealed to prevent fluid intrusion with "O" rings. TFE-fluorocarbon washers or TFE-fluorocarbon tape. Because of the percussive effort, joint

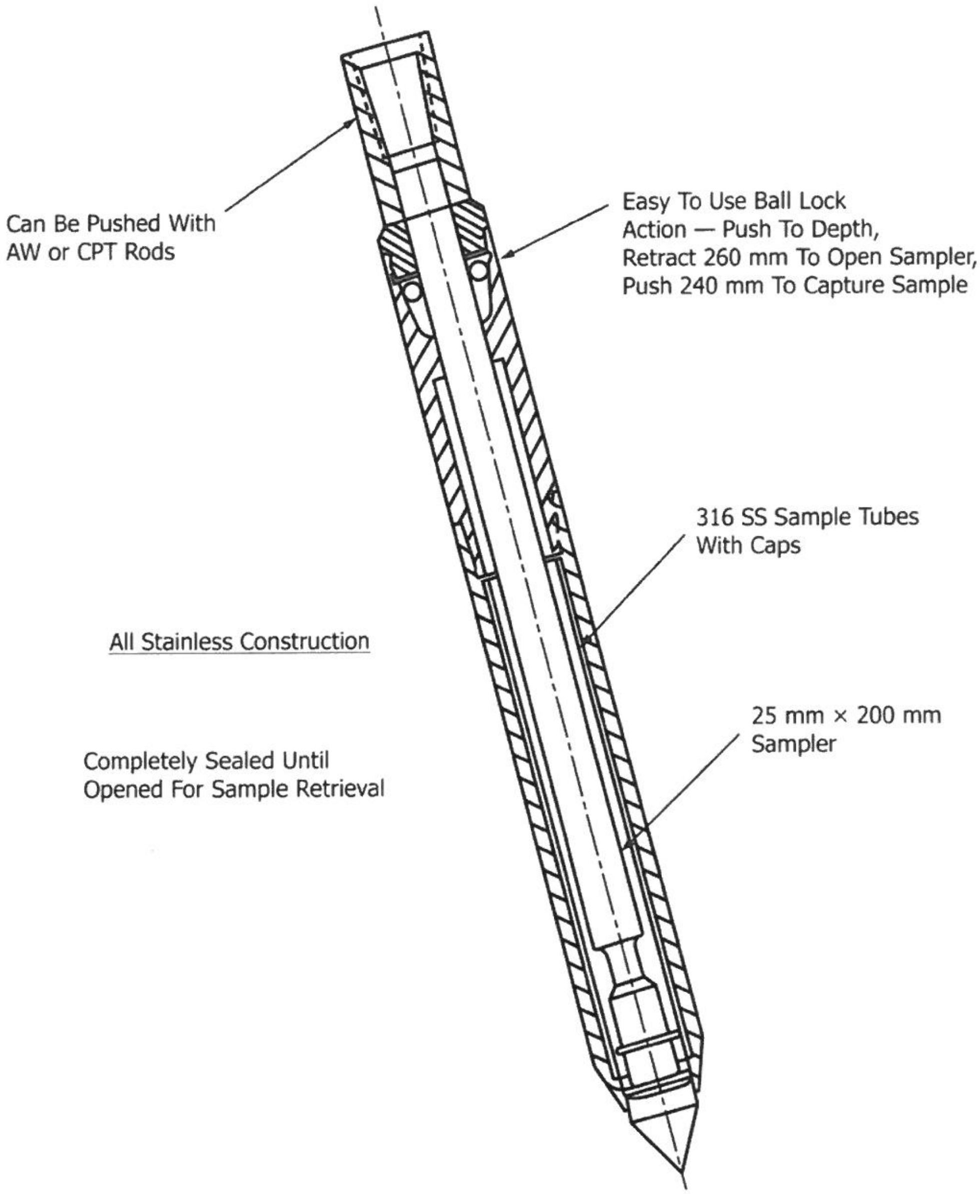


FIG. 7 Single Tube Piston Sampler Used on CPT and Drilling Operations

seals should be checked for each sampling effort. Dual Tube outer rods should have sufficient inside diameter to accommodate the equipment necessary to perform the desired action. For Direct Push monitoring well installation (D6724, D6725) research has shown (**21**) that the minimum nominal 100-mm [4-inches] inside diameter requirement normally specified for rotary drilled monitoring wells (D5092) is not required for the installation of smaller diameter direct push wells.

7.4 *Sampler Liners*—Sampler liners are used to collect and store samples for shipment to laboratories, for field index testing of samples and for removing samples from solid barrel type samplers. Most chemical testing of the soil core, if performed, requires rapid or immediate sub-sampling, containerization, and preservation of samples (see 5.2) for testing and therefore the material of the liner and interaction of the liner with chemicals is not a major concern. Liners are only used to retain soils for long term for classification and geotechnical index properties testing. Liners are available in lengths from 150 mm [6 in.] to 1.5 m [5.0 ft]. Liners should be sealed in accordance with Practice D4220 or sealed subsamples taken when samples are collected for moisture content physical testing. Liners generally are split in the field for subsampling. Individually split liners are available in some sizes for field use. The liner should have a slightly larger inside diameter than the soil specimen to reduce soil friction and enhance recovery (see 7.5). When a slightly oversized liner is used, the potential for air space exists around the sample. Certain chemical samples may be affected by the enclosed air. Liners having less tolerance may be required and a shortened sampled interval used to reduce friction in the liner. Metal liners can be reused after proper cleaning and decontamination. Plastic liners should be disposed of properly after use.

7.4.1 The most predominant liner material in used is clear medical grade Polyvinyl Chloride (PVC). The clear liner has the advantage of exposing the soil core to visual examination after recovery. Smearing of soil in the liner does occur and liners should be opened and examined and required subsamples taken. Liners are available in plastics, TFE-fluorocarbon, brass, and stainless steel. Other materials can be used as testing needs dictate, however, since there is limited concern when immediate subsamples are taken on chemical test results, there may be no need for more expensive non-reactive liner materials such as TFE-fluorocarbon or brass. Verify that liner materials meet local regulatory requirements and specifications in the project sampling plan and quality assurance plan.

7.5 *Cutting Shoes*—The Cutting Shoe is one of the most important parts affecting the quality and Recovery (9.5.4) of the soil specimens. General purpose cutting shoes work well in most formations but if core recovery is poor, then one should change the cutting shoe and liner design to optimize the sample recovery and quality. The Clearance Ratio (Ratio of ID of Cutting Shoe to ID of Liner) is the most important parameter for optimizing sample recovery and quality. In general higher clearance ratios are required in dense soil formations while lower ones can be used in softer formations. The cutting angle of the shoe also influences the sample quality. Sharper cutting shoes work better in fine grained formations but they are not as durable. Appendix X1 gives additional information on Cutting Shoe design. Contact your manufacturer if you have questions regarding recovery and quality issues.

7.6 *Sample Containers*—Sample containers should be prescribed according to the anticipated use of the sample specimen. Samples taken for chemical testing may require clean containers with specific preservatives (see 5.2). Practice D3694 and EPA SW-846 (4) provides information on some of the special containers and preservation techniques required for these containers generally will be cleaned to specific criteria. Samples for geotechnical testing require certain minimum volumes and specific handling techniques. Practice D4220 offers guidance for sample handling of samples submitted for geotechnical physical testing.

7.7 *Direct Push Power Sources*—Soil probing percussion driving systems, penetrometer drive systems, and rotary drilling equipment may be used to drive casings and direct push soil sampling devices. The equipment should be capable of applying sufficient static force, or dynamic force, or both, to advance the sampler to the required depth to gather the desired sample. The system must have adequate retraction force to remove the sampler and extension/drive rods once the selected strata has been penetrated. Rotation of the drill string can be added during insertion, as well as during retraction if the drive system can impart rotation.

7.7.1 *Retraction Force*—The retraction force can be applied by direct mechanical pull back using the hydraulic system of the power source; line pull methods using mechanical or hydraulic powered winches, or cathead and rope windlass type devices. Winches used with direct push technology should have a minimum of 900 kg [2000 lb] top layer rating capacity and a line speed of 120 m/min [400 ft/min] to provide effective tool handling. Direct push sampling tools can be retracted by back pounding using weights similar to those of standard penetration testing practices. Backpounding to recover samples can affect recovery and cause disturbances to the sample. Other forms of extraction, such as jacking, that do not cause undue disturbance to the sample, are preferable.

7.7.2 *Percussion Devices*—Percussion devices for use with direct push methods are hydraulically-operated hammers, air-operated hammers, and mechanically-operated hammers. Hydraulically-operated hammers should have sufficient energy to be effective in moving the samplers through the subsurface strata. The maximum energy application is dependent on the tools used. Hammer energy that exceeds tool tolerance will result in tool damage or loss and will not achieve the goal of collecting high quality samples. Air-operated hammers should be capable of delivering sufficient energy, as well. Hammer systems utilizing hydraulic oil or air should be operated in the range specified by the manufacturer. Manually-operated hammers can be used to advance direct push tools. These hammers can be operated mechanically or manually using cathead and rope. These systems generally involve using 63.5 kg [140 lb], standard penetration (see Test Method D1586) hammers, which can work well for direct push sampling. In operation, these hammers tend to be slower than hydraulic hammers and can cause tool damage if direct push tools are not designed to take the heavy blows associated with these hammers. The hydraulic- and air-operated hammers strike up to 2000 blows/min. In addition to the energy transferred, the rapid hammer action sets up a vibratory effect, which also aids in penetration. This vibratory effect, along with the percussive effort, may disturb some soil samples.

7.7.3 *Static Push Systems*—Cone penetrometer systems are an example of static push systems. They impart energy to the sampler and extension rods by using hydraulic rams to apply pressure. The pressure applied is limited to the reactive weight of the drive vehicle. Some portable systems use screwed in augers to anchor the machine for CPT testing (D6067). The earth augers provide the reaction force to advance the CPT probe. Retraction of the sampler and extension rods is by static pull from the hydraulic rams.

7.7.4 *Vibratory/Sonic Systems*—Sonic systems (D6914) utilize a vibratory device, which is attached to the top of the sampler extension rods. Reactive pressure and vibratory action are applied to the sampler extensions moving the sampler into the formation. In certain formations, sample recovery and formation penetration is expedited; however, all formations do not react the same to vibratory penetration methods.

7.7.4.1 *Sonic or Resonance Drilling Systems*—These are high powered vibratory systems that can be effective in advancing large diameter single or dual tube systems. They generally have depth capabilities beyond the smaller direct push systems.

7.7.5 *Rotary Drilling Equipment*—Direct push systems are readily adaptable to rotary drill units (D6286). The drill units offer a ready hydraulic system to operate percussion hammers, as well as reactive weight for static push. Drill units with direct push adaptations also offer drilling techniques should obstacles be encountered while using direct push technology. Large drill units may have reactive weights that can exceed the tool capacity, thereby resulting in damaged tools. Typical rotary drilling equipment is larger and more massive than smaller direct push equipment which can lead to limitations with site access and slower relocation times.

8. Conditioning

8.1 *Decontamination*—Sampling equipment that will contact the soil to be sampled should be cleaned and decontaminated before and after the sampling event (D5088). Extension rods should be cleaned prior to each boring to avoid the transfer of contaminants and to ease the connecting of joints. Thread maintenance is necessary to ensure long service life of the tools. Sample liners should be kept in a sealed or clean environment prior to use. All ancillary tools used in the sampling process should be cleaned thoroughly, and if contaminants are encountered, decontaminated before leaving the site. It should not be assumed that new tools are clean. They should be cleaned and decontaminated before use. Decontamination should be performed following procedures outlined in Practice D5088 along with any site safety plans, sampling protocols, or regulatory requirements.

8.2 *Tool Selection*—Prior to dispatch to the project site an inventory of the necessary sampling tools should be made. Sample liners, containers, sampling tools, and ancillary equipment should be checked to ensure its proper operation for the work program prescribed. Sampling is expedited by having two or more samplers on site. Since samples can be recovered quite fast, a supply of samplers will allow a boring to be completed so other functions can be performed while samples are being processed. Various Cutting Shoes and Liners should be available to optimize soil sampling Recovery and quality on site. A backup tool system adaptable to and within the capabilities of the power source should be available should the original planned method prove unworkable. Materials for proper sealing of boreholes should always be available at the site (D6011 section 9 Completion)

9. Procedure

9.1 While procedures for direct push soil sampling with two common direct push methods are outlined here, other systems may be available. As long as the basic principles of practice relating to sampler construction and use are followed, other systems may be acceptable.

9.2 *General Set-Up*—Select the boring location and check for underground and overhead utilities and other site obstructions. Establish a reference point on the site for datum measurements, and set the direct push unit over the boring location. Stabilize and level the unit, raise the drill mast or frame into the drilling position, and attach the hammer assembly to the drill head if not permanently attached. Attach the anvil assembly in the prescribed manner, slide the direct push unit into position over the borehole, save a portion of the sliding distance for alignment during tool advancement, and ready the tools for insertion.

9.2.1 *Tool Preparation*—Inspect the direct push tools before using, and clean and decontaminate as necessary. Inspect drive shoes for damaged cutting edges, dents, or thread failures as these conditions can cause loss of sample recovery and slow the advancement rate. Where permissible, lubricate rod joints with appropriate safe products, but clean water only may be the best option. Many organic lubricants can result in interferences with analytical tests to be performed on the collected samples (22). Verify that any lubricants used will not cause analytical interference or result in false positives before applying to the tools. Check impact surfaces for cracks or other damage that could result in failure during operations. Assemble samples and install where required, install sample retainers where needed, and install and secure sampler pistons to ensure proper operation where needed.

9.2.2 *Sample Processing*—Sample processing should follow a standard procedure to ensure quality control requirements are met (5.2). View sample in the original sampling device, if possible. Open the sampling device with care to keep disturbance to a minimum. When using liners or thin wall tubes, protect ends to prevent samples from falling out or being disturbed by movement within the liner. Measure recovery accurately, containerize as specified in the work plan or applicable ASTM procedures, and label recovered samples with sufficient information for proper identification. When collecting samples for volatile chemical analysis, sample specimens must be contained and preserved as soon as possible to prevent loss of these components. Follow work plan instructions or other appropriate documents (see Practice D6640) when processing samples collected for chemical analysis.

9.3 *Dual Tube System*—Assemble the outer casing with the cutting/drive shoe on the bottom. Assemble the sampler and liner, if used, and attach the sampler to the extension rods. Connect the drive head to the top of the sampler extension rods, and insert the sampler assembly into the outer casing. Position the outer casing and sampler assembly under the drill head, and move the drill head downward to bring pressure on the tool string. If soil conditions allow, advance the sampler/casing assembly into the soil at a steady controlled rate slow enough to allow the soil to be cut by the shoe and move up inside the sample barrel. If advancement is too rapid, it can result in loss of recovery because of soil friction and plugging in the shoe. Occasional hammer action during the push may help recovery by agitating the sample surface. If soil conditions prevent smooth static push advancement, activate the hammer to advance the sampler. Apply a continuous pressure while hammering to expedite soil penetration. The pressure required is controlled by subsurface conditions. Applications of excessive down pressure may result in the direct push unit being shifted off the borehole causing misalignment with possible tool damage. Stop the hammer at completion of advancement of the measured sampling barrel length. Release the pressure and move the drill head off the drive head. Attach a pulling device to the extension rods or position the hammer bail and retrieve the sampler from the borehole. At the surface remove the sampler from the extension rods and process. Soil classification is accomplished easily using split barrel samplers as the specimen is available readily for viewing, physical inspection and subsampling when the barrel is opened. However, unnecessary exposure of the sample to the atmosphere will lead to loss of volatile contaminants. If Liners are used they should be split of sections removed for soil classification and subsampling. Clean, decontaminate, and reassemble the sampler. Reattach the sampler to the extension rod, add the necessary extension rod and outer casing to reach the next sampling interval, and sound the borehole for free water before each sample interval. If water is present, it may be necessary to change sampling tools and select a sealed Single Tube sampler . Unequal pressure inside the casing may result in blow-in of material disturbing the soil immediately below the casing. Lower the sampler to its proper position, add the drive heads, and repeat the procedure. If it is desired that the pass through certain strata without sampling, install an extension drive point in lieu of the sampler (see Fig. 5). When the sampling interval is reached, remove the point and install the sampler. Advance the sampler as described. Upon completion of the borehole, remove the outer casing after instrumentation has been set or as the borehole is sealed as described in Section 10.

9.3.1 *Dual Tube System—Other Samplers:*

9.3.1.1 *Thin Wall Tubes*—Thin wall tubes (Practice D1587) can be used with the dual tube system. Attach the tube to the tube head using removable screws. Attach the tube assembly to the extension rods and position at the base of the outer casing shoe protruding a minimum of 6.25 mm [0.25 in.] to contact the soil ahead of the outer casing. Advance the tube, with or without the outer casing, at a steady rate similar to the requirements of Practice D1587. At completion of the advancement interval, let the tube remain stationary for 1 min. Rotate the tube slowly two revolutions to shear off the sample. Remove the tube from the borehole, measure recovery, and classify soil. The thin wall tube can be field extruded for on-site analysis or sealed in accordance with Practice D4220 and sent to the laboratory for processing. Samples for environmental testing generally require the subsampling and preservation of samples in controlled containers. Soil samples generally are removed from the sampling device for storage and shipping. Thin wall tubes should be cleaned and decontaminated before and after use.

9.3.1.2 *Sealed Single Tube Piston Sampler*—A Sealed Single Tube piston sampler can be used inside the Dual Tube system. This type of sampler may be required when 1.) there is water level inside the Dual Tube and a chemical testing requires virtually no possibility of cross contamination, or 2.) when the borehole becomes unstable and the continued use of the open tube sampling system cannot assure a sample of the native soils without other slough or heave in the recovered sample. Follow the section 9.4 for operation of Single Tube samplers inside of the Dual Tube.

9.3.1.3 *Open Barrel Samplers*—Use Open Single Tube barrel samplers (Figure 5 a) in advance of the outer casing where the soil conditions could cause swelling of split barrel samplers, or where friction against the outer casing precludes its advancement and sampling must still be accomplished. The sampler requires the use of liners for removal of the sample. The sampler must be cleaned and decontaminated before use.

9.3.1.4 *Standard Penetration Test Split Barrel Sampler (D1586)*—Attach the split spoon to an extension rod or drill rod. Using a mechanical or hydraulic hammer drive the sampler into the soil the desired increment, as long as that increment does not exceed the sampler chamber length. Remove the sampler from the borehole, disassemble, and process sample. Standard split barrel samplers can be used, as long as borehole wall integrity can be maintained and the additional friction can be overcome. If caving or sloughing occurs, the sampler tip should be sealed or other sampling tools used

9.4 *Single Tube System—*

9.4.1 *Sealed Sampler (see Figs. 3-7)*—Insert or attach the sample liner to the shoe, and insert the assembly into the solid barrel sampler. Install sample retaining basket if desired. Attach the latch coupling or sampler head to the sampler barrel, and attach the piston assembly with point and "O" rings if free water is present, to the latching mechanism or holder. Insert the piston or packer into the liner to its proper position so the point leads the sampler shoe. Set latch, charge packer, or install locking pin, and attach assembled sampler to drive rod. Add drive head and position under the hammer anvil. Apply down pressure, hammer if needed, to penetrate soil strata above the sampling zone. When the sampling zone is reached, insert the piston latch release and recovery tool, removing the piston, or insert the locking pin removal/extension rods through the drive rods, turn counterclockwise, and remove the piston locking pin so the piston can float on top of the sample, or release any other piston holding device. Direct push or activate the hammer to advance the sampler the desired increment. Retrieve the sampler from the borehole by withdrawing the extension/drive rods. Remove the shoe, and withdraw the sample liner with sample for processing. Clean and decontaminate the sampler, reload as described, and repeat the procedure. Extreme stress is applied to the piston when driving through dense soils. If the piston releases prematurely, the sample will not be recovered from the correct interval, and a resample attempt must be made. The piston sampler can be used as a re-entry grouting tool for sealing boreholes on completion if it is equipped with a removable piston.

9.5 *Quality Control:*

9.5.1 *Quality Control*—Quality control measures are necessary to ensure that sample integrity is maintained and that project data quality objectives are accomplished. By following good engineering principles and applying common sense, reliable site characterizations can be accomplished.

9.5.2 *Water Checks*—Water seeping into the direct push casing or connecting rods from contaminated zones may influence testing results. Periodically check for groundwater before inserting samplers into borehole or into outer casings in the two tube system. If water is encountered, it may be necessary to switch to the sealed piston type samplers to protect sample integrity. Sealed piston type samples may not always be water tight. Sealing of rod or casing joints can prevent groundwater from entering through the joints.

9.5.3 *Datum Points*—Establishment of a good datum reference is essential to providing reliable sample interval depths and elevators. Select datum reference points that are sufficiently protected from the work effort, and that can be located for future reference. Field measurements should be to 0.1 ft (3.05 mm). Measure extension rods as the bore advances to locate sample depth. Mark rods before driving each sample interval to determine accurate measurement of sample recovery and to accurately log borehole depth.

9.5.4 *Sample Recovery*—Record and report sample recovery for every sampling event. The Recovery is defined as the recovered sample length divided by the push/drive length as a percent. Sample recovery should be monitored closely and results documented. Poor recovery could indicate a change in sampling method is needed, that improper sampling practices are being conducted, or that sampling tools are incorrect. Adjust Cutting Shoes and liners to optimize sample recovery in the field (see 7.5 and Appendix X1). Sample recovery involves both volume and condition. Poor sample recovery should cause an immediate review of the sampling program.

9.5.5 *Decontamination*—Follow established decontamination procedures. Taking shortcuts may result in erroneous or suspect data.

9.5.6 *Equipment Rinsate Samples*—Equipment rinsate samples should be collected from decontaminated samplers Periodically during the sampling program in accordance with the quality assurance plan requirements. Clean water of known quality is poured over and through the assembled or partially assembled sampler so that all surfaces having potential sample contact, including liners, are rinsed. The rinse water is collected in the appropriate clean sample containers and preserved for analysis. The rinsate samples should be analyzed for the same analytes as the soil and sediment samples or groundwater samples. The rinsate samples will provide documentation that decontamination procedures are adequate and that cross contamination is controlled. For high priority sites and large projects it may be prudent to have rinsate samples analyzed on a quick turn-around basis to verify that sample integrity is maintained during the sampling program.

9.5.7 *Replicate Borings*—It is recommended that at a minimum one in twenty borings be replicated to provide some basic quality control on the repeatability of the boring and sampling process. Spacing between replicate borings should be on the order of 3 to 5 ft [1 to 1.5 m]. The same sampling techniques and tooling should be used in the replicate boring. This practice also will provide insight into: 1) lateral variability of soil and sediment strata and 2) heterogeneity of contaminant distribution for geo-environmental investigations.

10. Completion and Sealing

10.1 *Completion*—For boreholes receiving permanent monitoring devices, completion should be in accordance with Practice D5092, Guide D6724 or Practice D6725, site work plan, and or regulatory requirements.

10.2 *Borehole Sealing*—Seal direct push boreholes to minimize preferential pathways for containment migration. State regulations will generally prescribe acceptable grout mixtures and placement techniques; refer to local regulations for the state or county where the work is conducted. Additional information and guidance on borehole sealing can be found in Guide D5299, D6001 and Practice D6725. Recent work (Lackey et al., 2009 **(23)**, Ross 2010 **(24)**) have found that bentonite slurries often will dessicate and crack when emplaced in the vadose zone, especially in semi-arid to arid settings. When sealing boreholes in the vadose zone it was found that neat cement, cement-sand mixtures or bentonite chip provided the best seal to minimize fluid movement along the borehole (Lackey et al., 2009 **(23)**).Regulations generally direct bottom up borehole sealing as it is the surest and most permanent method for complete sealing. High pressure grouting is available for use with direct push technology for bottom up borehole sealing.

10.2.1 *Sealing by Slurry, Two Tube System*—Sound the borehole for free water. If water exists in the casing, place the appropriate tremie tube or extension rods, open-ended, to the bottom of the outer casing. Mix the slurry to standard specifications prescribed by regulation or work plan. Pump slurry through the tremie tube or extension/drive rod until it appears at the surface of the outer casing. Slowly retract the outer casing and tremie tube while maintaining a head of grout in the borehole. Keep the grout level inside the outer casing as the tools are retracted to prevent borehole wall collapse and poor integrity seal. If no free water exists in the borehole, the slurry can be placed by gravity. Top off the borehole as the outer casing as it is removed.

10.2.1.1 *Slurry Mixes*—Slurry mixes used for slurry grouting of direct push boreholes may be of lower viscosity when small diameter tremie pipes are required. Usable mixes are 6 to 8 gal [22.7 to 30.28 L] of water/94-lb (42.64-kg) bag of cement with 5 lb [2.27 kg] of bentonite or 24 to 36 gal [90.84 to 136.28 L] of water to 50 lb [22.68 kg] of bentonite.

10.2.2 *Sealing by Gravity—Dual Tube System*—Measure the cased hole to ensure it is open to depth. Slowly add bentonite chips or granular bentonite to fill the casing approximately 2 ft. Withdraw the casing 2 ft and recheck depth. Hydrate the bentonite by adding water. Repeat this procedure as the outer casing is withdrawn. The bentonite must be below the bottom of the casing during hydration. Wetness inside the rods may affect the flow of granular bentonite to the bottom of the casing. A tremie tube may be used to add water for hydration of dry bentonite. Fill the top foot of the borehole with material that is the same as exists in that zone.

10.2.3 *Borehole Sealing Single Tube System:*

10.2.3.1 *Gravity Sealing from Surface*—If the soil strata penetrated has sufficient wall strength to maintain an open hole, and the borings ends at or above the local water table, then it may be possible to add sealing materials from the surface. Dry bentonite chips or granular bentonite can be placed by gravity. The borehole depth and volume should be determined and the borehole sounded every 5 ft [1.5 m] to ensure bridging has not occurred. The bentonite should be hydrated by adding approximately 1 gallon [1.0 L] of clean water for each 5 ft of filled borehole. Seal the surface with native material.

10.2.3.2 *Wet Grout Mix Tremie Sealing*—Tremie sealing methods can be used with single tube systems when borehole wall strength is sufficient to maintain an open hole or when extension rods with an expendable point are used to reenter the borehole. The grout pipe should be inserted immediately after the direct push tools are withdrawn or through the annulus of the extension rods that have been reinserted down the borehole for grouting. Care must be taken to not plug the end of the grout pipe. Side discharge grout pipes also can be used to prevent plugging.

10.2.4 *Re-Entry Grouting*—If the borehole walls are not stable, the borehole can be re-entered by static pushing grouting tools, such as an expendable point attached to the extension/drive rods to the bottom of the original borehole. Pump a slurry through the rods as they are withdrawn. High pressure grouting equipment may be beneficial in pumping standard slurry mixes through small diameter gravity pipes. Care must be taken to ensure the original borehole is being sealed.

11. Reports: Test Data Sheets/Forms

11.1 Fields records must be kept for each soil sampling event. These records are documented on field data sheets to show the depths of drilling and sampling events to the nearest 5 cm (0.1 ft), recovery in percent to 2-3 significant digits, and records on sample processing, subsampling locations, and visual soil classification. Soil samples can be classified in accordance with Practice D2487 and/or D2488 or other methods as required for the investigation. Prepare the final report log in accordance with standards set in Guide D5434 listing the parameters required for the field investigation program. List all contaminants identified, instrument readings taken, and comments on sampler advancement. Record any special field tests performed and sample processing procedures beyond those normally used in the defined investigation. Record borehole sealing procedures, materials used, and mix formulas on the boring log. Survey or otherwise locate the boring site to provide a permanent record of its replacement.

11.2 *Backfilling Record*—Record the method of sealing, materials used, and volume of materials placed in each borehole. This information can be added to the field boring log or recorded on a separate abandonment form.

12. Keywords

12.1 decontamination; direct push; groundwater; sealing; soil and sediment sampling

APPENDIX

(Nonmandatory Information)

X1. FACTORS INFLUENCING SAMPLE RECOVERY IN DIRECT PUSH SOIL SAMPLING

X1.1 The major factors influencing sample recovery in Direct Push Soil Sampling are the Cutting Shoe inside diameter and shape, and the Liner inside diameter and length. The other major factor is to soil formation to be sampled including the soil type, particle size, cohesiveness, and stress history. The combination of Cutting Shoe and Liner should be optimized and matched to the soil formations to be sampled. It is important that prior to sampling that different equipment be available to match the soil formation in the field.

X1.2 Soil recovery (9.5.4) in direct push sampling is rarely close to the ideal 100% desired. The predominant use of long sample drive lengths of 1 to 1.5 m (3 to 5 ft) often results in less than desirable recovery. Shortening sample lengths will improve the recovery but that is rarely done. Recoveries of more than 100 % often occur in Direct Push Soil Sampling because of the large clearance ratios between the cutting shoe and liner. Extremely high recoveries can occur in heavily over consolidated clays that tend to expand. Conversely, recoveries of less than 100 % can occur in low density and low plasticity soils. Clean sands silts below groundwater may liquefy and run or fall out of the sampling tube during retraction of the sampler and as it clears water level. In cases of running sands the basket retianers should be used to help retain the soil.

X1.3 The Cutting Shoe is the most important feature that controls the sample recovery. Cutting Shoes are designed to have a smaller diameter opening than the Liner to help reduce the friction of the core inside the Liner. The ratio of inside diameter of the cutting shoe to the inside diameter of the liner is called the Clearance Ratio. If sample recovery in a soil formation is poor the operator should change the Cutting Shoe to match the formation.

X1.4 Research on intact soil sampling indicates the angle of the cutting shoe (Sharpness) should be less than 10 degrees for intact sampling. Most direct push cutting shoes are blunt with much flatter cutting angles and rounded cutting angles because they need to be very strong and durable to withstand the impact forces of Direct Push. These blunt surfaces transmit shock waves and possible bearing capacity failure in from of the cutting shoe edge and cause disturbance to the soil before it enters the shoe and barrel. In some dense plastic soils this can cause extreme expansion of the cores. If these symptoms occur in fine grained formations a sharpened cutting shoe may result in higher quality cores.

X1.5 Manufactures provide differing styles of cutting shoes that can be used in difficult soil deposits. Figures X1.1 through X1.6 show some examples of the Cutting Shoe designs for different formations. Consult your manufacturer for advice on cutting shoes for the soils to be tested.

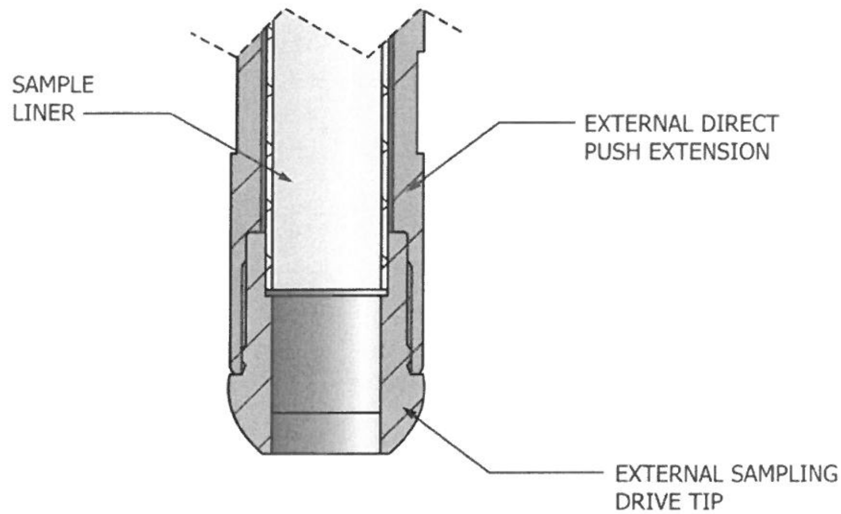


FIG. X1.1 Typical Sand and Silt Cutting Shoe

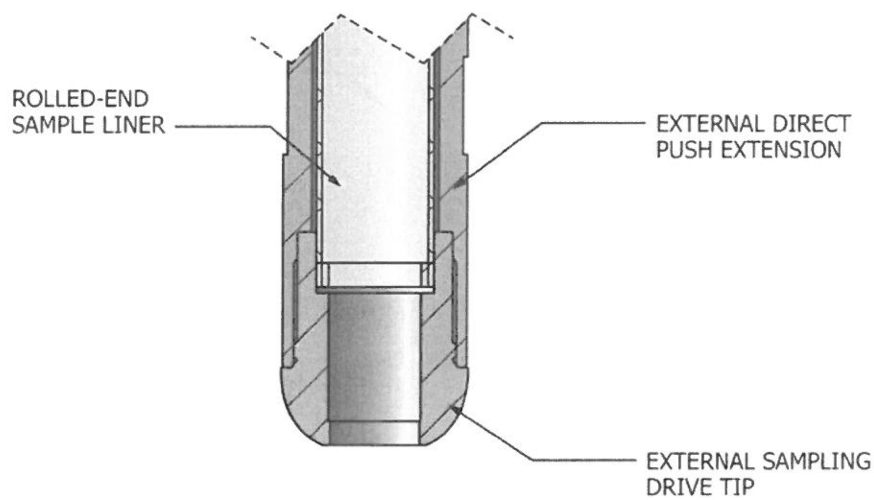


FIG. X1.2 Typical Clay Cutting Shoe

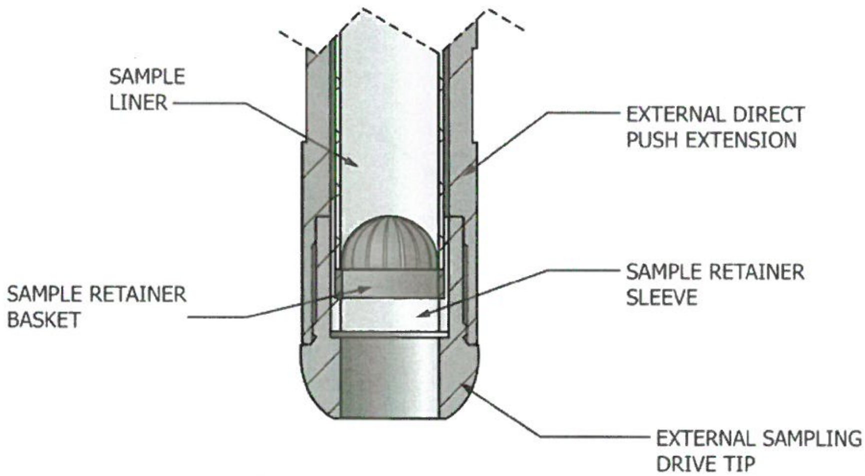


FIG. X1.3 Cutting Shoe for Loose Sand and Silts—Note Basket Retainer

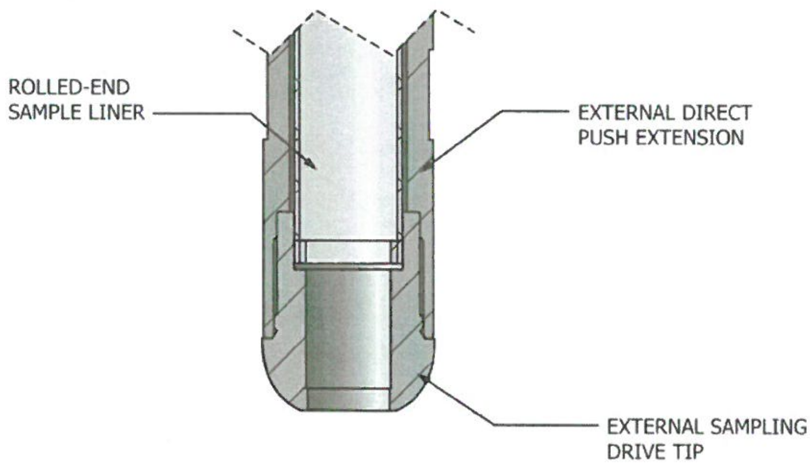


FIG. X1.4 Cutting Shoe for Very Loose Sands and Silts

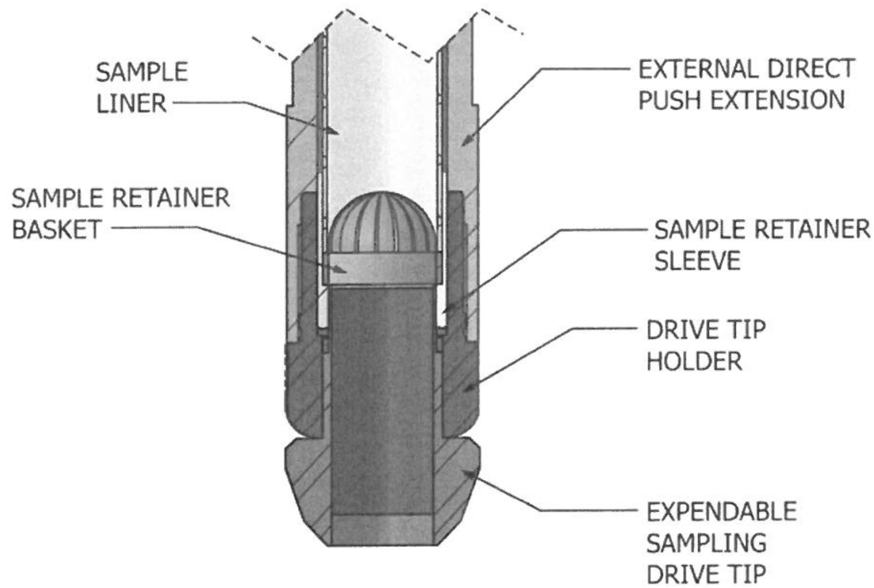


FIG. X1.5 Cutting Shoe for Stiff Over-Consolidated Clays

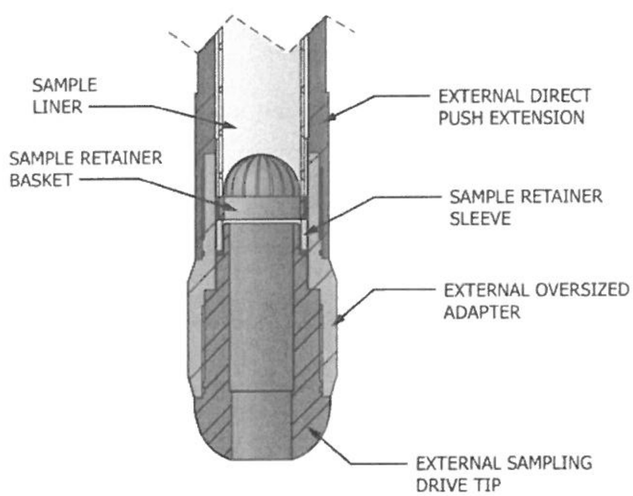


FIG. X1.6 Expendable Cutting Shoe Design for Stiff Clays

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Designation: D6914 – 04 (Reapproved 2010)

Standard Practice for Sonic Drilling for Site Characterization and the Installation of Subsurface Monitoring Devices[1]

This standard is issued under the fixed designation D6914; 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 covers procedures for using sonic drilling methods in the conducting of geoenvironmental exploration for site characterization and in the installation of subsurface monitoring devices.

1.2 The use of the sonic drilling method for geoenvironmental exploration and monitoring-device installation may often involve preliminary site research and safety planning, administration, and documentation. This guide does not purport to specifically address site exploration planning and site safety.

1.3 Soil or Rock samples collected by sonic methods are classed as group A or group B in accordance with Practices D4220. Other sampling methods may be used in conjunction with the sonic method to collect samples classed as group C and Group D.

1.4 The values stated in SI units are to be regarded as standard. The inch-pound units given in parentheses are for information only.

1.5 This practice offers a set of instructions for performing one or more specific operations. It is a description of the present state-of-the-art practice of sonic drilling. It does not recommend this method as a specific course of action. 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 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.

1.6 This practice does not purport to comprehensively address all the methods and the issues associated with drilling practices. 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 sampling of soil, and qualified professionals should have the flexibility to exercise judgment as to possible alternatives not covered in this practice. This practice is current at the time of issue, but new alternative methods may become available prior to revisions, therefore, users should consult manufacturers or sonic drilling services providers prior to specifying program requirements.

1.7 *This practice does not purport to address all the safety concerns, if any, associated with its use and may involve use of hazardous materials, equipment, and operations. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory requirements prior to use.* For good safety practice, consult applicable OSHA regulations and drilling safety guides.[2,3,4]

2. Referenced Documents [5]

2.1 *ASTM Standards—Soil Classification:*

D653 Terminology Relating to Soil, Rock, and Contained Fluids

D2113 Practice for Rock Core Drilling and Sampling of Rock for Site Investigation

D2488 Practice for Description and Identification of Soils (Visual-Manual Procedure)

D5434 Guide for Field Logging of Subsurface Explorations of Soil and Rock

2.2 *ASTM Standards—Drilling Methods:*

D1452 Practice for Soil Exploration and Sampling by Auger Borings

D5088 Practice for Decontamination of Field Equipment Used at Waste Sites

D5299 Guide for Decommissioning of Ground Water Wells,

[1] This practice 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] "Drilling Safety Guide," National Drilling Association.

[3] "Drillers Handbook," Thomas C. Ruda and Peter Bosscher, National Drilling Association.

[4] "Innovative Technology Summary Report," April 1995, U.S. Department of Energy.

[5] 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.

Vadose Zone Monitoring Devices, Boreholes, and Other Devices for Environmental Activities

D5791 Guide for Using Probability Sampling Methods in Studies of Indoor Air Quality in Buildings

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

D6151 Practice for Using Hollow-Stem Augers for Geotechnical Exploration and Soil Sampling

D6286 Guide for Selection of Drilling Methods for Environmental Site Characterization

2.3 *ASTM Standards—Soil Sampling:*

D420 Guide to Site Characterization for Engineering Design and Construction Purposes

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

D3550 Practice for Thick Wall, Ring-Lined, Split Barrel, Drive Sampling of Soils

D3694 Practices for Preparation of Sample Containers and for Preservation of Organic Constituents

D4220 Practices for Preserving and Transporting Soil Samples

D4700 Guide for Soil Sampling from the Vadose Zone

D6169 Guide for Selection of Soil and Rock Sampling Devices Used With Drill Rigs for Environmental Investigations

2.4 *ASTM Standards—Aquifer Testing:*

D4044 Test Method for (Field Procedure) for Instantaneous Change in Head (Slug) Tests for Determining Hydraulic Properties of Aquifers

D4050 Test Method for (Field Procedure) for Withdrawal and Injection Well Tests for Determining Hydraulic Properties of Aquifer Systems

D5092 Practice for Design and Installation of Ground Water Monitoring Wells

2.5 *ASTM Standards—Other:*

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

3. Terminology

3.1 Terminology used within this guide is in accordance with Terminology D653. Definitions of additional terms may be found in Terminology D653.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *amplitude*—range of drill bit movement necessary to overcome formation elasticity.

3.2.2 *bit face design*—the practice of changing the drill bit face to be neutral to, include, exclude, or shear the material being penetrated.

3.2.3 *forced vibration*—the tendency of one object to force an adjoining or interconnected object into vibrational motion.

3.2.4 *harmonic*—the point in a drill string where a special frequency creates a standing wave pattern throughout the string.

3.2.5 *hertz*—international unit of frequency, equal to one cycle per second.

3.2.6 *hydraulic extraction*—the removal of the sample specimen from the solid sampling barrel by the application of fluid.

3.2.7 *natural frequency*—the frequency or frequencies at which an object tends to vibrate when disturbed.

3.2.8 *resonance*—when one object (sine generator) vibrating at the natural frequency of a second object (drill pipe or casing) forces the second object into vibrational motion.

3.2.9 *sine wave*—a wave form corresponding to a single-frequency periodic oscillation.

3.2.10 *sinusoidal force*—energy force generated by an oscillator that is transmitted to the drill tool string.

3.2.11 *sonic*—the practice of using high frequency vibration as the primary force to advance drill tools through subsurface formations.

3.2.12 *standing wave pattern*—a vibratory pattern created within the drill string where the vibrating frequency of a carrier causes a reflected wave from one end of the drill string to interfere with incidental waves from the source in such a manner that at specific points along the drill string it appears to be standing still. The resulting disturbance is a regular pattern.

4. Summary of Practice

4.1 Sonic drilling is the utilization of high frequency vibration aided by down pressure and rotation to advance drilling tools through various subsurface formations. All objects have a natural frequency or set of frequencies at which they will vibrate when disturbed. The natural frequency is dependant upon the properties of the material the object is made of and the length of the object. The sonic drill head provides the disturbance to the drilling tools causing them to vibrate. To achieve penetration of the formation the strata is fractured, sheared, or displaced. The high frequency vibration can cause the soil in contact with the drill bit and drilling casing string to liquefy and flow away allowing the casing to pass through with reduced friction. Rotation of the drill string is primarily for even distribution of the applied energy, to control bit wear, and to help maintain borehole alignment. The use of vibratory technology reduces the amount of drill cuttings, provides rapid formation penetration, and the recovery of a continuous core sample of formation specimens for field analysis and laboratory testing. Boreholes generated by sonic drilling can be fitted with various subsurface condition monitoring devices. Numerous sampling techniques can also be used with this system including thin walled tubes, split barrel samplers, and *in-situ* groundwater sampling devices. Fig. 1 demonstrates the general principle of sonic drilling.

5. Significance and Use

5.1 Sonic drilling is used for geoenvironmental investigative programs. It is well suited for environmental projects of a production-orientated nature. Disposal of drilling spoils is a

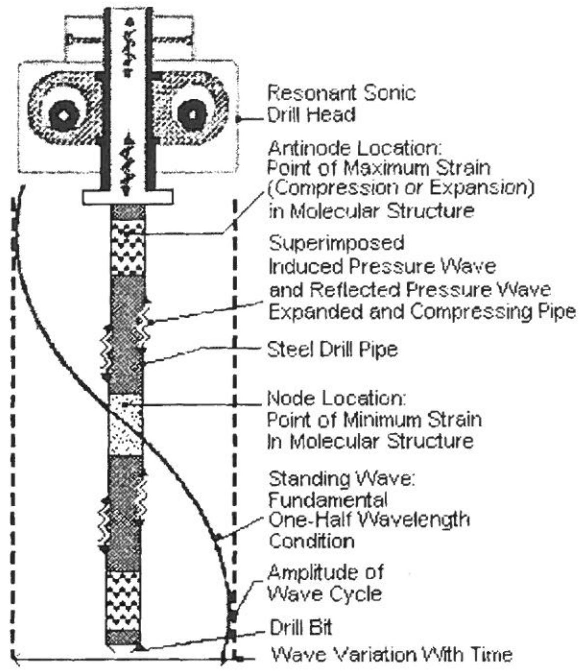


FIG. 1 General Principle of Sonic Drilling

major cost element in any environmental project. Sonic drilling offers the benefit of significantly reduced drill cuttings and reduced fluid production. Sonic drilling offers rapid formation penetration thereby increasing production. It can reduce field-work time generating overall project cost reductions. The continuous core sample recovered provides a representative lithological column for review and analysis. Sonic drilling readily lends itself to environmental instrumentation installation and to *in-situ* testing. The advantage of a clean cased hole without the use of drilling fluids provides for increased efficiency in instrumentation installation. The ability to cause vibration to the casing string eliminates the complication of backfill bridging common to other drilling methods and reduces the risk of casing lockup allowing for easy casing withdrawal during grouting. The clean borehole reduces well development time. Pumping tests can be performed as needed prior to well screen placement to insure proper screen location. The sonic method is readily utilized in multiple cased well applications which are required to prevent aquifer cross contamination. Notwithstanding the possibility of vibratory effects on the surrounding formations, the same sonic drilling plus factors for environmental monitoring device installations carry over for geotechnical instrumentation as well. The installation of inclinometers, vibrating wire piezometers, settlement gauges, and the like can be accomplished efficiently with the sonic method.

5.2 The cutting action, as the sonic drilling bit passes through the formation, may cause disturbance to the soil structure along the borehole wall. The vibratory action of directing the sample into the sample barrel and then vibrating it back out can cause distortion of the specimen. Core samples can be hydraulically extracted from the sample barrel to reduce distortion. The use of split barrels, with or without liners, may improve the sample condition but may not completely remove the vibratory effect. When penetrating rock formations, the vibration may create mechanical fractures that can affect structural analysis for permeability and thereby not reflect the true *in-situ* condition. Sonic drilling in rock will require the use of air or fluid to remove drill cuttings from the face of the bit, as they generally cannot be forced into the formation. Samples collected by the dry sonic coring method from dense, dry, consolidated or cemented formations may be subjected to drilling induced heat. Heat is generated by the impact of the bit on the formation and the friction created when the core barrel is forced into the formation. The sampling barrel is advanced without drilling fluid whenever possible. Therefore, in very dense formations, drilling fluids may have to be used to remove drill cuttings from the bit face and to control drilling generated heat. In dry, dense formations precautions to control drilling generated heat may be necessary to avoid affecting contaminant presence. The affects of drilling generated heat can be mitigated by shortening sampling runs, changing vibration level and rotation speed, using cooled sampling barrels, collecting larger diameter samples to reduce affect on the interior of the sample, and using fluid coring methods or by using alternate sampling methods such as the standard penetration test type samplers at specific intervals. Heat generated while casing the borehole through dense formations after the core sample has been extracted can be alleviated by potable water injection and/or by using crowd-in casing bits that shear the formation with minimal resistance. Should borehole wall densification be a concern it can be alleviated by potable water injection, by borehole wall scraping with the casing bit, by using a crowd-in style bit, or by injecting natural clay break-down compounds.

5.3 Other uses for the sonic drilling method include mineral investigations. Bulk samples can be collected continuously, quite rapidly, in known quantities to assess mineral content. Aggregate deposits can be accurately defined by using large diameter continuous core samplers that gather representative samples. A limited amount of rock can be effectively penetrated and crushability determined. In construction, projects include freeze tube installations for deep tunnel shafts, piezometers, small diameter piles, dewatering wells, foundation anchors with grouting, and foundation movement monitoring instrumentation. Sonic drills can be used to set potable water production wells. However, production may not equal more conventional potable well drilling techniques because of the need to transport drill cuttings to the surface in short increments. Sonic drill units presently in use are in various sizes and most are truck mounted. Sonic drills can be skid or all-terrain vehicle mounted to access difficult areas.

5.4 Sonic drills can be adapted to such other drill methods as conventional rotary (Guide D1583, Guide D5782), down hole air hammer work (Guide D5782), diamond bit rock coring; conventional and wireline (Practice D2113), direct push probing (Guide D6001, Guide D6286), thin wall tube sampling (Practice D1587), and standard penetration test split barrel sampling (Practice D1586). The sonic drilling equipment offers more adaptability than most existing drilling systems. However, it is important to keep in mind that the technique the machine is designed for is the one at which it will be the most efficient. Long term use of sonic drills for other drilling methods may not be cost effective.

NOTE 1—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. Agencies 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, user 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. Criteria for Selection

6.1 Important criteria to consider when selecting the sonic drilling method include the following:

6.1.1 Diameter of borehole,

6.1.2 Sample quality (Class A, B, C, D) for laboratory physical testing (Refer to Practices D4220),

6.1.3 Sample handling requirements such as containers, preservation requirements,

6.1.4 Subsurface conditions anticipated: soil type or rock type/hardness,

6.1.5 Groundwater depth anticipated,

6.1.6 Boring depth,

6.1.7 Instrumentation requirements,

6.1.8 Chemical composition of soil and contained pore fluids,

6.1.9 Available funds,

6.1.10 Estimated cost,

6.1.11 Time constraints,

6.1.12 History of method performance under anticipated conditions (consult experienced users and manufacturers),

6.1.13 Site accessibility,

6.1.14 Decontamination requirements,

6.1.15 Grouting requirements, local regulations, and

6.1.16 Amount of and disposal costs for generated drill cuttings and drilling wastes.

7. Apparatus

7.1 *Sonic Head*—The sonic drill head contains a sine generator, sine generator drive mechanism, lubrication system to reduce friction and control heat in the head, vibration isolation device, drill string rotating mechanism, and a connection to the drill string. The sine generator must be capable of producing sufficient energy to force movement in the drill string to accomplish the fracturing, shearing or displacement necessary for the borehole to be advanced as shown in Fig. 1.

7.1.1 *Sine Generator*—The sine generator uses eccentric, counter rotating balance weights that are timed to direct 100 percent of the vibration at 0 degrees and at 180 degrees (Figs. 2 and 3). The sine generator is powered hydraulically and generally operates at frequencies between 0 and 185 hertz delivering a full range of energy outputs for advancement of up to 30.48 cm (12 in.) drill casing.

7.1.2 *Lubrication System*—The lubrication system is fitted with oil coolers of sufficient capacity to keep the hydraulic fluid at an allowable operating range as recommended by the oil supplier.

7.1.3 *Vibration Isolation System*—In order to transmit the maximum vibratory energy to the drill string and not damage the drilling rig the vibration applied to the drill tools must be isolated from the drill rig as shown in Figs. 2 and 3. This can be accomplished by using air charged springs, manual disk springs, or such other methods as will meet that goal.

7.2 *Drilling Tools*—A significant variety of tooling is necessary to accomplish the sonic drilling program. The tools consist of drill rods, drill casing, sampler barrels, sampler bits, casing bits, direct push sampling probes, borehole water sample collection systems, etc. Individual drillers and companies have in-house tooling designed for specific purposes and projects. If these specialized tools provide high quality sampling and efficient drilling processes they are acceptable to the practice.

7.2.1 *Drilling Rods and Casing*—Drilling rods are used to propel and recover the sampling barrels. Drill rods are the most handled tools. The common sizes are 5.08 cm (2.0 in.) to 10.16 cm (4.0 in.) O.D. × 60.98 cm (2.0 ft), 1.524 m (5.0 ft), 3.38 m (10.0 ft), and 6.096 m (20.0 ft) lengths. Annular space between casing and rod is not critical allowing the same sized drill rod to be used with various sized sampling barrels. Current sonic drilling technology can be used to set drill casing in various sizes from 1.27 cm (0.5 in.) up to 30.48 cm (12.0 in.) nominal depending on project requirements.

7.2.2 *Sampler Barrel*—Sampler barrels (a.k.a. core barrels) are used to recover formation specimens and to clean the inside of the drill casing. Sampler barrels are either solid tubes or split barrels of various diameters and lengths. The sampling barrels

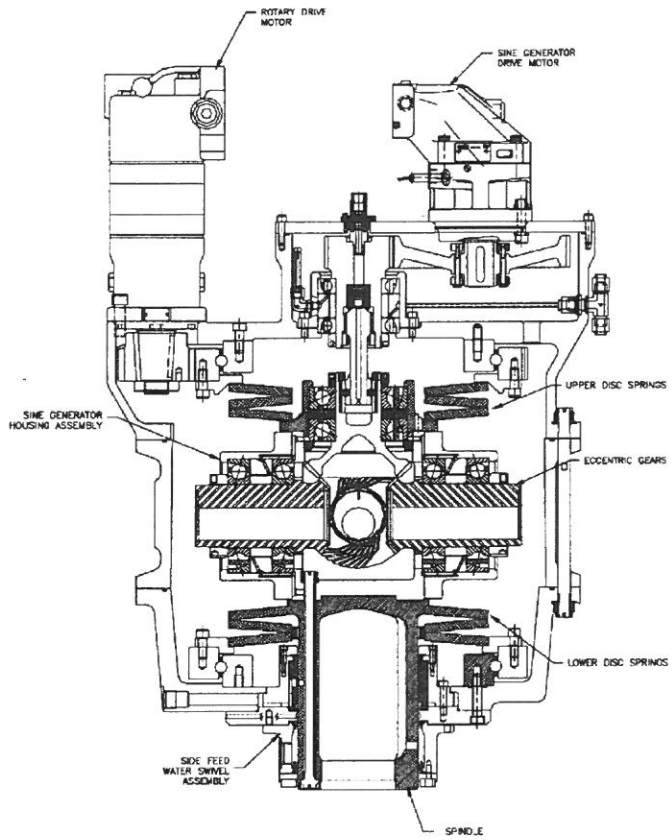


FIG. 2 Typical Sonic Drill Head with Disk Spring Form of Isolation System

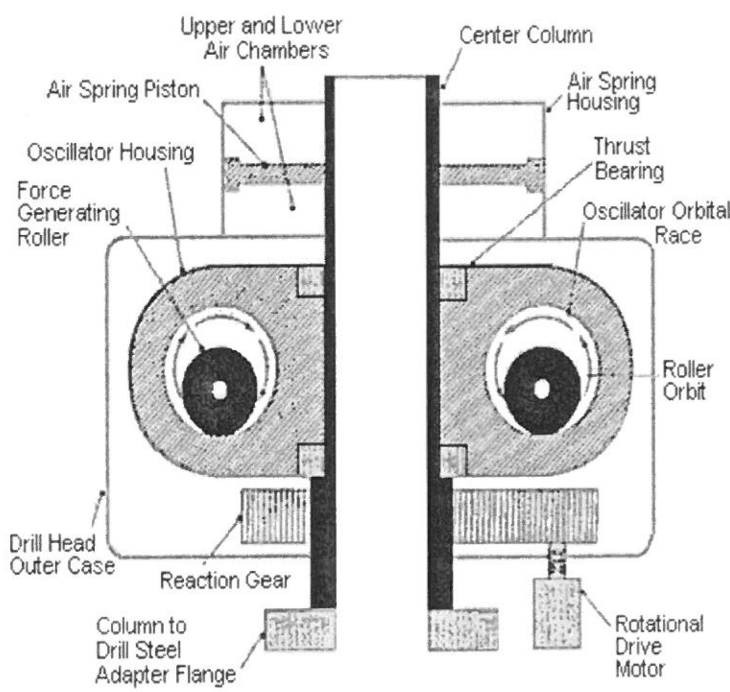


FIG. 3 Typical Sonic Drill Head with Air Spring Form of Isolation System

are generally sized to match the inside diameter of the various sizes of drill casing and to fulfill project requirements. The barrel is fitted with a drill bit/cutting shoe that holds the borehole alignment as it passes through the outer casing into the formation.

7.2.2.1 *Solid Barrels*—Solid sampler barrels are a solid length of tubing with thread sections on each end. They are available in various sizes and lengths. Typical sampling runs are 3.048 to 6.096 m (10.0 to 20.0 ft) in length. Sampling run length can be adjusted to provide the most optimum sample recovery. Sampler barrels can be joined to increase the length of sampling increment. In some formations there is a tendency to lose recovery with longer core run lengths while in others longer core runs may improve recovery. Samples of loose unconsolidated granular formations can be consolidated by the vibratory action. In loose or soft formations the inability of the soil structure to support the force necessary to move the material into the barrel can cause that material to be forced into the formation.

7.2.2.2 *Split Barrel Samplers*—Split barrel samplers are tubes that are split lengthwise with thread sections on both ends. The split sections utilize a tongue & groove feature that interlocks to prevent lateral movement between the two halves of the tube. Split barrel samplers are available in various diameters and lengths. While split barrel samplers provide a better format to view the specimen and may subject it to less disturbance, they do receive vibratory action during penetration. Depending on the method of construction, split barrels have a tendency to spread open in hard formations. They are quite heavy when fully loaded and may require special handling techniques. Liners, clear butyl or polyethylene based plastic, or stainless steel are available for use with split barrel and solid barrel samplers.

7.2.2.3 Standard formation sampling devices can be used in conjunction with the sonic drill rig for geotechnical applications. The standard penetration test D1586 can be performed if the unit is equipped with a cathead or an automatic-hammer 63.523 kg (140 lb). The hydraulically activated, D6519, as well as manual, fixed piston, thin wall tube samplers D1587 can be used if the unit is equipped with a fluid pump of sufficient capacity. Sonic drills are generally equipped with winch lines for using sampling tools in geotechnical drilling programs.

7.2.3 *Casing Drill Bits*—Drill bits are attached to the leading section of drill casing. Their function is to provide a cutting edge to assist in moving the casing through the various formations encountered and to direct the movement of formation materials during the making of the boring. The face of the drill bit follows one of three basic directional designs: (*1*) "Crowd-in" move most of the material encountered at the drill face into the borehole or casing as it is advanced. This style of bit face provides the best service in dense, dry, or cohesive formations as it helps reduce formation compaction and friction; (*2*) "Crowd-out" moves most of the material encountered at the drill face into the borehole wall. This design works better in softer and more granular, sands, gravels, and silt formations; and (*3*) "Neutral" allows the bit face material to choose the path of least resistance. Different bit face configurations are used to effectively penetrate different formations. The general-purpose bit face is fitted with carbide buttons spaced equally across and around the bit face. Fig. 4 shows a typical carbide button faced bit. The carbide buttoned bit works well in most formations and is considered a general-purpose bit. Carbide buttons are well suited for the impact action that occurs in sonic drilling. Other configurations include welded carbide chips and blocks in a matrix, saw tooth shapes both hard surfaced and plain, and tearing shoe designs with large irregular carbides for working in construction debris and penetrating refuse in landfills. Each of these designs has a useful purpose and can be quite effective at penetrating their respective formations.

7.2.4 *Sample Barrel Bit*—The sample barrel bit is designed to both penetrate the formation and to shape the sample so it will pass through the bit into the sample barrel with the least amount of friction or compression. The bit may be constructed with serrated, carbide buttoned, or some other form of roughened inside diameter surface, or with a machined space for a retainer basket to assist in the retention of the sample. The interior of the sampler bit should have a minimum inside diameter 3.175 mm (0.125 in.) less than the inside diameter of the sampling barrel to allow the passage of the sample into the core barrel with the least amount of resistance so as to not impede recovery or create unnecessary disturbance to the sample. The cutting face of the bit used should be the design best suited to the formation being penetrated. For dense formations with cobbles and boulders a bit face with carbide buttons may be used. For soft formations a serrated face, sharpened to force the cuttings away from the bit, works well. The choice of bit face type and sample retention method is governed by the characteristics of the formation and should be optimized as the borehole progresses to insure the highest recovery percentage with the least possible sample disturbance.

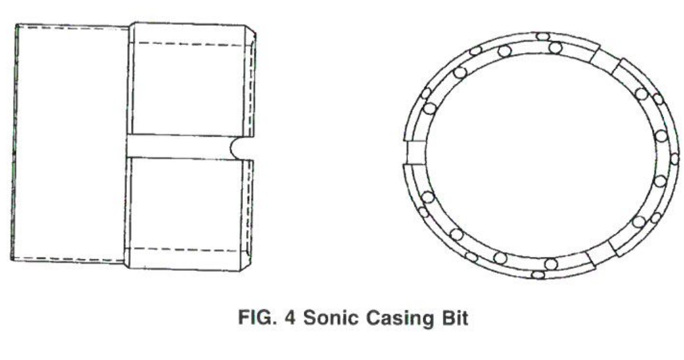


FIG. 4 Sonic Casing Bit

7.2.5 *Direct Push Sampling Tools*—Sonic drilling is a direct push drilling method as well. Therefore, soil sampling, soil vapor sampling, and water sampling tools similar to those used in the direct push industry are also available to the sonic drilling practice. *In-situ* water sampling tools are constructed using a screened inner stem attached to a point that is surrounded by an outer drive pipe. The point is the same diameter as the outer drive pipe to prevent the creation of an enlarged annular space that could provide an avenue for cross contamination between aquifers. The inner screen assembly is sealed from the formation during installation by an outer drive pipe fitted with "o" rings. With the friction of the soil holding the point in place while being driven to depth, the screen section is then exposed to the formation by pulling back on the outer drive pipe. The inner tube can have an inside diameter of 5.08 cm (2.0 in.) to 10.16 cm (4.0 in.) or larger to allow for larger capacity sampling pumps. Using higher capacity pumps accelerates the purging process and allows for rapid sampling from deep formations. The water sampling probes can be fitted with disposable points to allow for pressure grouting or installation of small diameter monitor wells.

7.3 *Sonic Drill Rig*—The sonic drill rig is similar to other drilling rigs in that it is a machine attached to a frame mounted on some form of carrier. The unit can be driven by a power take off assembly from the carrier engine or by an auxiliary engine. The unit has a feed frame for moving the drill head up and down to apply feed and retract pressure to the drill string and a mast for tool handling. Some units are equipped with automated tool handling devices. The sonic drill head is powered hydraulically. In addition to the sonic head, the feed system, drill fluid pumps, rod handling systems, and other auxiliary equipment demand power as well. Therefore, the power supply must be capable of providing the horsepower necessary to drive the system. The horsepower requirement is based on the desired productive capacity of the drill. The carrying vehicle must have sufficient gross vehicle weight to support the drill structure, rod handling equipment, fluid pumps, air compressors, and such tool storage as deck space allows.

7.3.1 *Drill Tower*—The drill rig may have a tower for extracting tools from the borehole. Tower lengths can vary, however, higher towers allow for longer tool pulls. The drill rig should have sufficient retraction power to lift a full-length string of the largest rated diameter drill tools from the deepest rated depth plus an additional 50 % or more of that total weight.

7.3.2 *Tool Handling*—Sonic drills traditionally use several different sizes of tooling. The units are generally equipped with some form of tool handling devices. Some units are equipped with a pivotal sonic head. This allows the head to tilt up 90 degrees to vertical so drill rod or casing can be aligned to the spindle for mechanical attachment. The length is then raised and rotated back to vertical for attachment to the drill string. Other units use mechanical rod loaders which position drill rods or casing for hook up. Wire rope winches can be used for drill rod tripping. Units using the winch method are generally fitted with a slide tray that can accommodate up to 6.096 m (20.0 ft) lengths of drill rod for reducing sample barrel retrieval time.

7.3.2.1 *Tool Joint Wrench and Rod Holder Table*—A key component of the sonic drill is the tool joint make-up, breakout, and rod holding table. The upper vice of the tool joint should be capable of bi-directional rotation to both close and open the tool joints. The throat of the joint wrench must be large enough to accommodate the largest rated O.D. tooling of the drill. The throat clearance may be accomplished by jaw retraction or by installing different sized jaws. The lower jaw assembly and its supporting members should be capable of supporting the total weight of the maximum O.D tooling at the maximum depth rating of the machine. The upper jaw may include some form of high-speed rod spinning device to expedite rod disconnection.

7.3.3 *Auxiliary Equipment*—Sonic drill units require a fluid pump or pumps depending on the anticipated work program. The pumps serve many purposes; to push drilling fluids down the bore hole for lubrication and bit face cuttings removal while advancing the outer casing over core barrels in certain formations, when rock drilling to assist in the removal of cuttings, for bit cooling and cuttings removal while diamond bit rock coring, for mixing of drill fluids and grouts, for grouting of instrumentation, to grout (backfill) bore holes, and for equipment cleaning. Drill fluid injection is generally more predominate when installing casing in saturated granular formations to maintain pressure equalization than when drilling more cohesive formations. The primary purpose of injecting fluids is to keep the inside of the drilling casing clean as it is advanced over the sampling barrel. Normally drill fluids are not recycled during sonic drilling so volume generated is generally small. As the sonic drilled borings can go to considerable depth it is recommended that the unit have a least one positive displacement type pump. If a second fluid pump is desired, it should be capable of supplying 1380 kN/m^2 (200 psi) for mixing and for cleaning. Progressive cavity, or peristaltic pumps, work well for this purpose. All fluid pumps should be equipped with pressure indicating gauges and pressure relief valves set at the necessary level to protect the pumps from damage and to prevent fracturing of the formation. Air compressors are sometimes used in conjunction with sonic drilling. They are utilized when operating down hole hammers or other air drilling methods to penetrate formations not conducive to penetration by sonic methods. Pressure requirements are governed by tool requirements, depth, and bore diameter, see Guide D3740. General tools needed to operate the sonic drill unit include rod lifting tools, pipe wrenches, fluid swivels, and handtools for general maintenance and repair. Other useful equipment would include portable or hydraulic powered arc welders, acetylene torches, steam cleaners, and portable generators. Portable fluid pumps and tanks are also useful for fluid containment and transfer.

7.4 *Expendable Supplies*—Expendable supplies are items such as monitor well materials, bentonite, cement, and their proper uses are described in referenced ASTM standards. They are not addressed in this practice.

8. Conditioning

8.1 *General*—Preparation of the sonic rotary drill unit for project work starts with a thorough check of the drill's operating system. This includes the inspection, testing, and repair of all emergency shutdown switches and other safety devices. The performance of regular routine maintenance procedures including fluid level checks, lubrication, hydraulic hose inspection, leakage repairs, and the inspection of the physical components with necessary repairs completed. A thorough cleaning of the drill unit is also recommended. Operating tools should be inspected, repaired if necessary, and inventoried, to insure that an adequate supply is on hand for the project. Drilling tools, casing, rods, bits, etc., should be checked for proper repair, and loaded in sufficient quantities to complete the project. It is recommended that additional tooling, beyond that required for the project, be taken to the site to reduce down time from breakage or damage, and to allow for increases in work effort that may occur because of site conditions.

NOTE 2—The items in Section 8 regarding inspection, cleaning, inventory, repair, storage, transportation, decontamination, equipment checks, and necessary supplies are primarily related to contractor efficiency. This is only a partial list of activities that are considered good drilling practice to prepare for drilling and are offered for consideration by users. It is recognized that strict conformance with these items is not imperative for sonic drilling and does not necessarily correlate to the quality of the work.

8.1.1 *Equipment Movement*—All tools, materials, and equipment needed for the project shall be loaded in a safe manner and secured in compliance with U.S. Department of Transportation, state, and local regulations. The drilling rig, support vehicles, and auxiliary equipment shall be brought to the project site fully fueled and ready for operation. Extra tooling, required instrumentation installation supplies, and other expendables should be stored in a central location in a safe and secure manner. The materials should be stored in a clean dry area in their original containers until transported to the decontamination area for cleaning if necessary or to the actual drill site for installation. All packaging debris, damaged or contaminated materials, and miscellaneous trash accumulate during drilling operations shall be containerized and disposed of properly.

8.2 *Decontamination*—If the drilling rig and tooling are to be used on a chemically contaminated site, site specific decontamination procedures must be followed. For general decontamination information refer to Practice D5088 for recommended procedures.

8.3 *Sampling Barrels*—The sampling barrels are in various lengths, generally 1.532 m (5.0 ft), 3.048 m (10 ft), or 6.096 m (20 ft). Barrels should be in equal increments to facilitate the accuracy of borehole depth measurements. Sampling barrels are either solid or split styles.

8.3.1 *Solid Sampling Barrels*—Check the barrel thread section for thread condition, dents, kinks, or excessive wear that could result in the loss of the barrel or the sampling shoe, or in improper assembly that will result in a reduction of energy transfer. The barrel body should be straight, without dents or wrench burrs that could cause injury. The inside of the barrel should be clean, free of any debris, rust build-up, or any obstructions.

8.3.2 *Split Sampling Barrels*—Check barrel thread section for thread condition, dents, kinks or excessive wear that could result in the loss of the barrel or sampling shoe, or in improper assembly that will result in a reduction of energy transfer. The barrel body sections should be straight, without dents, kinks, or wrench burrs that could cause injury. The split tongue and grooves must be clean and free from dents, kinks or burrs. The split barrels halves should fit together snugly without bowing or spreading. The inside of the barrel halves must be clean and free of any obstructions.

8.3.3 *Sampler Barrel Heads and Bits*—Sampler barrel heads should be checked for thread condition to insure proper assembly to facilitate energy transfer. Sampler barrel bits are constructed in different configurations for use in the various formations encountered. The proper bit should be selected for the anticipated formation to be encountered. The cutting face should be free of dents, without cracks, non-manufactured grooves, or indentations. The interior of the bit should be free of obstructions that would impede the movement of the sample in the barrel. Designs in the bit to aid in recovery are permitted. Bits designed for use with basket retainers should have clean undamaged shoulders for receiving basket retainers. Check to see that the required tolerance is present.

8.3.4 *Drilling Without Sampling*—When sonic drilling without sampling is desired the solid sampling barrel bit can be modified to incorporate a drive point. When the maximum boring depth is reached, the sampling barrel is over drilled with the casing to depth and the sampling barrel is removed before setting instrumentation. If a disposable drive point is used, the sampling barrel is withdrawn the length of the point and the point knocked out. Then borehole activities such as water sampling and setting monitor wells or other devices can be accomplished.

8.3.5 *Tool Selection*—Prior to dispatch to the project site, an inventory of the necessary tooling in the proper sizes, expendable items, and instrumentation supplies should be made. Drilling is an inexact science and as such planning should include provisions for possible contingencies that may arise based on the knowledge one can gather about the project and the geology of the site. Routinely used supplies such as drill casing and sample barrel bits, rod lifters, environmentally safe thread lubrication, sampler barrel couplers, and project specific materials should be available so work can proceed unimpeded. If using split barrels or thin wall tubes a sufficient number should be on hand so sample examination does not delay drilling. Expendable supplies such as sample retainer baskets, sample storage bags, or other containers, and other project specific materials should to be available in sufficient quantities so work can progress smoothly. Specialized sampling tools, necessary for project specific requirements, should be checked, cleaned and available in the required number. Refer to Guide D420 for additional information on soil sampling tool selection. Materials for proper sealing of boreholes should always be available at the site.

9. Procedure

9.1 *General Set Up*—A safety meeting and site/project information meeting is held. A complete set of job safety analyses procedures is reviewed; Utility clearance information is reviewed. The drill crew puts on the required personal protective safety gear. The drill foreman makes a general site reconnaissance and specifically reviews the borehole location before moving any equipment onto the site. All underground and overhead utilities locations are checked and all members of the drill crew receive knowledge of their whereabouts. Any overhead obstructions that may impede drill rig setup and operation are noted. The travel path to the boring location is evaluated for the safe movement of the equipment. Move the drill rig and service vehicles to the borehole location. Unload any auxiliary equipment or supplies from the drill that would interfere with the rig setup. Level the drill unit. The leveling jacks should have sufficiently sized ground contact pads to spread the load and prevent settling during drilling that can cause misalignment of the drill tools. Once the drill is level, raise and secure the mast. If drilling fluids are to be collected position a fluid containment vessel. Position the service vehicles as necessary for efficient tool handling and drilling support. Hook up any pumps, hoses, and position working tools as necessary.

9.1.1 *Drilling Methods*—Sonic drilling can be performed wet, using a drilling medium, or dry. The choice of method is determined by project requirements, formations to be penetrated, and the depth to be achieved. In sonic drilling, the sampling barrel is advanced dry except for those occasions when actual rock or concrete penetration is occurring and drill-cutting removal is necessary to prevent tool lockup. Bouldery formations and weathered bedrock can be drilled dry as long as they will allow the cuttings at the bit face to be forced into the formation without friction causing excessive heat or impeding penetration of the formation. Drilling progresses by fracturing, shearing, or displacement. Fracturing occurs when drilling through formations with cobbles, boulders, or rock formations. Shearing occurs when penetrating dense silt, clay, or soft shale. Displacement occurs in granular formations when the material is liquefied and moves away from the bit and casing, or up the casing or sampling barrel. In sonic drilling, as in other drilling practices, a combination of methods may be necessary to complete the project.

9.1.2 *Tool Preparation*—Attach the proper bit for the formation anticipated to the sampling barrel. Connect the sampling barrel to the drill head and tighten the drill bit and the sampling barrel to the drill head. Check the plumb of the casing in relation to the drill rig. The pre-torquing, or tightening of rod joints is essential to the transmission of energy through the rod string when using sonic technology. All drill rod and casing joints should be pre-torqued to the manufactures rated capacity and/or to a level equal to the maximum amount of force that the sonic head can impart. Failure to do so can result in a loss of energy as well as damage to the threaded joint and/or loss of tooling. It is generally necessary to rotate the drilling casing to provide for even bit wear, control borehole alignment, and to facilitate removal of the casing and samplers from the borehole on completion. Slow rotation speed is satisfactory as speed is not a controlling factor in advancing the tools. In certain formations rotation of the sampling barrel during core sampling may be necessary.

9.2 *Sample Barrel Insertion*—Advance the sample barrel into and through the topsoil, pavement, or other surface material. Withdraw the sampler from the borehole and remove initial penetration material. Reinsert the sampling barrel, apply down pressure, activate the sine generator, and began rotation if needed. Note bottom limit of penetration and adjust as needed by using various rod lengths to achieve desired sampling increment end point. It is desirable to end sample increments at the even meter (foot), or centimeter (one-half foot) increments for ease of bore hole measurements. Accurate measurements are critical to determine recovery, locate strata changes, and determine proper instrumentation location in the borehole.

9.2.1 *Sampling-Solid Barrel*—At the completion of the sampling run, stop down pressure, stop the sine generator and any rotation of the sampling barrel. If necessary disconnect from the sampling barrel and install casing over the sampling barrel. Extract the sampling barrel from the borehole using the drill head or such other method as will expedite the movement of the sampling barrel to the surface. At the surface, reattach the sampling barrel to the sine generator and position the sampling barrel to remove the sample. Remove the bit, protecting the bottom of sampling barrel to prevent any material from dropping out. Remove any material in the sampling bit and place it in the sample receiving bag in the correct orientation. Slide the sample bag over the sampling barrel the full remaining length of the bag so the sample does not fall. Allow the sample to flow into the bag by activating the sine generator as needed to vibrate the sample from the barrel. Keep the sample bag as close to the bottom of the sample barrel as possible while it fills to reduce sample dropping distance causing as little disturbance as possible. Samples are generally deposited in 61 m (2.0 ft) to 1.524 m (5.0 ft) length plastic bags for review, logging and analysis. Sample bag length should not exceed 1.524 m (5.0 ft) as the weight of the specimen collected becomes very difficult to handle without causing excessive disturbance. Change sample bags as needed until all sample is removed from the barrel. It is important that all material collected be contained for recovery measurements and for disposal. Accurate measurements of sample recovery are achievable with the solid barrel sampling method of sample collection if certain practices are followed. In some formations more precise measurements of recovery can be made using clear plastic sampler liners. Hydraulic extraction of the sample from the solid barrel sampler can also be utilized in some formations. The nature of sonic vibration and bit face displacement can cause some disturbance in granular and in other soils. This should be kept in mind when measuring recovery and examining core samples. Such measurements are best judged by experienced equipment operators and knowledgeable field logging personnel who are knowledgeable in recognizing the differences in disturbed verses non-disturbed formation materials. Clean the sampling barrel by flushing with clean water or decontaminating as necessary. If project needs require full decontamination remove the used sampling barrel to the decontamination area, attach a cleaned sampling barrel to the drill head, add the drill bit and tighten it, and reinsert the sample barrel into the borehole to the depth of the previously sampled increment. Repeat the sampling process. It may be advantageous to rotate the sampling barrel as is withdrawn from the borehole to aid in extraction. However, rotation during extraction should only be used when necessary to retrieve the sampling tools to avoid disturbing the sample or causing it to fall from the sampling barrel. In some formations it may be necessary to activate the sine generator to facilitate withdrawal of the sample barrel. Once the sample is collected however, any action applied could cause disturbance to the sample. All such actions should be avoided wherever possible.

9.2.2 *Sampling-Split Barrel*—The procedure for using split barrel samplers is the same as solid barrel samplers except that the split barrel design it is not able to accept heavy down pressure or high friction resistance rotation. The limits of the split barrel are easily exceeded and caution must be exercised when utilizing these tools. Split barrel samplers offer the potential for reducing sample disturbance as the sample is removed from the core barrel. Sample removal and cleaning follow the procedures in referenced ASTM standards. Measuring sample recovery may be more accurate with the split barrel as result of generally shorter run length and the ability to visibly observe the material being measured in the barrel before it is removed.

9.3 *Drilling with Casing*—It is generally necessary to stabilize the borehole with an outer casing to control caving or slough, to facilitate sample collection, to protect against aquifer cross contamination, to provide a controlled environment for well or instrumentation installation, and to insure proper bottom up grouting. Casing is either installed using drilling fluid or installed dry depending on the formation being penetrated. Casing is available in a variety of lengths and diameters common to the drilling industry to fit a range of project requirements. The casing is either advanced over the sampling barrel when using drilling fluid or after the sample barrel has been removed from the borehole when drilling dry. Proportional sizing of the sampling barrel to the casing is required to insure that the casing is properly cleaned.

9.3.1 *Drilling Casing Wet*—Various drilling fluids can be used to advance the casing ranging from clean potable water to specialized drilling fluids. The choice of fluid is dictated by the formation and the project requirements. There is generally no recirculation of the drilling fluid during sonic drilling. The drilling fluid serves several functions. It helps keep debris and drill cuttings from entering the casing; it provides a lubrication film between the outside of the casing and the formation materials; It removes drill cuttings from the face of the bit and from the borehole annulus; and the fluid helps to keep the sample barrel and the casing from becoming sand locked as the casing passes over the barrel. It is important that the annular space between the sampler barrel and the casing bit be kept to a minimum. This prevents material from moving into the annular space, reduces the amount of drilling fluid needed, and helps maintain borehole alignment. The drilling fluid is also used to maintain a pressure equalization head inside the casing to prevent any inflow of formation materials.

9.3.1.1 *Casing Insertion Wet*—The sampling barrel is advanced to the required depth increment as described previously. The drill head is disconnected from the sampling rod string. A plug is placed in the drill rod box to protect the threads and prevent any drill fluid from entering the sampling rod string. An equal length of drill casing is attached to the drill head and hoisted into position over the sampling rod string. As the casing is advanced using downpressure, rotation and vibration, drilling fluid is pumped into the casing string. The casing is advanced to the base of the sampling barrel shoe. Advancement is stopped. The drill head is disconnected from the casing and reconnected to the sampling barrel tool string. The sampling barrel is then removed and the sample extracted. The sampling barrel is cleaned and then reinserted, additional drill string added, and the sample barrel advanced to the next increment. Then the casing installation procedure is repeated. There is a slight amount of contact between the top of the sampling increment and the drilling fluid when the sample barrel is withdrawn. However, as no drilling fluid is recycled, the composition of the drilling fluid remains known and controlled. As soon as the sample specimen begins to enter the barrel the fluid in the barrel is pushed upward and the sides of the sample barrel are sweep clean by the friction of the passing soil.

9.3.1.2 *Bore Hole Slough or Cave-In*—As with all drilling methods there are times when special techniques are needed to maintain control of the bore hole. In certain formations, if the head pressure in the borehole is not equalized, the groundwater will carry formation materials in as it equalizes in the borehole. If project constraints do not allow the adding of compensating fluids other techniques must be employed. To provide room for the deposited material a second sampling barrel can be added on top of the first. As the materials are essentially liquefied along the barrel surface there is relatively little influence exerted on the lower portions of the sample from the upper portions. However, to insure sample quality and integrity every effort should be made to eliminate as much cave-in as possible.

9.3.1.3 *Drilling Casing Dry*—When installing casing dry, advance the sampling barrel through the scheduled interval. Remove the sample barrel and process the sample. Connect the drill head to the casing and advance the casing to the bottom of the previously sampled increment. Disconnect from the casing. Insert the sample barrel and vibrate through the borehole material in the casing to the top of the next scheduled sampling increment. Remove the sampling barrel and clean it in accordance with project requirements. Reinsert the sampling barrel and advance it to the end of the next sampling increment. Then repeat the procedure. In certain formations a double length sample barrel can be utilized to both remove the borehole material and to continuously sample the next increment in one tool trip. Whenever slough is encountered in the borehole it should be measured and properly noted on the boring log. Determining the need for cleanout runs with the core barrel is primarily a driller skill.

9.4 *Bore Hole Testing*—The sonic drilling method lends itself well to many forms of borehole testing in most formations primarily because of the clean cased hole provided and from the versatility of the machine. Actual procedures for water and aquifer testing, or other formation properties investigation procedures are given in referenced ASTM standard and will not be individually addresses here. The very high level of energy that can be imparted to the drill bit by the sonic drill gives it the ability to advance casing and core barrels into very dense formations. In these dense formations, when drilling dry, the borehole wall may be affected by the forcing of soil particles into it. Should this condition be of concern it can be alleviated by using potable water injection while advancing the casing, by using a crowd in style bit that directs materials sheared from the borehole wall into the casing, by borehole wall scraping with the casing bit, or by injecting natural clay breakdown compounds.

9.4.1 Pump testing to determine aquifer characteristics, Test Method D4050, is easily accomplished because of the clean hole and the minimal disturbance that is caused to the formation. This results in a rapidly clearing formation that reaches its maximum production rate quickly. Minimum turbidity with rapid production results in less development water for disposal and expedited test results. This is especially significant when setting smaller diameter wells, which can only accommodate low volume pumps. Slug tests, Test Method D4044, can also readily be preformed because of the clean borehole wall.

9.4.2 *Well Installation*—Wells, Practice D5092, of various sizes can be set using the sonic method. Advantages are that in many formations the casing in the screened zone can be set without fluid to keep the formation clean and to reduce development and/or pumping time. The vibratory effect can be used to good advantage to settle filterpack material around the screen and eliminate bridging of backfill materials as the casing is removed.

9.4.3 *Other Instrumentation*—Any type of instrumentation that can be set with any other drilling method can be set with sonic drilling. *In-situ* borehole tests such as pressure meters D4719, vane shear devices D2573, permeability testing using packers D4630, etc., can be used with the sonic method as long as the borehole wall is prepared in accordance with the proper ASTM standard. When utilizing these types of testing methods it may be necessary to advance the casing into the borehole using water injection and a crowd in bit to minimize sonic drilling's effect on soil pore pressure.

9.5 *Incorporating Other Drilling Practices*—The sonic drill rig easily accommodates other drilling methods should they be needed to satisfactorily complete projects. Rock coring adaptations can be incorporated to do diamond bit coring either wireline or conventional. Sonic drills generally have low rotary rpm ratings. Adequate speeds for rock coring can be acquired through a gear driven speed multiplier, a high-speed coring head, 2-speed rotation motors, or if available, adjustment to the rotational output of the sonic drill head. Downhole hammers can be readily adapted to the sonic drill with the incorporation of a compressed air source. The low rpm rating works very well with downhole hammer. As the sonic drill offers all basic drill functions air or fluid rotary techniques can be easily adapted as well. Standard soil sampling techniques can be utilized with the sonic drill. Split barrel sampling with standard penetration tests, thin walled tubes, and the like can be easily incorporated.

10. Completion and Sealing

10.1 Information on the sealing of boreholes can be found in Guide D5299, and in Guides D5791, D5782, D5783, and D5784. State or local regulations may control both the method and the materials for borehole sealing.

11. Record Keeping

11.1 *Field Report*—The field report may consist of boring log or a report of the sampling event and a description of the sample. Soil samples can be classified in accordance with Practice D2488 or other methods as required for the investigation. Prepare the log in accordance with Guide D5434, which lists the parameters required for the field investigation program. List all information related to drilling and the sampling event, including depth, fluid injection, drilling parameters, sampling Intervals, recovery, strength index readings such as pocket pentrometer, classification of soil, and any comments on sampler or casing advancement. If a computer collects drill performance data, add identifying marks to log so correct information can be downloaded and incorporated into the final log as necessary.

12. Keywords

12.1 drilling; resonance; soil and rock sampling; sonic; subsurface exploration

Appendix C

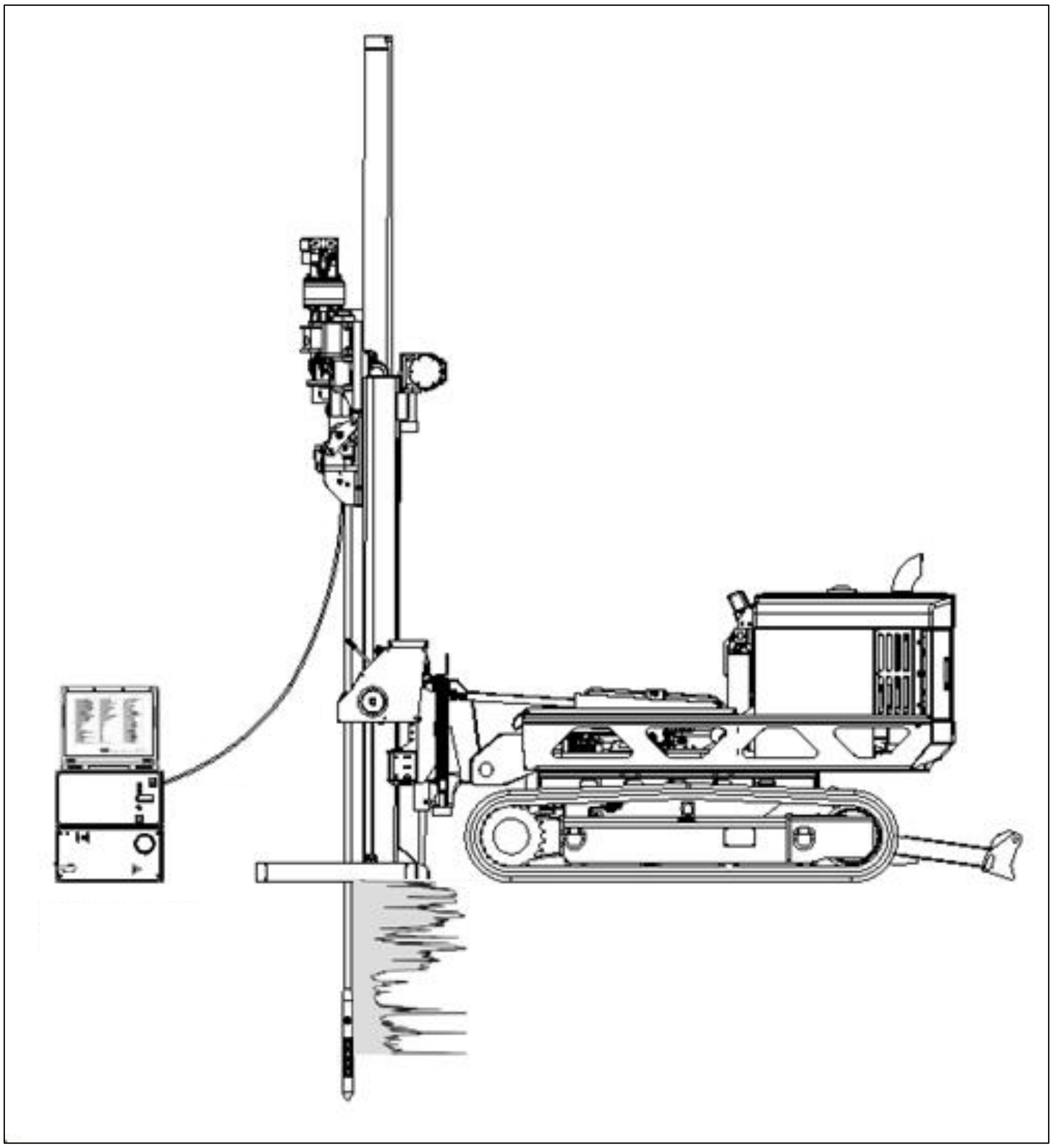
Manufacturer's Information

Geoprobe® Hydraulic Profiling Tool (HPT) System

Standard Operating Procedure

Technical Bulletin No. MK3137

Prepared February 6, 2013



1.0 Objective

This document serves as the standard operating procedure for the Geoprobe® Hydraulic Profiling Tool (HPT) system. In this procedure, the HPT system is used to measure the pressure response of soil to injected water for identifying potential flow paths and to assist with characterization of soil type. This document has been updated from Geoprobe Systems® Technical Bulletin No. MK3137 (March 2007) to show the use of an FI6000 field instrument for HPT system control and data acquisition.

2.0 Background

2.1 Definitions

Geoprobe®*: A brand of high quality, hydraulically-powered machines that utilize both static force and percussion to advance sampling and logging tools into the subsurface. The Geoprobe® brand name refers to both machines and tools manufactured by Geoprobe Systems®, Salina, Kansas. Geoprobe® tools are used to perform soil core and soil gas sampling, groundwater sampling and testing, electrical conductivity and contaminant logging, grouting, and materials injection.

**Geoprobe® and Geoprobe Systems® are registered trademarks of Kejr, Inc., Salina, Kansas.*

Hydraulic Profiling Tool (HPT) System: A system manufactured by Geoprobe Systems® to evaluate the hydraulic behavior of subsurface soil. The tool is advanced through the subsurface at a constant rate while water is injected through a screen on the side of the probe. An in-line pressure sensor measures the pressure response of the soil to water injection. The pressure response identifies the relative ability of a soil to transmit water. Both pressure and flow rate are logged versus depth.

2.2 Introduction

The HPT system has been developed by Geoprobe Systems® for the geohydrologic characterization of soils. The HPT probe and logging system is able to quickly provide logs that are easily interpreted. HPT logs are used to indicate hydraulic conductivity, EC, hydrostatic profile, and areas of EC/permeability anomalies.

The HPT system is designed to evaluate the hydraulic behavior of unconsolidated materials. As the probe is pushed or hammered at 2 cm/s, clean water is pumped through a screen on the side of the HPT probe at a low flow rate, usually less than 300 mL/min. Injection pressure, which is monitored and plotted with depth, is an indication of the hydraulic properties of the soil. That is, a low pressure response would indicate a relatively large grain size, and the ability to easily transmit water. Conversely, a high HPT pressure response would indicate a relatively small grain size and the lack of ability to transmit water.

An electrical conductivity measurement array is built into the HPT probe. This allows the user to collect soil electrical conductivity (EC) data for lithologic interpretation. In general, the higher the electrical conductivity value, the smaller the grain size, and vice versa. However, other factors can affect EC, such as mineralogy and pore water chemistry (brines, extreme pH, contaminants). In contrast, HPT pressure response is independent of these chemical and mineralogical factors.

There are four primary components of the HPT system: the probe assembly, trunkline, HPT Flow Module (K6300 Series), and Field Instrument (FI6000 series). These primary components are shown in Figure 2.1.

The probe assembly consists of the HPT probe and connection section. This assembly houses the downhole HPT pressure transducer, water and electrical connections, and the probe body with the injection screen and electrical conductivity array.

Injecting water at a constant rate is integral to system operation. The HPT Flow Module houses the pump and associated hand crank mechanism used for adjusting the output flow of the HPT pump. The flow module also contains the HPT flow measurement and injection line pressure transducers. HPT flow can be adjusted from approximately 50 to 500 ml/min. The HPT pump is a positive displacement pumping device with minimal decrease in flow over the HPT operating pressure range. The flow module is equipped with an internal bypass that is factory set to open and return flow to the supply reservoir at a pressure of 120 psi.   When the soil resistance to water injection becomes sufficiently great, the HPT Flow Module bypass will open, returning some or all of the pumped flow to the supply reservoir. The flow meter only measures flow leaving the module to the HPT probe. The HPT Flow Module is connected to the Field Instrument via a data cable.

Water and power are transmitted from the controller to the probe assembly via the HPT trunkline. The probe rods must be pre-strung with the trunkline before advancing the probe.

Data collection occurs in real time by connecting the controller to the field instrument. The field instrument collects, stores and displays transducer pressure, flow rate and electrical conductivity, line pressure, probe rate, and diagnostic parameters, with depth.

Since the HPT pressure response is analogous to the soil's ability to transmit water (and therefore the to the soil's dominant grain size), the HPT system can be used to identify potential contaminant migration pathways. Similarly, it can help identify zones for remedial material injection or provide qualitative guidance on how difficult injection may be in different zones of the formation.

The HPT system may be used to direct other investigation methods, such as soil and groundwater sampling and slug testing. HPT pressure response and EC data can help target zones of geologic and hydraulic interest, minimizing the number of soil and groundwater samples required to adequately develop a site conceptual model. When hydraulic conductivity values are required, the HPT system can also help the user identify zones to slug test, as well as the length of the screen required to adequately test the zone.

The HPT system also can be used to collect static water pressure data at discrete intervals during the logging process. These static pressure data can be used to calculate static water levels or to create a hydrostatic profile for the log.

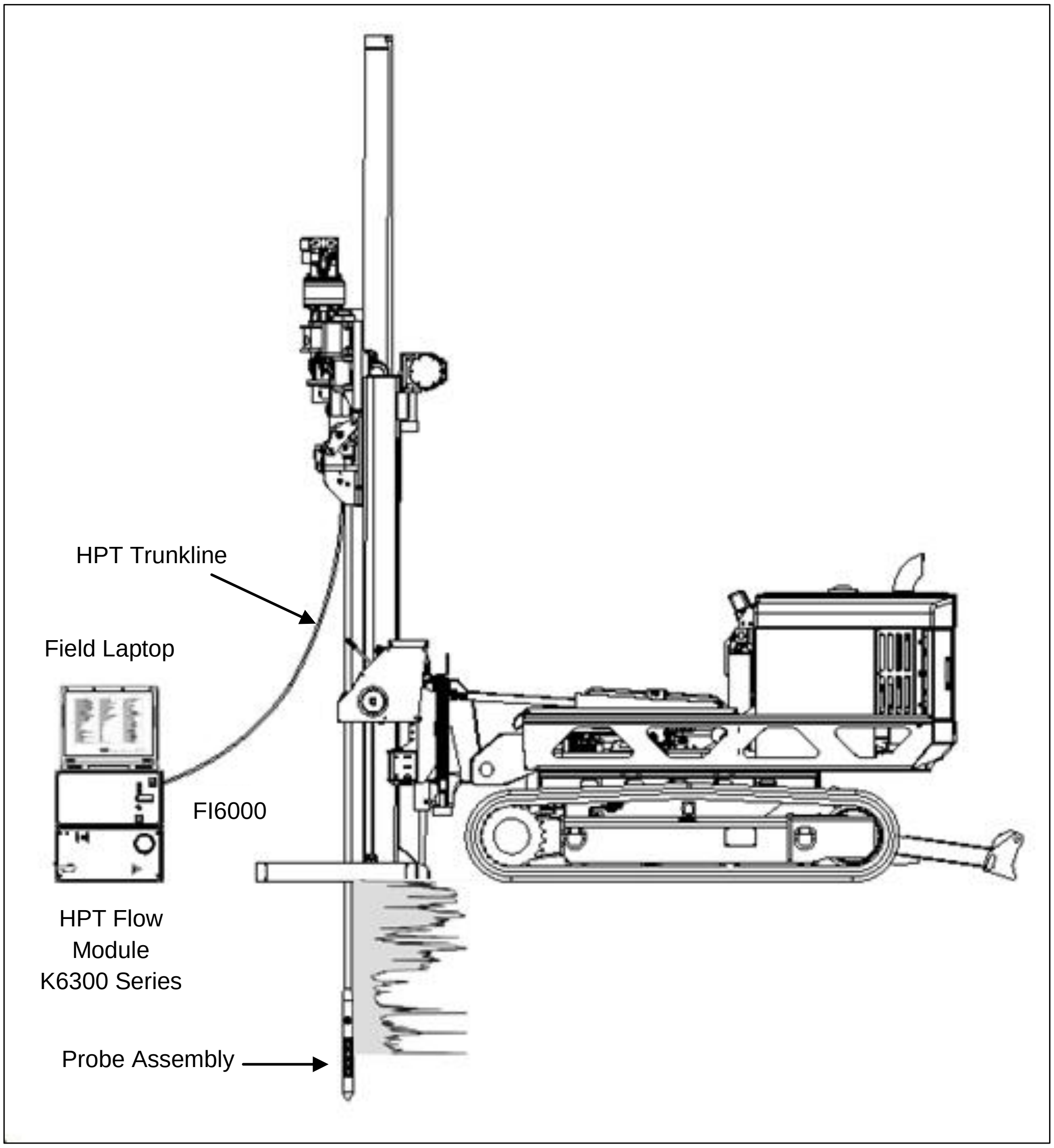


Figure 2.1: HPT Components

3.0 Tools and Equipment

The following equipment is required to perform and record an HPT log using a Geoprobe® 66- or 78-Series Direct Push Machine. Refer to Figures 3.1, 3.2, and 3.3 for identification of the specified parts.

Basic HPT System Components	Quantity	Part Number
Field Instrument, 120V	-1-	FI6000
Field Instrument, 220V	*	FI6003
HPT Acquisition Software	-1-	K6020
HPT Flow Module, 120V	-1-	K6300
HPT Flow Module, 220V	*	K6303
HPT Probe, 1.75 inch	-1-	K6050
MIP/HPT Connection Tube	-1-	31641
MIP/HPT Adapter 1.5 Pin x LB Box	-1-	20712
HPT Probe, 2.25 inch	**	K8050
2.25 Probe Rod, 24 inch	**	32656
2.25 Inch Water Seal Adapter	**	45170
2.25 Inch Water Seal Drive Head	**	48866
HPT Reference Tube 1.75 in HPT Probe	-1-	50344
HPT Reference Tube 2.25 in HPT Probe	**	50344
HPT Trunkline 150 ft.	-1-	K6415
HPT Trunkline 200 ft.	(optional)	K6420
HPT Service Kit *(contains the following)*	-1-	29028
O-Ring Pick	*-1-*	*AT102*
Term Block 4 POS Green	*-4-*	*7700*
Electrical Tape, 0.75-in. x 60-ft.	*-1-*	*6167*
Membrane Ratchet Wrench Asm	*-1-*	*48877*
Coupling 1/8 to 1/8 Tube	*-5-*	*48842*
Oetiker #7 Band Clamp 5.8 x 7mm	*-10-*	*48724*
HPT Sensor Module	*-2-*	*43327*
Silicone Dielectric Compound	*-1-*	*41274*
Butt Connector Red (10 pak)	*-2-*	*39807*
HPT Trunkline Seal Asm.	*-4-*	*37031*
Trunkline Seal Spacer (1 pair)	*-2-*	*36378*
O-Ring 120 BUNA 70	*-10-*	*3537*
HPT Screen Asm	*-4-*	*28895*
HPT Spring Washer (pkg 10)	*-1-*	*52399*
Tube Nylon 0.25 OD x 0.04 W Flexible	*-1-*	*20727*
Tubing 0.125 ID x 0.25 OD Polyur Yellow	*-1-*	*17957*
EC Probe Test Jig	-1-	SC563
EC Test Load	-1-	37785
Stringpot, 100-inch	-1-	SC160-100
Stringpot Cordset, 65-feet (19.8 m)	-1-	16401

*Use in place of 120V components if desired.

**Use in place of 1.75 inch probe and components if desired.

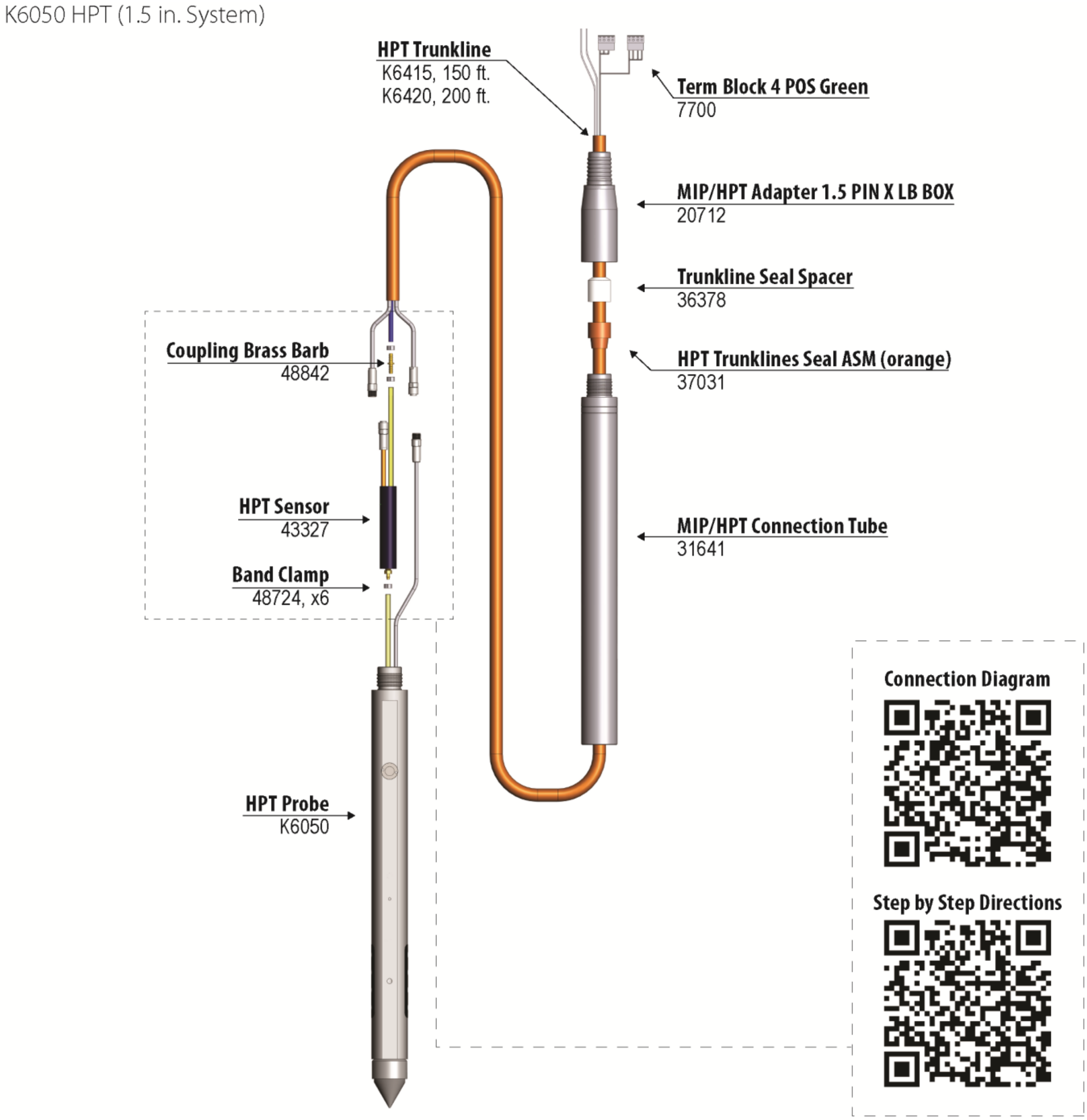


Figure 3.1 PN K6050 1.75 inch HPT Probe and components

http://geoprobe.com/tool-string-diagrams/k6050-hpt

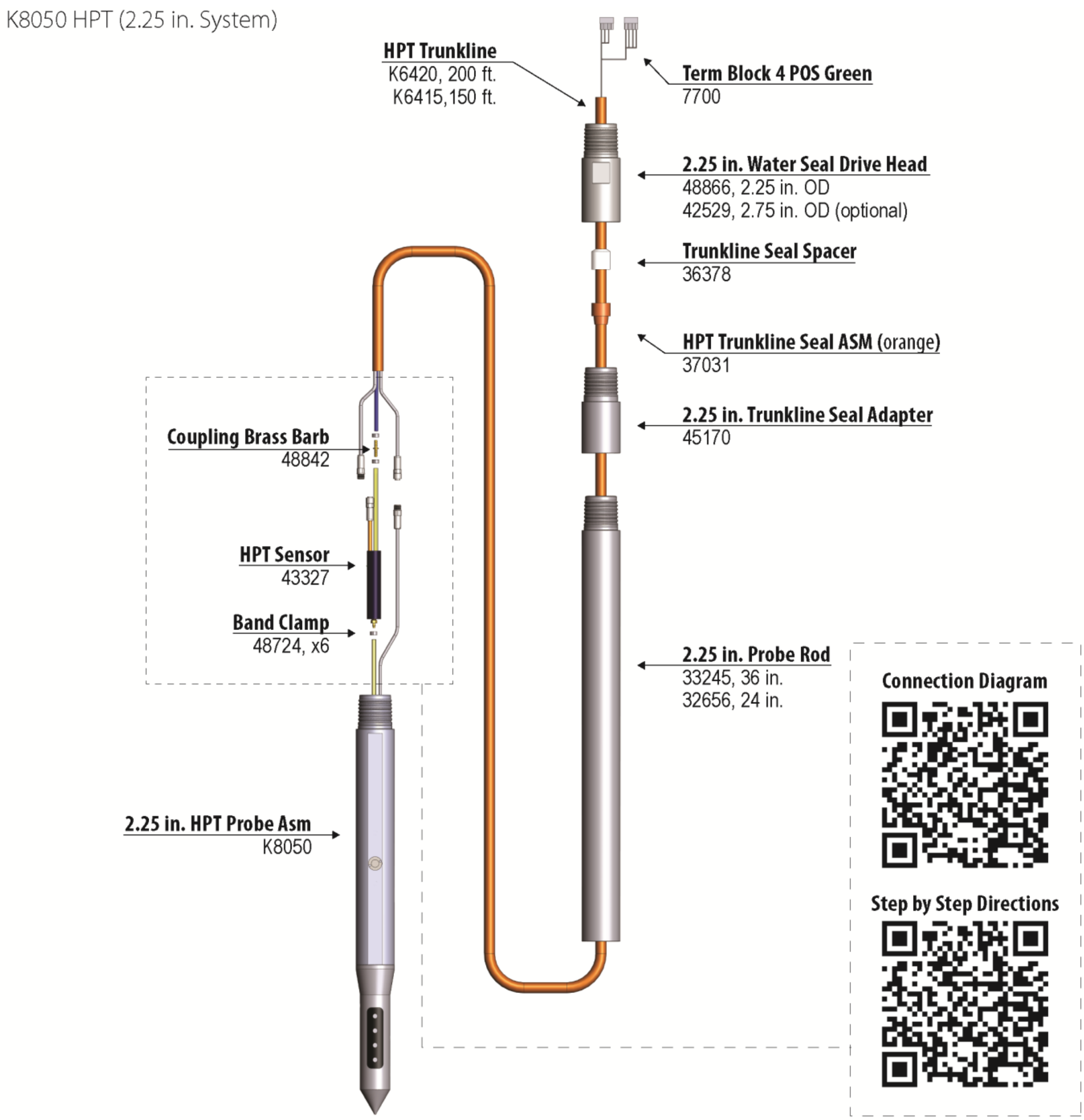


Figure 3.2 PN-K8050 2.25 inch HPT Probe and components

http://geoprobe.com/tool-string-diagrams/k8050-hpt

HPT Sensor Connection Diagram

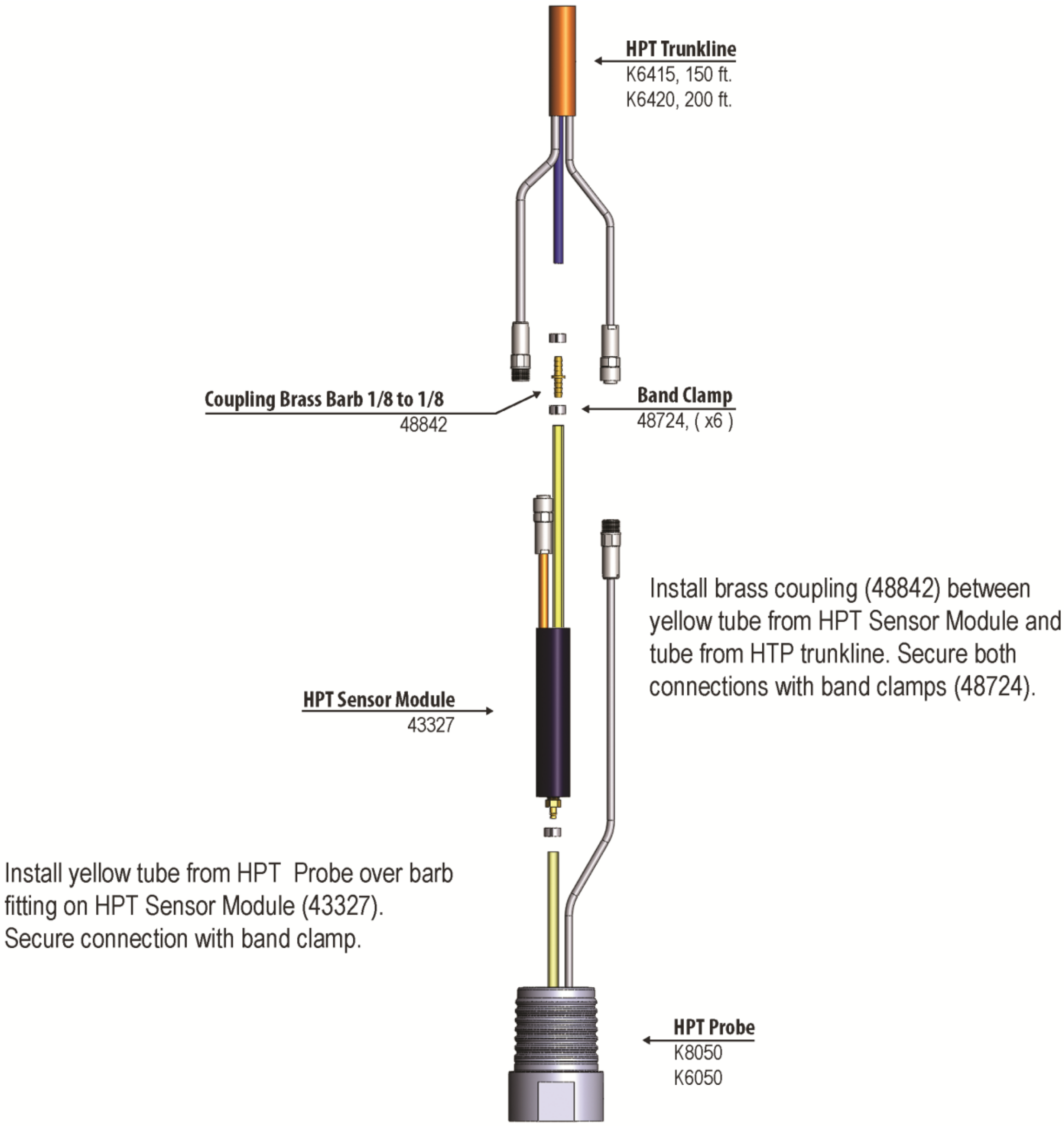


Figure 3.3 PN 43327 HPT Sensor Module Connection Diagram

http://geoprobe.com/tool-string-diagrams/hpt-sensor-connection-diagram

4.0 HPT Assembly

Refer to Appendix A

Threading the Rods

- Protect the end to be threaded through the rods with electrical tape or shrink tubing.
- Probe rods must alternate directions prior to threading the trunkline.
- The end of the HPT trunkline with chrome connectors is the downhole or probe end.
- The probe end of the trunkline will always enter the male end and exit the female end of the probe rods.
- The instrument end (no chrome connectors) will always enter the female end and exit the male end of the probe rods.
- After the trunkline is through the probe rods make sure the downhole end is threaded through the male end of the drive head and connection tube prior to connecting to the probe.
- The trunkline is now ready to connect to the instrument and HPT pressure sensor and probe.

5.0 Field Operation

5.1 Instrument Setup

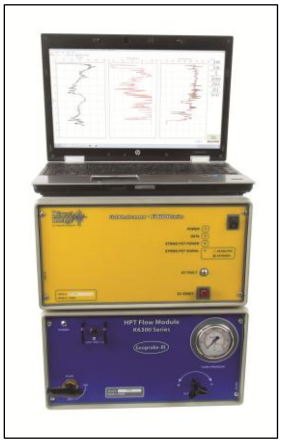


Figure 5.1: HPT Instrument Setup

1. Connect the HPT Controller (K6300), Field Instrument (FI6000) and laptop (Fig. 5.1) to an appropriate power source.

2. Connect the FI6000 to the K6300 using the 62-pin serial cable inserted into the acquisition port of each instrument.

3. Secure the EC wires into the Green terminal block connector and insert into the FI6000. The wires match to the EC dipoles in the following top down order when the probe tip is on the ground – white, black, yellow and blue (Fig 5.2).

Figure 5.2: EC Wire Connections

4. Secure the HPT sensor wires to the appropriate inputs on the green terminal block connector and connect to the rear of the K6300. The top down order of the wires which is listed on the back of the instrument is: brown, orange, red and reserved (open).

5. Insert the nylon water line tubing from the trunkline into the water output connector on the back of the K6300.

6. Connect the HPT water supply hose into the input port on the rear of the K6300 and insert the filtered end of the supply line into a water supply tank. The bypass line connects to the bypass port and will follow the supply line back to the supply tank.

7. Connect the USB cable between the USB interface port on the rear of the FI6000 to USB input on the field laptop computer.

8. A stringpot is required to measure depth. Bolt the stringpot onto the machine and the stringpot onto the bracket. Connect the plastic connector end of the stringpot cable to the “Stringpot” connector on the back of the Field Instrument and the metal connector to the stringpot. Pull the stringpot cable and attach to the stringpot piston weight which should be mounted to the probe machine foot and pull the keeper pin so the weight is free to move.

5.2 Starting the Software

1. Make sure the FI6000 and K6300 are connected together with the 62 pin cable, powered on and connected to the computer by the USB cable for the software to load properly.

2. Start the DI Acquisition Software which should open in HPT mode.

3. Select “Start New Log”. The software will request log information and have you browse for a storage location and create and save a file name for the log (Fig. 5.3).

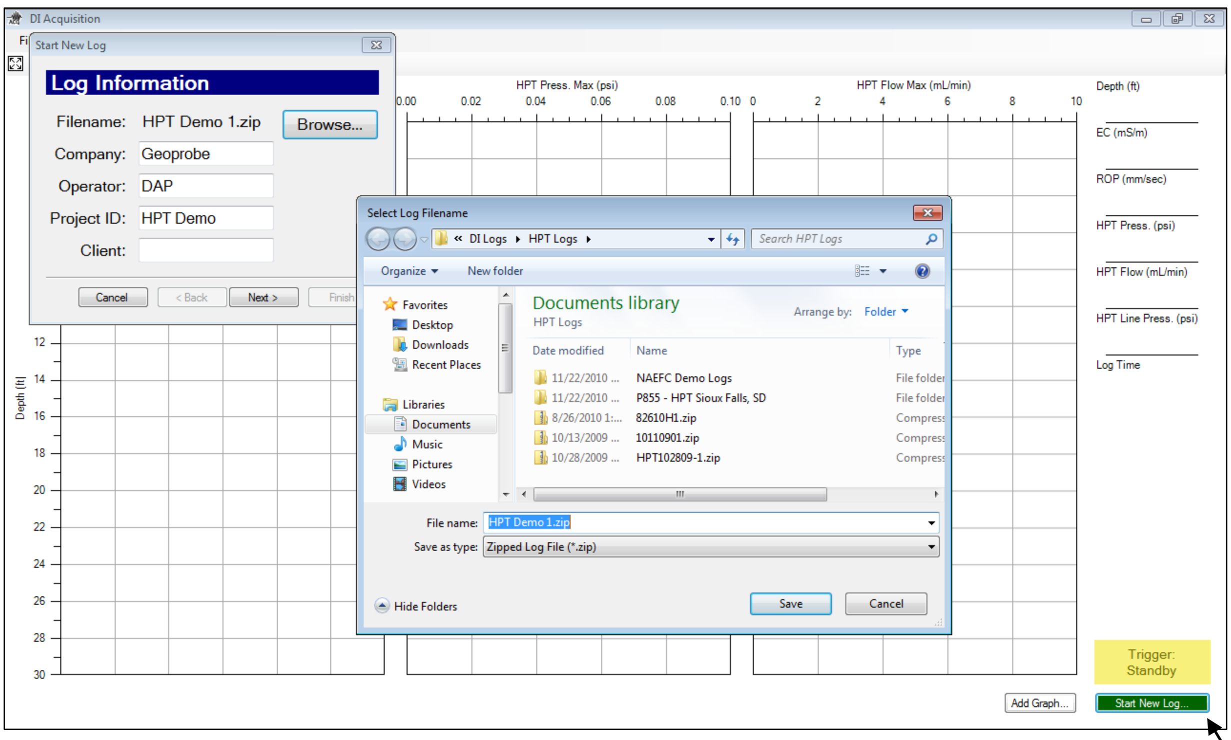


Figure 5.3: DI Acquisition Software – Start New Log Sequence

4. Select “Next”. If the software has been run before it will show a list of previous settings including Probe Type, EC Configuration, Stringpot length, rod length and HPT Transducer. If any of these have changed or you are unsure select “No” but if they are all the same select “yes”. If you select “No” the software will have you select the proper settings after the EC Load Test, if you selected “Yes” the selection of these settings will be bypassed.

5.3 QA Testing the EC and HPT Systems

Both the EC and HPT components must be tested before and after each log. This is required to ensure that the equipment is working properly and capable of generating good data before and after the log.

A. Electrical Conductivity Load Test

1. Secure the EC 3 position test load connector (37785) to the test input jack on the back of the Field Instrument.

2. Secure the EC Probe Test Jig into the input on the EC 3 position test load.

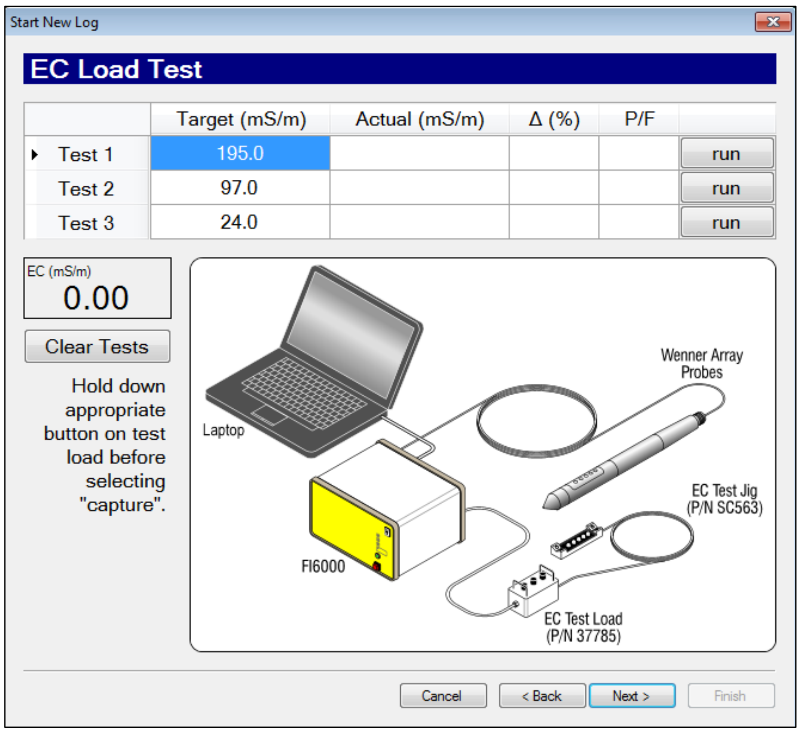


Figure 5.4: EC Load Test Screen

3. Clean and dry the EC dipoles as well as several inches of the probe body above the pins.

4. Place the EC Test Jig (SC563) so that the four springs on the test jig touch the four dipoles of the Wenner EC array (Fig. 5.4). Make sure the trunkline and test jig wires go in the same direction. The other spring on the test jig will ground the probe body above the Wenner array. Make sure the springs are pulled out far enough to make a solid contact on the dipoles.

5. When you get to the EC Load Test Screen and the EC test load and test jig are in place on the probe press down on the test 1 button on the test load and select “run” of Test 1 (Fig. 5.4). After 5 seconds the actual value will acquire and will pass if within 10% of the target value. Continue on with Test 2 and 3.

6. If any of the EC load tests fail do not pass within the allowed 10% acceptance range you can make adjustments on the test jig and rerun the test by just re-clicking the “run” button for an individual test.

7. If the tests continue to fail, select “Next” and the software will conduct the “EC Troubleshooting Tests.” The Instrument Calibration Tests (Fig. 5.5) checks of the calibration within the FI6000. If these are far out of range it will influence the EC Test load values and will need to return to Geoprobe® for repair. The “Probe Continuity and Isolation Tests” confirm each of the wires is a complete circuit and is fully isolated from one another. If a probe continuity test fails just outside the target range of <8ohms this is typically a contact issue with the test jig and the dipoles. If the continuity is in the thousands of ohms this is a break in the EC wire circuit – either in the probe, the trunkline or the connection between them.

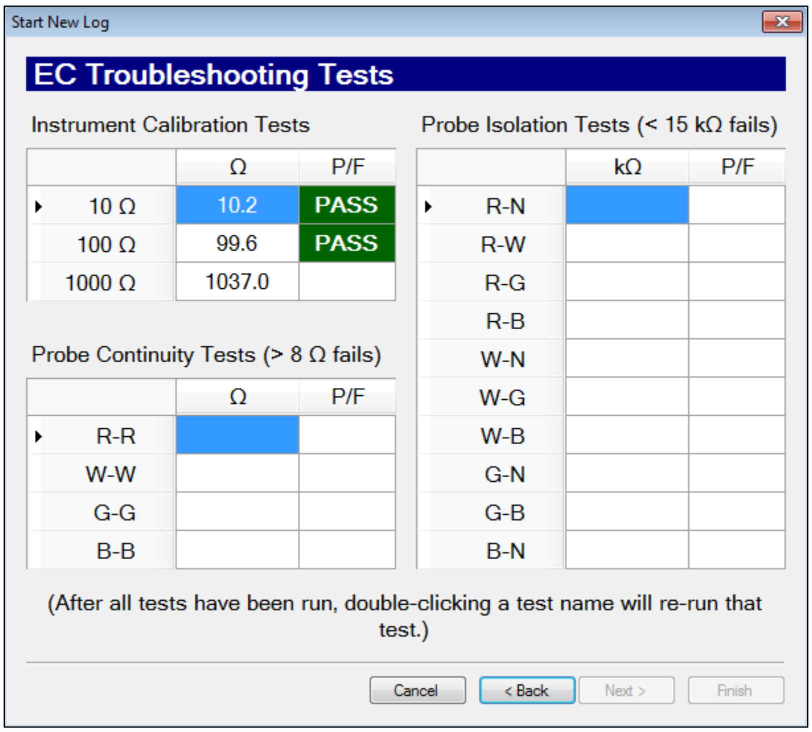


Figure 5.5: EC Troubleshooting Test Screen

8. When these tests are complete select next. In the next screen, the software will provide an EC option, if one is available. The EC Load Test will only work if EC can be operated in Wenner array meaning all of the EC wires in the continuity test pass with results <8ohms on the individual circuits. EC can be operated and collect good data in one odf the dipole areas: top, middle or bottom dipole. If the R-R test fails but the others pass the software will provide the option in the next screen to run either middle dipole or bottom dipole arrays. If R-R and G-G are both an incomplete circuit then no EC array is available to run and a new probe must be connected or the problem fixed. In the Wenner configuration it requires 2 adjacent dipoles to operate in dipole mode. If an EC array is chosen and run in this last manner then all of the EC information collected will be bad data.

B. HPT Reference Testing

Reference testing is done to ensure that the HPT pressure sensor is in working order and to evaluate the condition of the HPT injection screen. The HPT reference test calculates atmospheric pressure which is required to obtain static water level readings and to determine the estimated K values for the log in our post log processing software the DI Viewer.

Reference Test Procedure

1. Connect a clean water source to the HPT controller and turn on the pump.

2. Allow water to flow through the system long enough so that no air remains in the trunkline or probe (air in the system can cause inaccurate flow and pressure measurements).

3. Insert the probe into the HPT reference tube and allow the water to flow out the valve adjusting the flow rate to between 250-300ml/min (Fig. 5.5). Ensure that the reference tube is close to vertical.

4. With a stable pressure reading and the water flowing out of the valve select "capture" - bottom with flow (Fig. 5.6)

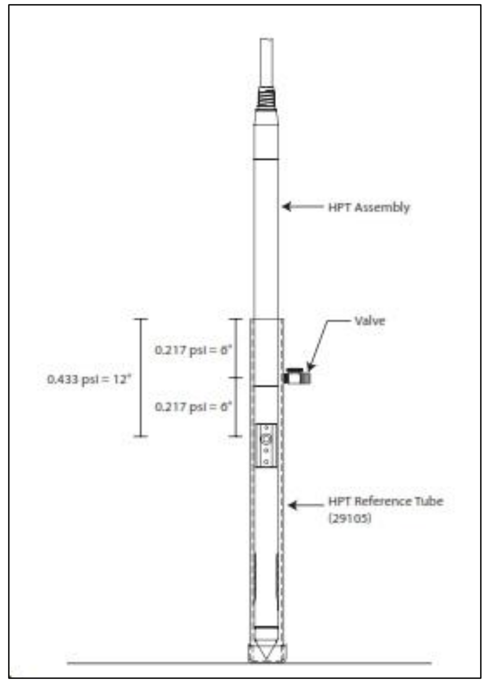


Figure 5.5: HPT Reference Test Setup

5. Close the valve and allow the water to overflow the top of the tube. When the pressure stabilizes select "capture" - top with flow.

6. Shut off the water flow. When the pressure stabilizes select "capture" - top flow = 0.

7. Open the valve and allow the water to drain out. When the pressure stabilizes select "capture" - bottom flow = 0.

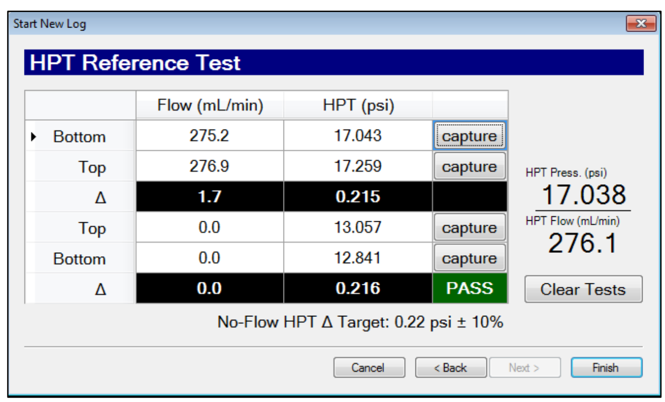


Figure 5.6: HPT Reference Test Screen

The HPT reference test reading flow = 0 is the true test of the condition of the pressure sensor and is the only sensor test to have a pass/fail reading on it. Ideally, the pressure difference between the top and bottom values will be 0.22 psi (1.52kPa). Typical pressure readings of the sensor will be in the 12PSI-15PSI (83kPa-104kPa) range.

5.4 Running an HPT Log

1. Place the rod wiper on the ground over the probing location and install the drive cushion in place of the anvil of the probing machine.

2. Place the probe tip in the center of the rod wiper, and place the slotted drive cap on top of the HPT probe.

3. Start the HPT water flow. **Note**: It is important that there is always water flowing when the probe is advanced to avoid soil particles from moving through the screen and causing problems with the pressure readings or causing a blockage behind the screen.

4. Adjust the probe so that it is vertical and advance the probe until the HPT screen is at the ground surface.

5. Click the trigger button in the lower right hand corner of computer screen. (The Trigger label will flash and the background will change from yellow to green).

9. Advance the probe at a rate of 2 cm/s. If necessary, feather the hammer to maintain this advance rate.

10. Perform a dissipation test (Section 5.4) in a zone of higher permeability indicated by lower HPT pressure.

11. After completing the log, press the trigger button again and select “Stop Log”.

12. Pull the rod string using either the rod grip pull system or a slotted pull cap. Run a post-log EC test and HPT response test (Section 5.2).

5.5 Performing a Dissipation Test

At least one dissipation test must be performed in order to calculate the static water level and estimated K readings from the log. Dissipation tests need to be performed below the water table and are best in zones of high permeability where the injection pressure can dissipate off quickly once the flow is shut off.

1. Stop in a zone of higher permeability which is indicated by lower HPT inject pressure.

2. Switch the DI Acquisition display view from the depth screen to the time screen by pressing the F10 key (F9 and F10 toggle between the depth and time screen of the acquisition software).

3. The screen will be grayed out which means that the data up to that point has not been saved. Select “Start Dissipation Test” which will turn the screen from gray to a white background indicating that you are now saving the time data.

4. Now shut the pump switch off and when the line pressure reaches zero, turn the flow valve off.

5. The HPT Pressure will begin to drop (dissipate the hydrostatic increase) and allow it to stabilize so very little visible drop in pressure is seen. When the pressure has fully dissipated turn the flow valve and the pump switch back on. When the flow and pressure are reestablished select "End Dissipation test."

6. Select F9 to return to the depth screen and advancing the tool into the ground.

   Note: Performing a dissipation test in zones of higher permeability may only take 30 seconds or so but if the HPT pressure was higher to start with it may take a long time up to several hours to dissipate off to equilibrium. This is why targeting the most permeable zone to perform the dissipation tests is most desirable.

6.0 HPT Log Interpretation

Below is a typical HPT log, which consists of both the HPT pressure response and electrical conductivity. In general, both HPT pressure and EC values increase with decreasing grain size, and decrease with increasing grain size. The log in Figure 6.1 shows good consistency between EC and HPT pressure for the majority of the log. It is only between 32'-42'bgs that we see some divergence of the graphs with higher HPT pressure while the EC readings remained low. This can happen for reasons such as poor mineralogy of the soil. Refusal was encountered in a shale layer beginning at 75'bgs and it can be noted that as we enter this layer the HPT flow gets suppressed as the pressure reaches a maximum value of 100PSI (690kPa). The second graph of the log shows the hydrostatic profile on the secondary series of the graph. The hydrostatic profile has 2 black triangles which indicate where dissipation tests were run and used to calculate the profile. The red circle indicates the calculated water table based upon where the hydrostatic profile intersects atmospheric pressure. The fourth graph is the estimate K or groundwater flow graph. This is calculated based upon HPT pressure and HPT flow relationships. Less permeable soil will have less groundwater flow.

It is fairly common to see zones where EC readings and HPT pressure contradict one another. In cases where EC readings are low and HPT pressure trends higher as in the log in Figure 6.1 the following are possible reasons:

- Poor mineralogy of the soil particles resulting in silt and clay soils with very low EC readings. This is seen in many locations along the east coast of the United States.
- Silts intermixed with sand particles.
- Weathered bedrock may have low EC but would have low permeability.

Where we have cases of higher EC and lower HPT pressure typically is due to an ionic influence in the soil or groundwater. These higher EC readings can range from very slight to higher than typical soil readings. Very high EC readings can occur when the probe contacts metallic objects in the soil which will ground them out and typically will cause hard sharp spikes in the EC data.

- Chloride or other ionic contaminant (sea water, injection materials)
- Sea Water intrusion
- Wire, metal objects or Slag

In cases where HPT and EC do not confirm one another it is important to take confirmation soil and/or groundwater samples to help understand the difference between the two graphs.

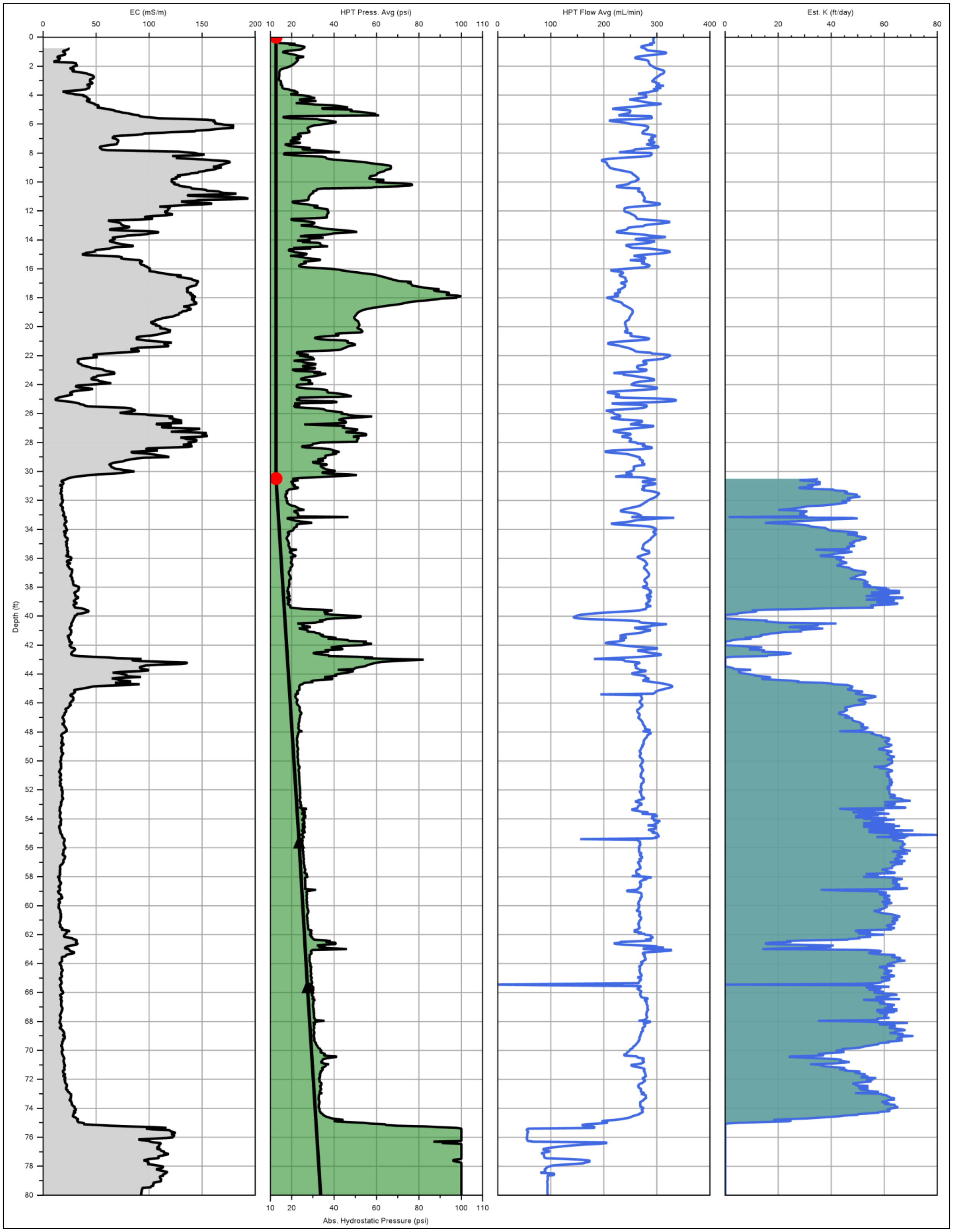


Figure 6.1: HPT Log file showing (left to right):
Electrical Conductivity (EC), HPT Injection Pressure with Hydrostatic Profile, HPT Flow, and Estimated K

7.0 Troubleshooting

7.1 Using the HPT Controller Test Load

The HPT Controller Test Load (32441) is included with the HPT Controller to help troubleshoot the HPT pressure sensor, trunkline, and controller. If there is a major problem with the HPT pressure sensor or the system wiring the system will not read anywhere close to atmospheric pressure with the probe at the surface. Commonly if the HPT sensor has broken the software will read either a maximum or minimum value which would be 100PSI or 0PSI (690kPa or 0KPa). If there is damaged wiring or nothing is connected to the controller the system typically reads 50PSI (345kPa).

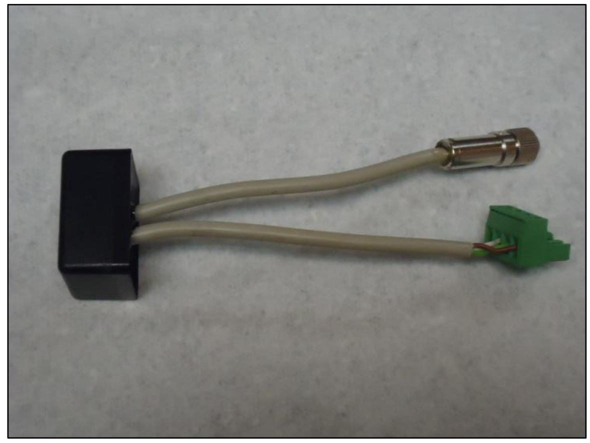


Figure 7.1: HPT Test Load PN32441

When connected to either the trunkline (in place of the pressure sensor), or the controller (in place of the trunkline and pressure sensor), the test load will cause the pressure sensor value to read a pressure ranging from approximately 25PSI-35PSI (172kPa – 241kPa).

To use the test load, set up the system as previously described. Turn on both the field instrument and HPT controller and start the HPT software. Plug the green wire connector of the test load into the HPT sensor connector on the back of the HPT controller. If the pressure sensor value reads somewhere around 30PSI (207kPa), the controller is able to properly read pressures so the problem is in the trunkline or the HPT sensor. If HPT controller has not moved from what it was reading or is way out from the expected value of the load test the HPT controller may require servicing. Contact Geoprobe Systems® for service.

Next, connect the HPT sensor wires of the trunkline to the controller with the green connector and then connect the test load to the female chrome connector on the downhole end of the trunkline in place of the pressure sensor. Again, the pressure value displayed on the field instrument should be somewhere around 30PSI (207kPa) and should be the same as what was seen with the load test connected into the controller. If the load test through the trunkline is around 30PSI (207kPa), then both the trunkline and the controller are working properly and the problem is in the HPT sensor. If it is not, the trunkline may be defective and should be replaced. Before restringing another HPT trunkline, first connect the new trunkline sensor wires into the HPT controller and the downhole end into the test load. If the system now reads in the expected test load range the trunkline needs replacing.

Finally, connect the pressure sensor to the trunkline. If it reads atmospheric pressure, approximately 12PSI-15PSI (83kPa-104kPa), then the pressure transducer is functioning properly. However, if it does not, replace the sensor with a new one and re-check the pressure reading. Be sure to enter the new sensor calibration values into the software prior to starting the new log. Additional pressure sensors purchased from Geoprobe®.

7.2 Common Problems

Problem: The pressure transducer is hooked up to the trunkline, but the software is reporting a reading of ~ 50PSI (345kPa).
Solution: Make sure that the trunkline wires are secured to the green terminal blocks and plugged in to the back of the HPT controller. Check components using the HPT Controller Test Load (Section 7.1).

Problem: The pressure transducer is hooked up to the trunkline, but the software is reporting a reading of 100PSI or 0PSI (690kPa or 0KPa).
Solution: Make sure all of the connections are good and recheck the pressure reading. If still bad connect a new HPT pressure sensor onto the trunkline and see if it reads atmospheric pressure. If not check all the components using the HPT Controller Test Load (Section 7.1).

Problem: The pressure with flow values keep drifting when water is flowing out the port or over the top of the reference tube.
Solution 1: If the trunkline was just connected and flow was just started air may still be in the lines. Allow the water to continue to flow through system which will purge out the remaining air. When it appears that most of the air is out of the lines pressing your finger over the injection screen for a few seconds can help to drive out any remaining air from the trunkline.
Solution 2: There may be debris behind the screen. Remove the HPT injection screen with the membrane wrench and turn the water flow on, place your finger over the open port to drive out debris. Replace the screen and retry the reference test with flow.
Solution 3: If the with flow pressure values continue to not settle down and provide close to the expected difference for a 6" water column then the problem may be inside the HPT control box. When you remove the cover of the HPT controller there will be a brass filter located on the left side when viewing from the front of the instrument (Fig 7.2). Particulates and precipitates can collect inside this filter causing problems with HPT pressure stability. Remove this filter and open up using appropriate wrenches. The filter can be easily cleaned by rinsing water over the screen. Reassemble and return to its proper location inside the control box. Resume reference testing the system.

Figure 7.2: Location of Inline Filter in K6300 and buildup of particulates in filter.

Problem: EC won't pass the QA tests.

Solution: Check the trunkline to probe EC connections ensuring they are tight. Run the troubleshooting tests (Section 4.3A), test EC on a new probe.

APPENDIX A

Making HPT Probe, Sensor and Trunkline Connections

http://geoprobe.com/literature/hpt-sensor-connection-tutorial

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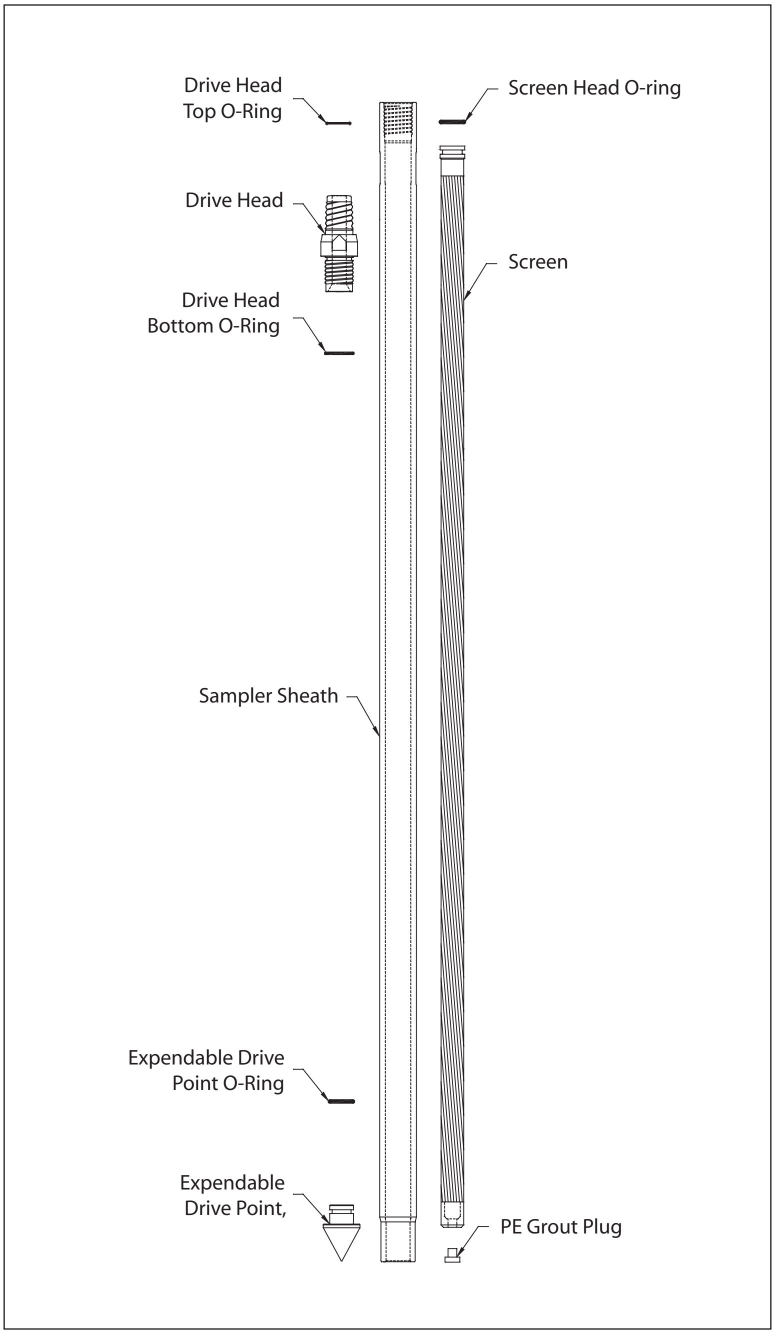
GEOPROBE® SCREEN POINT 16 GROUNDWATER SAMPLER

STANDARD OPERATING PROCEDURE

Technical Bulletin No. MK3142

PREPARED: November, 2006



GEOPROBE® SCREEN POINT 16 GROUNDWATER SAMPLER PARTS

Geoprobe Systems®

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Screen Point 16 Groundwater Sampler is manufactured under U.S. Patent 5,612,498

1.0 OBJECTIVE

The objective of this procedure is to drive a sealed stainless steel or PVC screen to depth, deploy the screen, obtain a representative water sample from the screen interval, and grout the probe hole during abandonment. The Screen Point 16 Groundwater Sampler enables the operator to conduct abandonment grouting that meets American Society for Testing and Materials (ASTM) Method D 5299 requirements for decommissioning wells and borings for environmental activities (ASTM 1993).

2.0 BACKGROUND

2.1 Definitions

Geoprobe®: A brand name of high quality, hydraulically powered machines that utilize both static force and percussion to advance sampling and logging tools into the subsurface. The Geoprobe® brand name refers to both machines and tools manufactured by Geoprobe Systems®, Salina, Kansas. Geoprobe® tools are used to perform soil core and soil gas sampling, groundwater sampling and monitoring, soil conductivity and contaminant logging, grouting, and materials injection.

Screen Point 16 (SP16) Groundwater Sampler: A direct push device consisting of a PVC or stainless steel screen that is driven to depth within a sealed, steel sheath and then deployed for the collection of representative groundwater samples. The assembled SP16 Sampler is approximately 51.5 inches (1308 mm) long with an OD of 1.625 inches (41 mm). Upon deployment, up to 41 inches (1041 mm) of screen can be exposed to the formation. The Screen Point 16 Groundwater Sampler is designed for use with 1.5-inch probe rods and machines equipped with the more powerful GH60 Hydraulic Hammer. Operators with GH40 Series hammers may chose to use this sampler in soils where driving is difficult.

Rod Grip Pull System: An attachment mounted on the hydraulic hammer of a direct push machine which makes it possible to retract the tool string with extension rods or flexible tubing protruding from the top of the probe rods. The Rod Grip Pull System includes a pull block with rod grip jaws that are bolted directly to the machine. A removable handle assembly straddles the tool string while hooking onto the pull block to effectively grip the probe rods as the hammer is raised. A separate handle assembly is required for each probe rod diameter.

2.2 Discussion

In this procedure, the assembled Screen Point 16 Groundwater Sampler (Fig. 2.1A) is threaded onto the leading end of a Geoprobe® probe rod and advanced into the subsurface with a Geoprobe® direct push machine. Additional probe rods are added incrementally and advanced until the desired sampling interval is reached. While the sampler is advanced to depth, O-ring seals at each rod joint, the drive head, and the expendable drive point provide a watertight system. This system eliminates the threat of formation fluids entering the screen before deployment and assures sample integrity.

Once at the desired sampling interval, extension rods are sent downhole until the leading rod contacts the bottom of the sampler screen. The tool string is then retracted approximately 44 inches (1118 mm) while the screen is held in place with the extension rods (Fig. 2.1B). As the tool string is retracted, the expendable point is released from the sampler sheath. The tool string and sheath may be retracted the full length of the screen or as little as a few inches if a small sampling interval is desired.

There are three types of screens that can be used in the Screen Point 16 Groundwater Sampler. Two of the these, a stainless steel screen with a standard slot size of 0.004 inches (0.10 mm) and a PVC screen with a standard slot size of 0.010 inches (0.25 mm), are recovered with the tool string after sampling. The third screen is also manufactured from PVC with a standard slot size of 0.010 inches (0.25 mm), but is designed to be left downhole when sampling is complete. This disposable screen has an exposed screen length of approximately 43 inches (1092 mm). The two screens that are recovered with the sampler both have an exposed screen length of approximately 41 inches (1041 mm).

(continued on following page)

An O-ring on the head of the stainless steel screens maintains a seal at the top of the screen. As a result, any liquid entering the sampler during screen deployment must first pass through the screen. PVC screens do not require an O-ring because the tolerance between the screen head and sampler sheath is near that of the screen slot size.

The screens are constructed such that flexible tubing, a mini-bailer, or a small-diameter bladder pump can be inserted into the screen cavity. This makes direct sampling possible from anywhere within the saturated zone. A removable plug in the lower end of the screens allows the user to grout as the sampler is extracted for further use.

Groundwater samples can be obtained in a number of ways. A common method utilizes polyethylene (TB25L) or Teflon® (TB25T) tubing and a Check Valve Assembly (GW4210). The check valve (with check ball) is attached to one end of the tubing and inserted down the casing until it is immersed in groundwater. Water is pumped through the tubing and to the ground surface by oscillating the tubing up and down.

An alternative means of collecting groundwater samples is to attach a peristaltic or vacuum pump to the tubing. This method is limited in that water can be pumped to the surface from a maximum depth of approximately 26 feet (8 m). Another technique for groundwater sampling is to use a stainless steel Mini-Bailer Assembly (GW41). The mini-bailer is lowered down the inside of the casing below the water level where it fills with water and is then retrieved from the casing.

The latest option for collecting groundwater from the SP16 sampler is to utilize a Geoprobe® MB470 Series Mechanical Bladder Pump (MBP)*. The MBP may be used to meet requirements of the low-flow sampling protocol (Puls and Barcelona 1996, ASTM 2003). Through participation in a U.S. EPA Environmental Technology Verification study, it was confirmed that the MB470 can provide representative samples (EPA 2003).

**The Mechanical Bladder Pump is manufactured under U.S. Patent No. 6,877,965 issued April 12, 2005.*

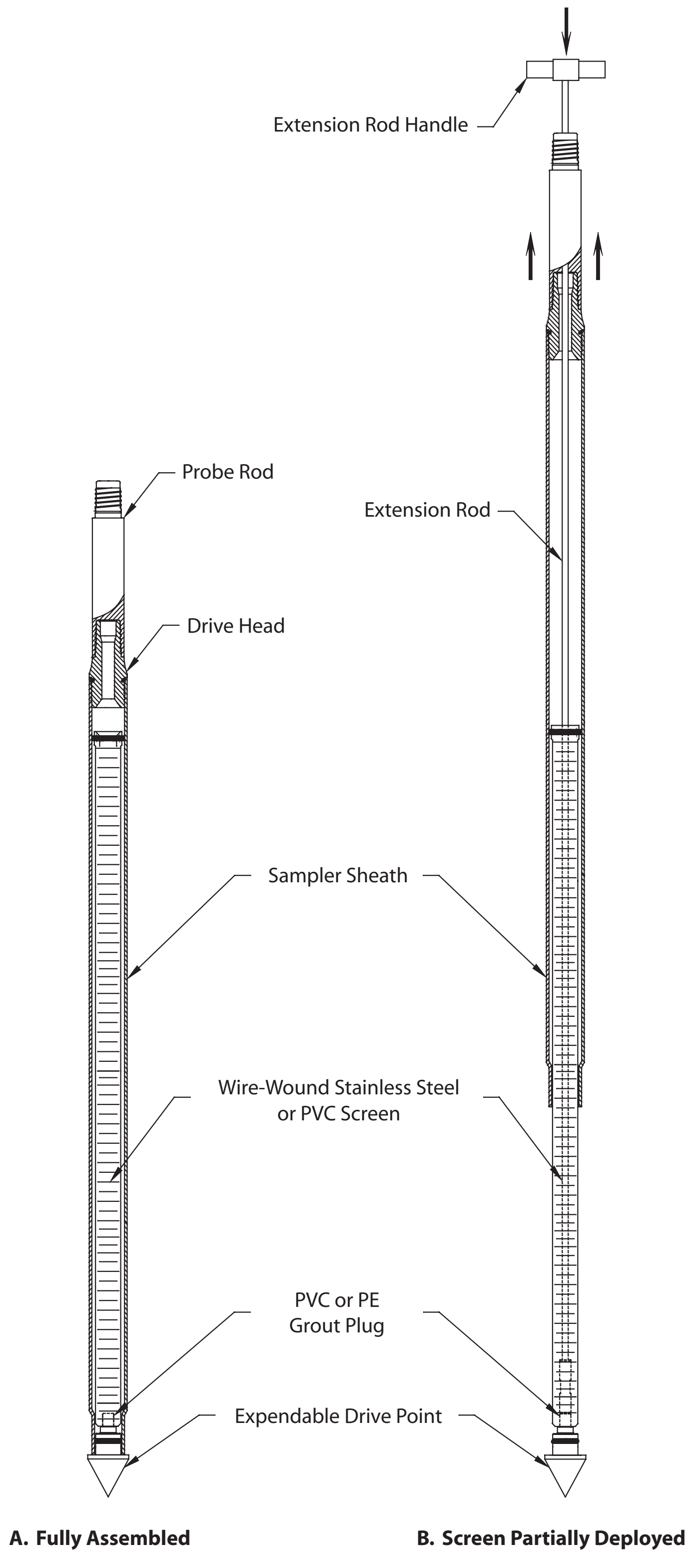


FIGURE 2.1
Screen Point 16 Groundwater Sampler

3.0 TOOLS AND EQUIPMENT

The following tools and equipment can be used to successfully recover representative groundwater samples with the Geoprobe® Screen Point 16 Groundwater Sampler. Refer to Figures 3.1 and 3.2 for identification of the specified parts. Tools are listed below for the most common SP16 / 1.5-inch probe rod configurations. Additional parts for optional rod sizes and accessories are listed in Appendix A.

SP16 Sampler Parts	Part Number
SP16 Sampler Sheath	15187
SP16 Drive Head, 0.5-inch bore, 1.5-inch rods*	18307
SP16 O-ring Service Kit, 1.5-inch rods *(includes 4 each of the O-ring packets below)*	15844
O-rings for Top of SP16 Drive Head, 1.5-inch rods only (Pkt. of 25)	*15389*
O-rings for Bottom of SP16 Drive Head (Pkt. of 25)	*13196*
O-rings for GW1520 Screen Head (Pkt. of 25)	*GW1520R*
O-rings for SP16 Expendable Drive Point (Pkt. of 25)	*GW1555R*
Screen, Wire-Wound Stainless Steel, 4-Slot*	GW1520
Grout Plugs, PE (Pkg. of 25)	GW1552K
Expendable Drive Points, steel, 1.625-inch OD (Pkg. of 25)*	GW1555K
Screen Point 16 Groundwater Sampler Kit, 1.5-inch Probe Rods *(includes 1 each of: 15187, 18307, 15844, GW1520, GW1535, GW1540, GW1555K, and GW1552K)*	15770

Probe Rods and Probe Rod Accessories	Part Number
Drive Cap, 1.5-inch probe rods, threadless, (for GH60 Hammer)	12787
Pull Cap, 1.5-inch probe rods	15090
Probe Rod, 1.5-inch x 60-inch*	11121

Extension Rods and Extension Rod Accessories	Part Number
Screen Push Adapter	GW1535
Grout Plug Push Adapter	GW1540
Extension Rod, 60-inch*	10073
Extension Rod Coupler	AT68
Extension Rod Handle	AT69
Extension Rod Jig	AT690
Extension Rod Quick Link Coupler, pin	AT695
Extension Rod Quick Link Coupler, box	AT696

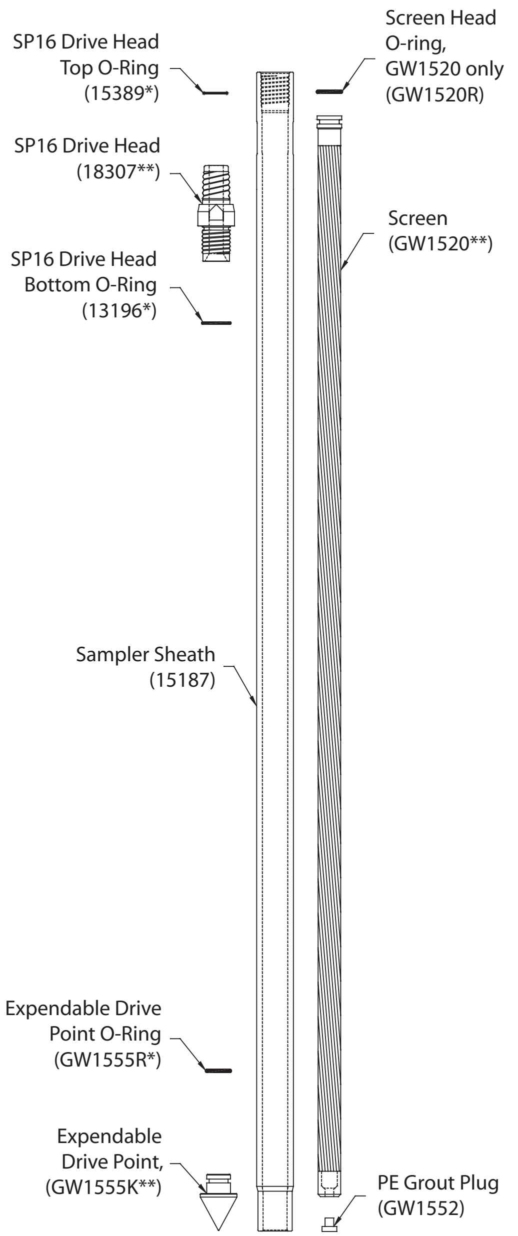
Grout Accessories	Part Number
Grout Nozzle, for 0.375-inch OD tubing	GW1545
High-Pressure Nylon Tubing, 0.375-inch OD / 0.25-inch ID, 100-ft. (30 m)	11633
Grout Machine, self-contained*	GS1000
Grout System Accessories Package, 1.5-inch rods	GS1015

Groundwater Purging and Sampling Accessories	Part Number
Polyethylene Tubing, 0.375-inch OD, 500 ft.*	TB25L
Check Valve Assembly, 0.375-inch OD Tubing*	GW4210
Water Level Meter, 0.438-inch OD Probe, 100 ft. cable*	GW2000
Mechanical Bladder Pump**	MB470
Mini Bailer Assembly, stainless steel	GW41

Additional Tools	Part Number
Adjustable Wrench, 6.0-inch	FA200
Adjustable Wrench, 10.0-inch	FA201
Pipe Wrenches	NA

* See Appendix A for additional tooling options.

** Refer to the Standard Operating Procedure (SOP) for the Mechanical Bladder Pump (Technical Bulletin No. MK3013) for additional tooling needs.



* Included in the SP16 O-ring Service Kit (15844)
** Part numbers show most common tool configuration. See Appendix A for alternative parts.

FIGURE 3.1
SP16 Sampler Parts

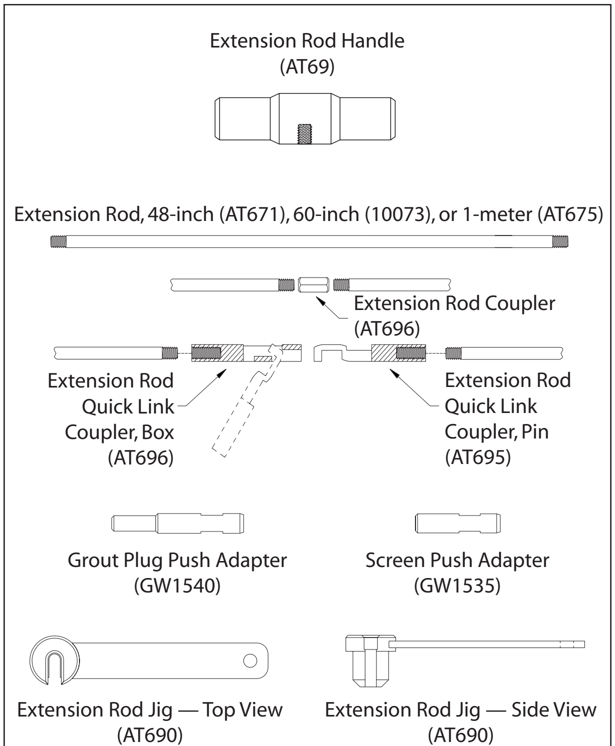


FIGURE 3.2
Geoprobe® Extension Rods and Accessories

4.0 OPERATION

4.1 Basic Operation

The SP16 sampler utilize a stainless steel or PVC screen which is encased in an alloy steel sampler sheath. An expendable drive point is placed in the lower end of the sheath while a drive head is attached to the top. O-rings on the drive head and expendable point provide a watertight sheath which keeps contaminants out of the system as the sampler is driven to depth.

Once the sampling interval is reached, extension rods equipped with a screen push adapter are inserted down the ID of the probe rods. The tool string is then retracted up to 44 inches (1118 mm) while the screen is held in place with the extension rods. The system is now ready for groundwater sampling. When sampling is complete, a removable plug in the bottom of the screen allows for grouting below the sampler as the tool string is retrieved.

4.2 Sampler Options

The Screen Point 15 and Screen Point 16 Groundwater Samplers are nearly identical. Subtle differences in the design of the SP16 sampler make it more durable than the earlier SP15 system. Operators of GH60-equipped machines should always utilize SP16 tooling. Operators of machines equipped with GH40 Series hammers may also choose SP16 tooling when sampling in difficult probing conditions.

A 1.75-inch OD Expendable Drive Point (17066K) and Disposable PVC Screen (16089) provide two useful options for the SP16 sampler. The 1.75-inch drive point may be used when soil conditions make it difficult to remove the sampler after driving to depth. The disposable PVC screen may be left downhole after sampling (when regulations permit) to eliminate the time required for screen decontamination.

4.3 Decontamination

In order to collect representative groundwater samples, all sampler parts must be thoroughly cleaned before and after each use. Scrub all metal parts using a stiff brush and a nonphosphate soap solution. Steam cleaning may be substituted for hand-washing if available. Rinse with distilled water and allow to air-dry before assembly.

4.4 SP16 Sampler Assembly (Figure 4.1)

Part numbers are listed for a standard SP16 sampler using 1.5-inch probe rods. Refer to Page 6 for screen and drive head alternatives.

1. Place an O-ring on a steel expendable drive point (GW1555K). Firmly seat the expendable point in the necked end of a sampler sheath (15187).

2. Install a PE Grout Plug (GW1552) in the bottom end of a Wire-wound Stainless Steel Screen (GW1520). Place a GW1520R O-ring in the groove on the top end of the screen.

3. Slide the screen inside of the sampler sheath with the grout plug toward the bottom of the sampler. Ensure that the expendable point was not displaced by the screen.

4. Install a bottom O-ring (13196) on a Drive Head (18307 or 15188). Thread the drive head into the sampler sheath using an adjustable wrench if necessary to ensure complete engagement of the threads. Attach a Drive Cap (12787 or 15590) to the top of the drive head.

NOTE: The 18307 drive head should be used whenever possible as the smaller 0.5-inch ID provides a greater material cross-section for increased durability.

Sampler assembly is complete.

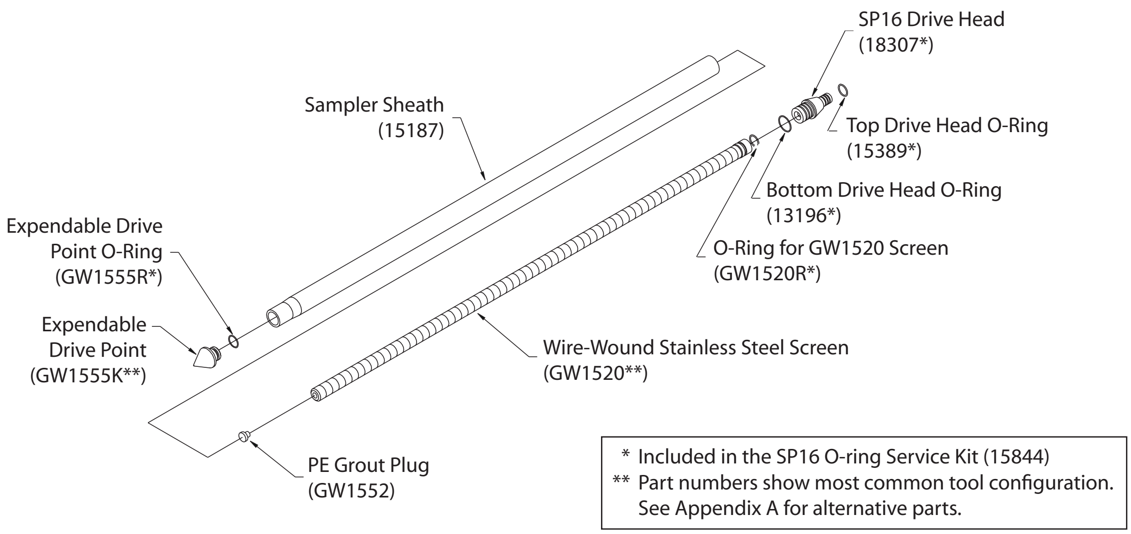


FIGURE 4.1
Screen Point 16 Groundwater Sampler Assembly

4.5 Advancing the SP16 Sampler

To provide adequate room for screen deployment with the Rod Grip Pull System, the probe derrick should be extended a little over halfway out of the carrier vehicle when positioning for operation.

1. Begin by placing the assembled sampler (Fig. 2.1.A) in the driving position beneath the hydraulic hammer of the direct push machine as shown in Figure 4.2.

2. Advance the sampler with the throttle control at slow speed for the first few feet to ensure that the sampler is aligned properly. Switch to fast speed for the remainder of the probe stroke.

3. Completely raise the hammer assembly. Remove the drive cap and place an O-ring in the top groove of the drive head. Distilled water may be used to lubricate the O-ring if needed.

Add a probe rod (length to be determined by operator) and reattach the drive cap to the rod string. Drive the sampler the entire length of the new rod with the throttle control at fast speed.

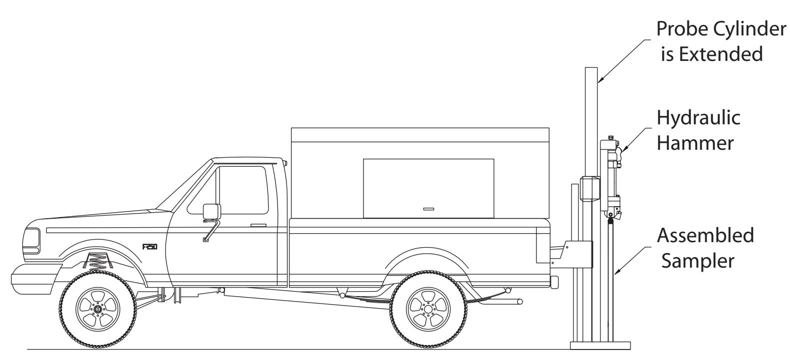


FIGURE 4.2
Screen Point 16 Groundwater Sampler in Driving Position

4. Repeat Step 3 until the desired sampling interval is reached. Approximately 12 inches (305 mm) of the last probe rod must extend above the ground surface to allow attachment of the puller assembly. A 12-inch (305 mm) rod may be added if the tool string is over-driven.

5. Remove the drive cap and retract the probe derrick away from the tool string.

4.6 Screen Deployment

1. Thread a screen push adapter (GW1535) on an extension rod of suitable length (AT671, 10073, or AT675). Attach a threaded coupler (AT68) to the other end of the extension rod. Lower the extension rod inside of the probe rod taking care not to drop it down the tool string. An extension rod jig (AT690) may be used to hold the rods.

2. Add extension rods until the adapter contacts the bottom of the screen. To speed up this step, it is recommended that Extension Rod Quick Links (AT695 and AT696) are used at every other rod joint.

3. Ensure that at least 48 inches (1219 mm) of extension rod protrudes from the probe rod. Thread an extension rod handle (AT69) on the top extension rod.

4. Maneuver the probe assembly into position for pulling.

5. Raise (pull) the tool string while physically holding the screen in place with the extension rods (Fig. 4.3.B). A slight knock with the extension rod string will help to dislodge the expendable point and start the screen moving inside the sheath.

   Raise the hammer and tool string about 44 inches (1118 cm) if using a GW1520 or GW1530 screen. At this point the screen head will contact the necked portion of the sampler sheath (Fig. 4.3.C.) and the extension rods will rise with the probe rods. Use care when deploying a PVC screen so as not to break the screen when it contacts the bottom of the sampler sheath.

   The Disposable Screen (16089) will extend completely out of the sheath if the tool string is raised more than 45 inches (1143 mm). Measure and mark this distance on the top extension rod to avoid losing the screen during deployment.

6. Remove the rod grip handle, lower the hammer assembly, and retract the probe derrick. Remove the top extension rod (with handle) and top probe rod. Finally, extract all extension rods.

7. Groundwater samples can now be collected with a mini-bailer, peristaltic or vacuum pump, tubing bottom check valve assembly, bladder pump, or other acceptable small diameter sampling device.

   When inserting tubing or a bladder pump down the rod string, ensure that it enters the screen interval. The leading end of the tubing or bladder pump will sometimes catch at the screen head giving the illusion that the bottom of the screen has been reached. An up-and-down motion combined with rotation helps move the tubing or bladder pump past the lip and into the screen.

4.7 Abandonment Grouting for GW1520 and GW1530 Screens

The SP16 Sampler can meet ASTM D 5299 requirements for abandoning environmental wells or borings when grouting is conducted properly. A removable grout plug makes it possible to deploy tubing through the bottom of GW1520 and GW1530 screens. A GS500 or GS1000 Grout Machine is then used to pump grout into the open probe hole as the sampler is withdrawn. The following procedure is presented as an example only and should be modified to satisfy local abandonment grouting regulations.

1. Maneuver the probe assembly into position for pulling. Attach the rod grip puller to the top probe rod. Raise the tool string approximately 4 to 6 inches (102 to 152 cm) to allow removal of the grout plug.

2. Thread the Grout Plug Push Adapter (GW1540) onto an extension rod. Insert the adapter and extension rod inside the probe rod string. Add extension rods until the adapter contacts the grout plug at the bottom of the screen. Attach the handle to the top extension rod. When the extension rods are slightly raised and lowered, a relatively soft rebound should be felt as the adapter contacts the grout plug. This is especially true when using a PVC screen.

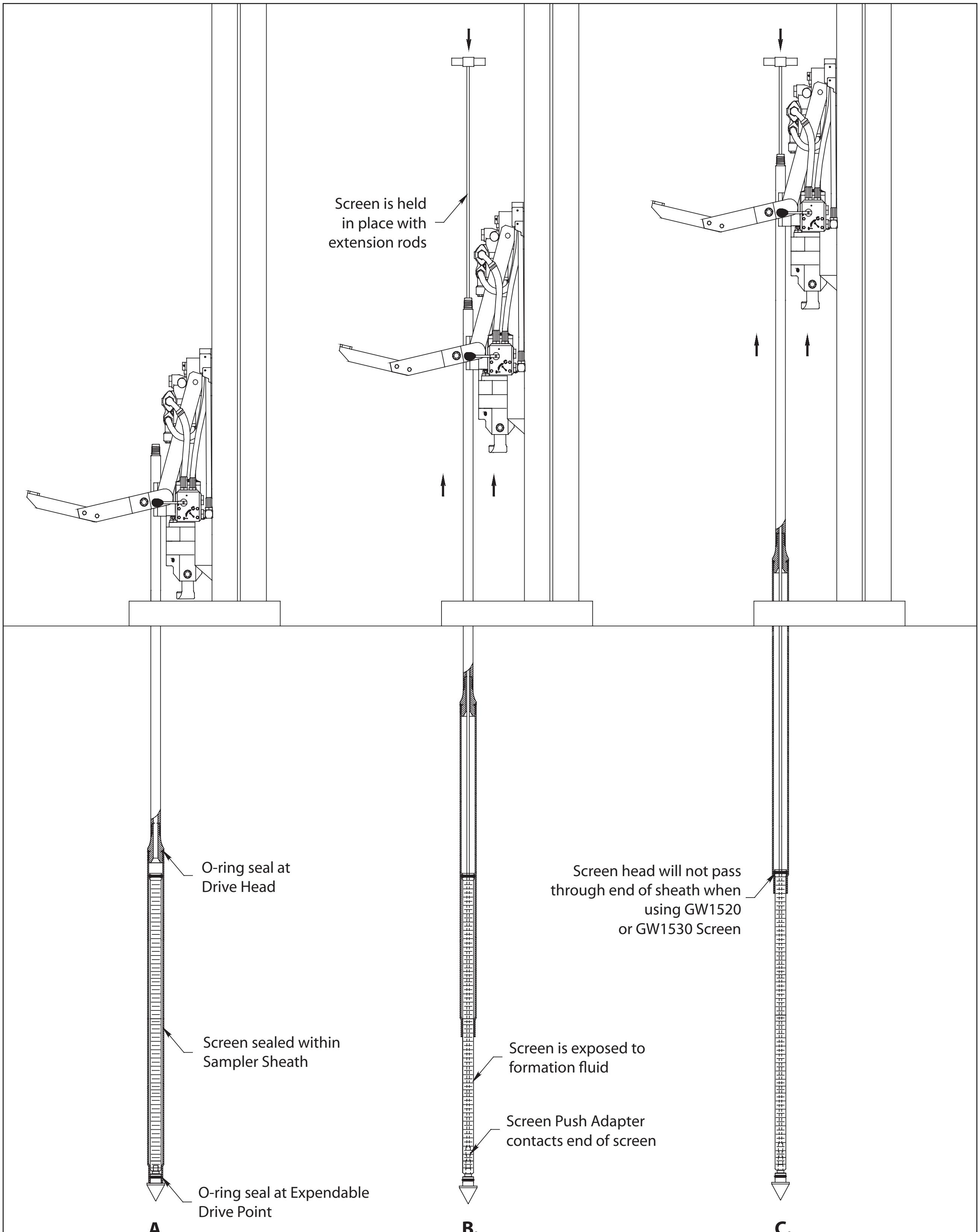


FIGURE 4.3

Screen Deployment for SP16 Sampler

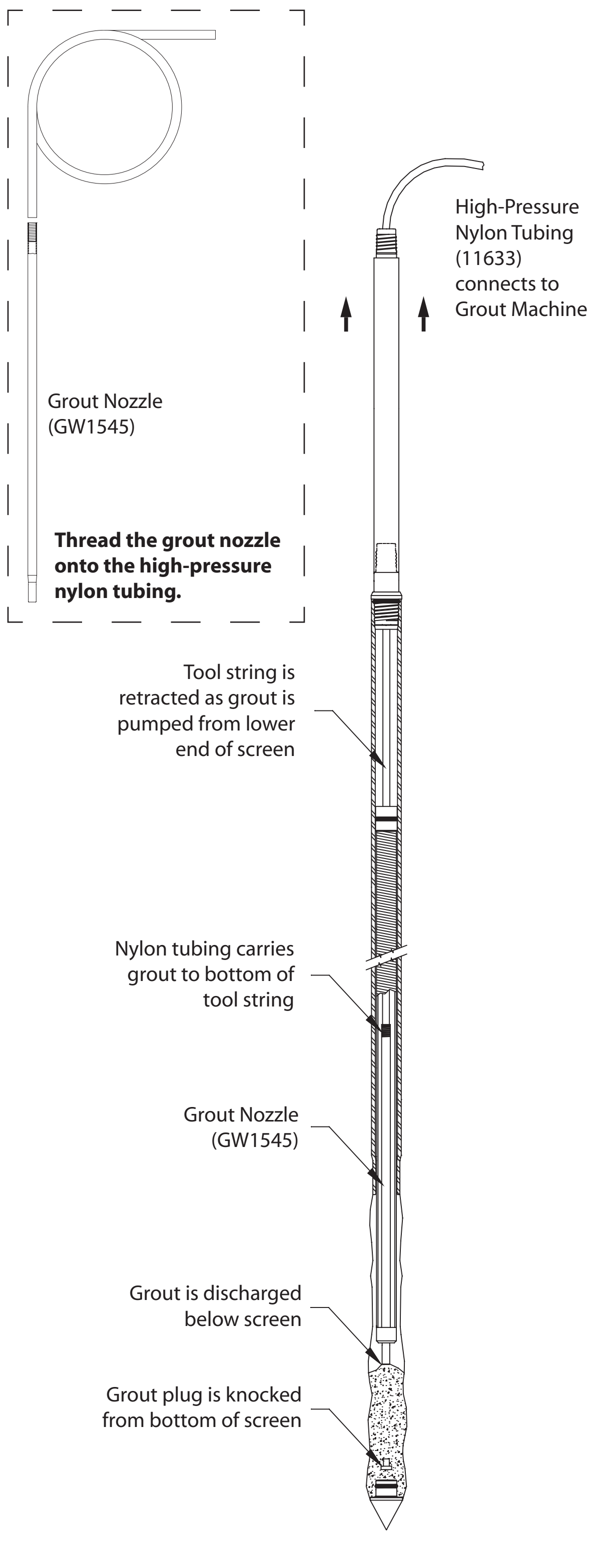


FIGURE 4.4
Grouting the SP16 Sampler With a GW1520 or GW1530 Screen

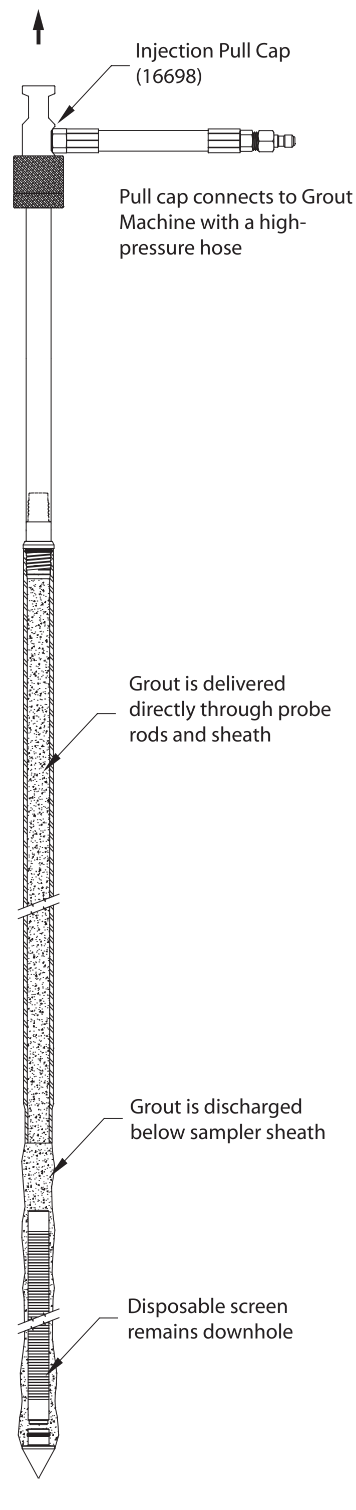


FIGURE 4.5
Grouting the SP16 Sampler With a 16089 Disposable Screen

3. Place a mark on the extension rod even with the top of the probe rod. Apply downward pressure on the extension rods and push the grout plug out of the screen. The mark placed on the extension rod should now be below the top of the probe rod. Remove all extension rods.

   Note: When working with a stainless steel screen, it may be necessary to raise and quickly lower the extension rods to jar the grout plug free. When the plug is successfully removed, a metal-on-metal sensation may be noted as the extension rods are gently "bounced" within the probe rods.

4. A Grout Nozzle (GW1545) is now connected to High-Pressure Nylon Tubing (11633) and inserted down through the probe rods to the bottom of the screen (Fig. 4.4). It may be necessary to pump a small amount of clean water through the tubing during deployment to jet out sediments that settled in the bottom of the screen. Resistance will sometimes be felt as the grout nozzle passes through the drive head. Rotate the tubing while moving it up-and-down to ensure that the nozzle has reached the bottom of the screen and is not hung up on the drive head.

   Note: *All probe rods remain strung on the tubing as the tool string is pulled. Provide extra tubing length to allow sufficient room to lay the rods on the ground as they are removed. An additional 20 feet is generally enough.*

5. Operate the grout pump while pulling the first rod with the rod grip pull system. Coordinate pumping and pulling rates so that grout fills the void left by the sampler. After pulling the first rod, release the rod grip handle, fully lower the hammer, and regrip the tool string. Unthread the top probe and slide it over the tubing placing it on the ground near the end of the tubing.

6. Repeat Step 5 until the sampler is retrieved. Do not bend or kink the tubing when pulling and laying out the probe rods. Sharp bends create weak spots in the tubing which may burst when pumping grout. Remember to operate the grout pump only when pulling the rod string. The probe hole is thus filled with grout from the bottom up as the rods are extracted.

7. Promptly clean all probe rods and sampler parts before the grout sets up and clogs the equipment.

4.8 Abandonment Grouting for the 16089 Disposable Screen

ASTM D 5299 requirements can also be met for the SP16 samplers when using the 16089 disposable screen. Because the screen remains downhole after sampling, the operator may choose either to deliver grout to the bottom of the tool string with nylon tubing or pump grout directly through the probe rods using an Injection Pull Cap (16698). A GS500 or GS1000 Grout Machine is needed to pump grout into the open probe hole as the sampler is withdrawn. The following procedure is presented as an example only and should be modified to satisfy local abandonment grouting regulations.

1. Maneuver the probe assembly into position for pulling with the rod grip puller.

2. Thread the screen push adapter onto an extension rod. Insert the adapter and extension rod inside the probe rod string. Add extension rods until the adapter contacts the bottom of the screen. Attach the handle to the top extension rod.

3. The disposable screen must be extended at least 46 inches (1168 mm) to clear the bottom of the sampler sheath. Considering the length of screen deployed in Section 4.7, determine the remaining distance required to fully extend the screen from the sheath. Mark this distance on the top extension rod.

4. Pull the tool string up to the mark on the top extension rod while holding the disposable screen in place.

   The screen is now fully deployed and the sampler is ready for abandonment grouting. Apply grout to the bottom of the tool string during retrieval using either flexible tubing (as described in Section 4.7) or an injection pull cap (Fig. 4.5). This section continues with a description of grouting with a pull cap.

5. Remove the rod grip handle and maneuver the probe assembly directly over the tool string. Thread an Injection Pull Cap (16698) onto the top probe rod and close the hammer pull latch over the top of the pull cap.

6. Connect the pull cap to a Geoprobe® grout machine using a high-pressure grout hose.

7. Operate the pump to fill the entire tool string with grout. When a sufficient volume has been pumped to fill the tool string, begin pulling the rods and sampler while continuing to operate the grout pump. Considering the known pump volume and sampler cross-section, time tooling withdrawal to slightly "overpump" grout into the subsurface. This will ensure that all voids are filled during sampler retrieval.

   The grouting process can lubricate the probe hole sufficiently to cause the tool string to slide back downhole when disconnected from the pull cap. Prevent this by withdrawing the tool string with the rod grip puller while maintaining a connection to the grout machine with the pull cap.

4.9 Retrieving the Screen Point 16 Sampler

If grouting is not required, the Screen Point 16 Sampler can be retrieved by pulling the probe rods as with most other Geoprobe® applications. The Rod Grip Pull System should be used for this process as it allows the operator to remove rods without completely releasing the tool string. This avoids having the probe rods fall back downhole when released during the pulling procedure. A standard Pull Cap (15164) may still be used if preferred. Refer to the Owner's Manual for your Geoprobe® direct push machine for specific instructions on pulling the tool string.

5.0 REFERENCES

American Society of Testing and Materials (ASTM), 2003. D6771-02 Standard Practice for Low-Flow Purging and Sampling for Wells and Devices Used for Ground-Water Quality Investigations. ASTM, West Conshocken, PA. (www.astm.org)

American Society of Testing and Materials (ASTM), 1993. ASTM 5299 *Standard Guide for Decommissioning of Groundwater Wells, Vadose Zone Monitoring Devices, Boreholes, and Other Devices for Environmental Activities.* ASTM West Conshohocken, PA. (www.astm.org)

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Geoprobe Systems®, 2006, *Model MB470 Mechanical Bladder Pump Standard Operating Procedure (SOP), Technical Bulletin No. MK3013.*

Puls, Robert W., and Michael J. Barcelona, 1996. Ground Water Issue: Low-Flow (Minimal Drawdown) Ground Water Sampling Procedures. EPA/540/S-95/504. April.

U.S. Environmental Protection Agency (EPA), 2003. Environmental Technology Verification Report: Geoprobe Inc., Mechanical Bladder Pump Model MB470. Office of Research and Development, Washington, D.C. EPA/600R-03/086. August.

Appendix A
ALTERNATIVE PARTS

The following parts are available to meet unique soil conditions. See section 3.0 for a complete listing of the common tool configurations for the Geoprobe® Screen Point 16 Groundwater Sampler.

SP16 Sampler Parts and Accessories	**Part Number**
SP16 Drive Head, 0.625-inch bore, 1.5-inch rods	15188
Expendable Drive Points, aluminum, 1.625-inch OD (Pkg. of 25)	GW1555ALK
Expendable Drive Points, steel, 1.75-inch OD (Pkg. of 25)	17066K
Screen, PVC, 10-Slot	GW1530
Screen, Disposable, PVC, 10-Slot	16089

Groundwater Purging and Sampling Accessories	**Part Number**
Polyethylene Tubing, 0.25-inch OD, 500 ft.	TB17L
Polyethylene Tubing, 0.5-inch OD, 500 ft.	TB37L
Polyethylene Tubing, 0.625-inch OD, 50 ft.	TB50L
Check Valve Assembly, 0.25-inch OD Tubing	GW4240
Check Valve Assembly, 0.5-inch OD Tubing	GW4220
Check Valve Assembly, 0.625-inch OD Tubing	GW4230
Water Level Meter, 0.375-inch OD Probe, 100-ft. cable	GW2001
Water Level Meter, 0.438-inch OD Probe, 200-ft. cable	GW2002
Water Level Meter, 0.375-inch OD Probe, 200-ft. cable	GW2003
Water Level Meter, 0.438-inch OD Probe, 30-m cable	GW2005
Water Level Meter, 0.438-inch OD Probe, 60-m cable	GW2007
Water Level Meter, 0.375-inch OD Probe, 60-m cable	GE2008

Grouting Accessories	**Part Number**
Grout Machine, auxiliary-powered	GS500

Probe Rods, Extension Rods, and Accessories	**Part Number**
Probe Rod, 1.5-inch x 1-meter	17899
Probe Rod, 1.5-inch x 48-inch	13359
Drive Cap, 1.5-inch rods (for GH40 Series Hammer)	15590
Rod Grip Pull Handle, 1.5-inch Probe Rods (for GH40 Series Hammer)	GH1555
Extension Rod, 48-inch	AT671
Extension Rod, 1-meter	AT675

Equipment and tool specifications, including weights, dimensions, materials, and operating specifications included in this brochure are subject to change without notice. Where specifications are critical to your application, please consult Geoprobe Systems®.

Geoprobe Systems®

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Appendix D

Laboratory Methods

Attachment A. Sequential Extraction Test Description

Selected soil samples will be subjected to sequential extraction analysis to quantify the different forms of COCs present, as well as, the abundances of Fe- and Mn-oxyhydroxides. The extraction procedure is designed to release COC fractions from a sample according to their availability by subjecting the sample to a series of chemical treatments targeted at specific chemical forms.

A simplified procedure consisting of seven extraction steps will be performed yielding the following fractions: (1) soluble, (2) exchangeable (strongly adsorbed), (3) acid soluble (AVS, carbonates, and Mn-oxides), (4) amorphous iron oxides; (5) crystalline iron oxides; (6) sulfides/selenides, and (7) insoluble. Twelve COCs[1] and pH will be determined for each of the fractions collected. Details of the sequential extraction procedure, which is adapted from Keon et al. (2001), are provided in Table 1. The crystalline iron oxide extraction fluids are based on Wenzel et al. (2001), and the HF extraction from Keon et al. (2001) is not included.

Sequential extraction procedures will be performed on subsamples taken from homogenized, sieved core samples. All sample handling and fraction collection shall be done anoxically in a glovebox (under a positive-pressure Ar atmosphere to avoid oxidation artifacts).

References

Keon, N. E., Swartz, C. H., Brabander, D. J., Harvey, C., Hemond, H. F. 2001. Validation of an Arsenic Sequential Extraction Method for Evaluating Mobility in Sediments. *Environmental Science & Technology* 35: 2778-2784.

Wenzel, W.W., Kirchbaumer, N., Prohaska, T., Stingeder, G., Lombi, E., Adriano, D. 2001. Arsenic fractionation in soils using an improved sequential extraction procedure. *Anal Chim Acta* 436:309-323.

[1] COCs = Arsenic, antimony, boron, cadmium, chromium, fluoride, iron, manganese, molybdenum, selenium, sulfate, and thallium

Table 1. Sequential Extraction Procedure

Target Fraction	Extraction Fluid	Procedure
Soluble	1 M $MgCl_2$, pH 8	1. Add 100 mL fluid to 1 g sample in centrifuge tube. 2. Agitate in tumble-shaker for 2 hours at room temperature. 3. Centrifuge for 25 minutes at 11,000g. 4. Decant fluid and filter. 5. Repeat steps 1 to 4 with new extraction fluid. 6. Repeat steps 1, 3 and 4 with DI water. 7. Combine all decanted fluid, and analyze for pH and COCs*.
Exchangeable (Strongly Adsorbed)	1 M NaH_2PO_4, pH 5	8. Add 100 mL fluid to same 1 g sample in centrifuge tube. 9. Agitate in tumble-shaker for 16 hours at room temperature. 10. Centrifuge for 25 minutes at 11,000g. 11. Decant fluid and filter. 12. Repeat steps 8 to 11 with new extraction fluid for 24 hours. 13. Repeat steps 8, 10 and 11 with DI water. 14. Combine all decanted fluid and analyze for pH and COCs*.
Acid Soluble (AVS, Mn-oxides, carbonates)	1 N HCl	15. Add 100 mL fluid to same 1 g sample in centrifuge tube. 16. Agitate in tumble-shaker for 1 hour at room temperature. 17. Centrifuge for 25 minutes at 11,000g. 18. Decant fluid and filter. 19. Repeat steps 15 to 18 with new extraction fluid for 1 hour. 20. Repeat steps 15, 17 and 18 with DI water. 21. Combine all decanted fluid and analyze for pH and COCs*.
Amorphous Iron Oxide	0.2 M ammonium oxylate/oxalic acid, pH 3	22. Add 100 mL fluid to same 1 g sample in centrifuge tube. 23. Agitate in tumble-shaker for 2 hours at room temperature in the dark (wrapped in aluminum foil). 24. Centrifuge for 25 minutes at 11,000g. 25. Decant fluid and filter. 26. Repeat steps 22 to 25 with new extraction fluid for 2 hours. 27. Repeat steps 22, 24 and 25 with DI water. 28. Combine all decanted fluid and analyze for pH and COCs*.
Crystalline Iron Oxide	0.2 M ammonium oxylate/oxalic acid with 0.1 M ascorbic acid, pH 3	29. Add 100 mL fluid to same 1 g sample in centrifuge tube. 30. Set in hot water bath (96 deg. C) for 30 minutes. 31. Centrifuge for 25 minutes at 11,000g. 32. Decant fluid and filter. 33. Repeat steps 22 to 25 (i.e. use the amorphous iron oxide extraction fluid), except only agitate for 10 minutes. 34. Repeat steps 29, 31 and 32 with DI water. 35. Combine all decanted fluid and analyze for pH and COCs*.
Sulfides / Selenides	16 N HNO_3	36. Add 100 mL fluid to same 1 g sample in centrifuge tube. 37. Agitate in tumble-shaker for 2 hours at room temperature. 38. Centrifuge for 25 minutes at 11,000g. 39. Decant fluid and filter. 40. Repeat steps 36 to 39 with new extraction fluid. 41. Repeat steps 36, 38 and 39 with DI water. 42. Combine all decanted fluid and analyze for pH and COCs*.
Insoluble	16 N HNO_3 + 30% H_2O_2	43. Prepare same 1 g sample according to EPA 3050B. 44. Analyze for COCs*.

*COCs = Arsenic, antimony, boron, cadmium, chromium, fluoride, iron, manganese, molybdenum, selenium, sulfate, and thallium

Batch Adsorption Test Description

Description of the batch adsorption testing procedure is described in EPA's *Batch Type Procedures for Estimating Soil Adsorption of Chemicals* (EPA 530/SW-87/006-F, April 1992). Chapter 17 of this document (Laboratory Procedures for Generating Adsorption Data) is included in this Attachment. Applicable steps are summarized in the table below.

The following soil:solution ratios ($g_{adsorbent}$:$mL_{solution}$) will be used (assuming a fixed groundwater volume of 200 mL):

<u>Soil: Solution</u>
1:4
1:10
1:50
1:200

Note that ratios are based on oven-dry equivalent weights of adsorbent, which must be calculated from air-dry weights using the method in Chapter 17, Section 7 of EPA (1992) (see attached document).

The selected equilibration time will be 72 hours; however, in order to test the effect of equilibration time on adsorption, three soil samples with sufficient volume will also be run at the 1:50 soil:solution ratio at additional equilibration times of 24 hours and 120 hours. This means there will be a total of:

  11 samples x 4 ratios
<u>+ 3 sample x 2 additional times</u>
50 tests total

This will require 50 x 0.2 L = 10 L of unimpacted groundwater.

Groundwater in each test will be spiked with sodium arsenate to the following concentration:

1 mg/L arsenic

At the completion of each test, dissolved arsenic and pH will be measured.

Table 1. Batch Adsorption Test Procedure (EPA 1992, Chapter 17)

Chapter 17 Subsections	Subsection Title	Procedure
7.1 – 7.5	Preparation of Adsorbents	7.1 Air dry samples until in equilibrium with moisture content of laboratory air. 7.2 Weigh air-dried samples and pass through 2-mm screen sieve. Crush large aggregates (without grinding). If pebbles are present, remove and weigh these. 7.3 Homogenize sample. Use unbiased splitting procedure to remove representative subsample. 7.4 Determine moisture content of air-dried sample. 7.5 Determine the mass of the sample, corrected for moisture content (see equation in Section 7.5.1).
8.5	Soil:Solution Procedure	8.5.1 Calculate mass of adsorbent sample for the various soil: solution ratios based on an oven-dried equivalent weight. The volume of adsorbent plus solution should occupy 80-90% of the container. 8.5.2 Weigh the samples of adsorbent (no anaerobic special handling procedures are required). 8.5.3 Place the weighed samples into clean, labeled containers. 8.5.4 Pipette the solution containing the solutes from the stock (1 mg/L arsenic-fortified groundwater) solution. The volume of solution should be identical in all containers. 8.5.5 Pipette the stock solution into a container holding no adsorbent. This is the laboratory “blank.” One blank will be used for this study. 8.5.6 Close the bottles, ensuring watertight seal, and place on rotary tumbler for mixing. 8.5.7 Collect, preserve, and analyze an aliquot of stock solution before contact with reaction containers, adsorbent, and other surfaces. This is the initial concentration that will be used for calculating total adsorption. 8.5.8 Agitate samples at 29 rpm for specified test duration (24, 72, or 120 hours) at room temperature. 8.5.9 After test, open containers and record temperature and pH. 8.5.10 Separate the solid and liquid phase using either centrigugation or filtration (Section 5.2). Collect and preserve aliquots of each supernate of sufficient volume to determine arsenic concentration. 8.5.11 Determine the arsenic concentration of the aqueous phase.

United States
Environmental Protection
Agency

Office of Solid Waste
and Emergency Response
Washington, DC 20460

EPA/530/SW-87/006-F
April 1992

EPA

Technical Resource Document

Batch-Type Procedures For Estimating Soil Adsorption of Chemicals

CHAPTER 17

LABORATORY PROCEDURES FOR GENERATING ADSORPTION DATA

Procedures for the determination of the soil:solution ratio, equilibration time, and other parameters necessary for the construction of adsorption isotherms are contained in this chapter:

The rationale for these procedures, presented in previous chapters, should be studied before attempting to use them. This chapter refers to parts of the TRD that elucidate topics relevant to a specific procedural step. The flow diagram (fig. 44) summarizes the procedures and their interrelationships.

1 Scope of Application

1.1 The extent of adsorption of a chemical (solute) from solution by an adsorbent (sediment, soil, clay) at equilibrium can be estimated using these procedures.

1.2 These methods apply to the generation of adsorption isotherms or curves for inorganic and organic (volatile and nonvolatile) compounds; these isotherms indicate how the extent of adsorption varies with the equilibrium concentration of the solute.

1.3 Contingencies within these methods allow for the construction of adsorption isotherms at various solute concentration ranges.

1.4 These methods can be used for constructing adsorption isotherms to study the adsorption behavior of solutes in synthetic waste solutions, laboratory extracts, or field leachates including aerobic and anaerobic solid-liquid systems.

2 Summary of Methods

The experimental design of these methods is based on a batch technique as opposed to a column approach. Two general techniques for obtaining adsorption data are incorporated in these methods. The first technique involves mixing a batch of solutions, each with the same volume but containing serial dilutions of the initial solute concentrations, with a fixed mass of adsorbent in each reaction vessel. The second technique involves mixing a batch of solutions, each with the same volume and initial concentration of the solute, with different amounts of the adsorbent. In either case, the change in solute concentrations after contact with the adsorbent provides the basis for the construction of adsorption isotherms (chapter 12). The appropriate soil:solution ratios and equilibration times are determined to maximize the accuracy of the adsorption isotherm and to complement analytical capabilities.

3 Interferences

Solutes of unknown stability must be handled with care to determine whether precipitation, hydrolysis, photodegradation, microbial degradation, oxidation-reduction (e.g., Cr^{3+} to Cr^{6+}), or other physicochemical processes are operating at a significant rate within the time frame of the procedure. The instability and hence loss of the solute from solution may affect the outcome of this procedure (see chapter 4). The com-

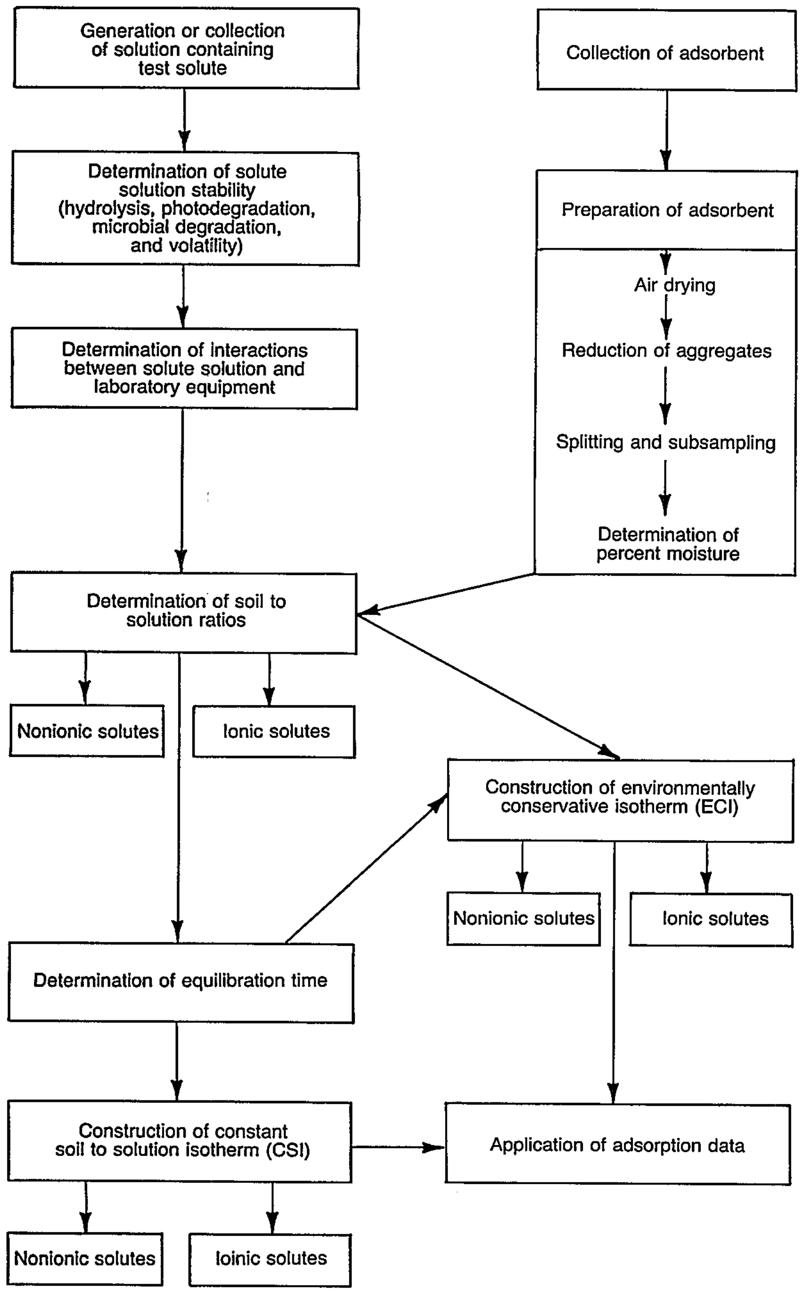

Figure 44 Flow diagram of the procedures for generating batch adsorption data.

patibility of the method and the solute of interest may be assessed by determining the differences between the initial solute concentration and the final blank concentration of the solute. If this difference is greater than 3%, then the adsorption data generated must be carefully evaluated (see 8.5.11).

4 Terminology and Definitions

4.1 Solute—chemical species (e.g., ion, molecule) in solution

4.2 Solute solutions include:

4.2.1 A solution of reagent water containing a known amount of a solute derived from laboratory reagents.

4.2.2 A solution containing a variety of solutes extracted from a material in a laboratory setting by the use of methods such as the ASTM-A or ASTM-B extraction procedures. (Note: neither the EPA Extraction Procedure nor the proposed Toxicity Characteristic Leaching Procedure is recommended. These procedures were designed for waste classification and were not intended to produce solutions that mimic in-situ leachates.)

4.2.3 A solution containing a variety of solutes collected in a field situation representing a leachate or waste effluent.

4.3 Adsorption—a physicochemical process whereby solutes are retained by an adsorbent and concentrated at solid-liquid interfaces (chapter 1).

4.4 Adsorbate—chemical species adsorbed by an adsorbent.

4.5 Adsorbent—substance that adsorbs the solute from solution.

5 Equipment and Procedural Requirements

5.1 Laboratory equipment

5.1.1 Agitation equipment: the National Bureau of Standards extractor (rotating tumbler) or equivalent will be used exclusively as the agitation apparatus (chapter 8).

5.1.2 Rotation rate: with procedures involving inorganic, volatile, and nonvolatile organic compounds, the rotary extractor will be operated at 29 ± 2 rpm.

5.1.3 Glove box or bags: when anaerobic adsorbent-solute systems are being handled, these procedures may have to be conducted in air-tight enclosures filled with an oxygen-free inert gas (e.g., N_2, Ar) to prevent or retard oxidation.

5.2 Phase-separation equipment

5.2.1 Inorganic compounds: a filtration apparatus made of materials compatible with the solutions being filtered and equipped with a 0.45-µm pore-size membrane filter or a constant-temperature centrifuge capable of separating ≥0.1-µm particles will be used to separate the solid phase from the solid-liquid suspensions.

5.2.2 Filtration membrane: if filtration is used, the affinity of the filtration membrane for the solute must be evaluated to prevent errors in the results.

5.2.3 Organic compounds: a constant-temperature centrifuge, compatible with the reaction containers and capable of separating ≥0.1-µm particles, should be used for organic solutes. The transfer of the organic solute solutions from the reaction containers to centrifuge containers is not an acceptable procedure because of adsorption, volatilization, and other losses. The reaction container should be used as the centrifugation container. Filtration of organic solutions is not a recommended practice (chapter 7).

5.2.4 Calculation of centrifugation time may be calculated by using equation 1,

$$t = \frac{9\eta \ln (R_b/R_t)}{2\omega^2 r^2(\rho_p - \rho)} \quad [1]$$

where $\omega^2 = \frac{4\pi^2(\text{rpm})^2}{60}$

t = time (min),

η = viscosity of water (8.95×10^{-3} g/sec-cm at 25°C),

r = partical radius (cm),

ρ_p = partical density (g/cm^3)

ρ = density of solution (g/cm^3),

rpm = revolutions per minute,

R_t = distance (cm) from the center of the centrifuge rotor to the top of solution in centrifuge tube, and

R_b = distance (cm) from the center of the centrifuge rotor to bottom of the centrifuge tube.

Removal of particles that are as small as 0.1 µm in radius and have a particle density of 2.65 g/cm^3 from a solution with a density of 1 g/cm^3 may be estimated using equation 2,

$$t\,(\text{min}) = \frac{3.71 \times 10^8}{(\text{rpm})^2} \ln(R_b/R_t) \qquad [2]$$

5.3 Reaction containers

5.3.1 Inorganic solutes: containers compatible with the rotary extractor should be used with inorganic solutes. The containers shall be composed of materials that adsorb negligible amounts of the solute. They must have a watertight closure made of chemically inert materials (polypro-pylene, Teflon, or similar material). The size of the container should be such that the solid and liquid phases will fill about 80% to 90% of the container.

5.3.2 Nonvolatile organic solutes: amber glass serum bottles and stainless steel centrifuge tubes or bottles compatible with the rotary extractor and centrifuge are suggested to be used in conjunction with nonvolatile organic solutes. The container must have a watertight closure made of chemically inert materials (Teflon, plastic, or similar material). The size of the container must be compatible with the centrifuge, and be such that the volume of the solid and liquid phases should fill 80% to 90% of the container.

5.3.3 Volatile organic solutes: amber glass, 125-mL serum bottles (Wheaton no. 223787 or equivalent) fitted with Teflon septa (Pierce no. 12813 Tuf-Bond Discs or equivalent) will be used with volatile organic solutes. The size of this serum bottle (125 mL) is compatible with several types and brands of centrifuges. This size provides sufficient volume such that the volume of the solid and liquid should occupy 100% of the container (i.e., there should be no head space).

5.3.4 Note that the commonly available materials for containers can be ranked starting with the material most inert with respect to the adsorption of hydrophobic solutes (T.C. Voice, written communication, 1986):

- Corex,
- Pyrex (not much different from Corex),
- silanized serum bottles,
- other glasses, and
- stainless steel, Teflon, and plastic.

5.4 Reagents

5.4.1 Reagent-grade chemicals will be used in all experiments and must conform to the specifications of the American Chemical Society. Other grades may be used, provided that the reagent is pure enough to be used without lessening the accuracy of the determination.

5.4.2 Unless otherwise indicated, references to water mean type IV reagent water, as defined in the Handbook for Analytical Quality Control in Water and Wastewater (EPA-600/4-79-019).

5.5 Solute Solution and Adsorbent Requirements

5.5.1 To construct adsorption isotherms for inorganic solutes, a minimum of 5 liters of solute solution would be required, based on the use of 200-mL samples of the solute solution with 250-mL reaction containers. Investigators using reaction containers that are a different size should adjust the estimated total volume of solution proportionately.

5.5.2 To construct adsorption isotherms for organic solutes, approximately 9 liters of solute solution would be required, based on the use of 100-mL samples of the solute solution with 125-mL reaction containers. Investigators using different-sized reaction containers should adjust the estimated total volume of solution proportionately.

5.5.3 The mass of adsorbent required to complete this procedure will vary depending on the volume of reaction containers, soil:solution ratios, and related factors. Based on 250-mL reaction containers and the minimum soil:solution ratio of 1:4 (50 g adsorbent per 200 mL of solute solution), about 2 kg of adsorbent would be required.

5.5.4 This procedure should take about 5 to 9 days, excluding time for analysis.

6 Volatile Organic Solutes: Experimental Considerations

6.1 Stock solutions could either be purchased as certified solutions or prepared from pure standard materials (liquid or gaseous phases). Solutions should be prepared in methanol. The use of pipettes to transfer solutions cannot be recommended; glass syringes should be used to prevent losses due to volatization. Because of the toxicity of some volatile organic compounds, solutions should be prepared and transferred in a fume hood, and a NIOSH/MESA-approved toxic-gas respirator should be used by the analyst.

6.2 Preparation of stock volatile solute solutions

6.2.1 Place approximately 9 mL of methanol into a 10-mL ground glass stoppered volumetric flask. Allow the flask to stand open until all methanol-wetted surfaces have dried. Weigh the flask with the remaining methanol to the nearest 0.01 mg. Using a syringe, immediately add the test solute, until the change in weight of the flask corresponds to the desired concentration of the test solute in the methanol. Be sure that the drops of solute fall directly into the methanol without contacting the neck or sides of the flask. Dilute to volume with methanol, put the stopper on the flask, and mix by inverting it several times.

6.2.2 Transfer the stock solution into a Teflon-sealed screw-cap vial. Store, with little or no head space, at approximately 4°C. All stock solutions must be replaced after 1 month, or sooner if a comparison with quality-control standards indicates a loss of accuracy.

6.2.3 Stabilize the temperature of the stock solution at 20°C before preparing secondary solutions.

6.2.4 Store all solutions so that head space within the container is zero or minimal.

6.3 Preparation of volatile organic compound solutions

6.3.1 Place 990 mL of type IV water that has been boiled and cooled to 20°C into each of a series of clean 1-L amber-glass bottles. (Generally eight solute concentrations are required for completion of the adsorption procedures.) Seal the bottles with open-top screw caps fitted with Teflon-lined septa.

6.3.2 Inject measured amounts of the stock solution (prepared as described in section 6.2) into each of the bottles. Mix by inverting the bottles several times but avoid excessive shaking, which may result in partial loss of the solute.

6.3.3 Solutions stored in containers with head space are not stable and should be discarded 1 hour after preparation if not used in an experiment.

6.4 Filling of reaction containers

6.4.1 Immediately upon completing the steps described in section 6.3, pour each solute solution carefully—to minimize agitation—into preweighed reaction containers or other containers that have a predetermined volume (section 6.5) and contain specific amounts of adsorbent. Fill the containers completely; allow no head space. Shake gently to remove trapped air from the adsorbent. Place the Teflon-faced septum and aluminum seal on the container and invert to be sure no head space remains.

6.5 Determination of Reaction Container Volume

6.5.1 When transferring the solutions prepared as described in section 6.3 into the reaction containers, pour them quickly but gently into containers of predetermined weight or volume.

6.5.2 Because the volume of solute solution is not measured during transfer into the reaction containers, this volume is determined indirectly.

6.5.3 Reaction vessels containing the same amount of adsorbent as those described in section 6.4 to determine the container volume for each soil:solution ratio. Pipette type IV water is pipetted into each container until there is no head space. With a calibrated syringe, measure the water added to each of the containers. The amount of solute solution referred to in section 6.4 should be the volume as determined in this section (6.5).

6.5.4 Alternatively, determine the volume of solution added (described in section 6.4) by weighing the container with the adsorbent before and after adding the solution. The weight can be converted to a volume if the density of the added solution is known.

6.6 Throughout all experiments, use blanks to determine effects of adsorption/desorption from containers as well as losses due to volatilization. Refer to section 8.5.11 for discussion of blanks.

6.7 For more information on preparing solutions for volatile constituents or the analyses of these constituents, refer to U.S. EPA test methods 601 and 602 in Methods for Organic Analysis of Municipal and Industrial Wastewater (EPA-600/4-82-057).

7 Preparation of Adsorbents

7.1 Spread samples of adsorbents such as soils, clays or sediments out on a flat surface in a layer no more than 2 to 3 cm deep. Then allow them to air dry, out of direct sunlight, until they are in equilibrium with the moisture content of the room atmosphere. The sample should be dried enough to facilitate processing and subsampling. Do <u>not</u> oven-dry samples (chapter 2). Process anaerobic samples in a similar manner for these and subsequent steps, but these operations should be conducted in a glove box or glove bag filled with an oxygen-free inert gas (e.g., N_2 or Ar) to prevent oxidation.

7.2 Weigh the entire sample after it has been air-dried. Pass the sample through a 2-mm-screen sieve. Using a clean mortar and rubber-tipped pestle, crush large aggregates without grinding the sample. Aggregates such as pebbles and stones that cannot be crushed should be removed, collected, and weighed.

7.3 Mix the sieved material until the sample is homogeneous. To obtain subsamples of size, use a riffle splitter or some other unbiased splitting procedure (*Annual Book of ASTM Standards:* method C702, Reducing Field Samples of Aggregate to Testing Size, in part 14; or method D2013-72, Preparing Coal Samples for Analysis, in part 26).

7.4 Determine the moisture content of the air-dried sample by using method D2216, Laboratory Determination of Moisture Content of Soils, from *Annual Book of ASTM Standards*, part 19.

7.5 Determine the mass of the sample, corrected for moisture content, required for study.

7.5.1 Determine the air-dry soil (adsorbent) mass equivalent to the desired mass of oven-dried soil:

$$A = M_s [1 + (M/100)]$$

where A = air dry soil mass (g),
M_s = mass of oven-dried soil desired (g), and
M = percent moisture

8 Determination of Soil:Solution Ratios for Ionic Solutes

8.1 A series of soil:solution ratios ranging from 1:4 to 1:500 should be tested and evaluated for the construction of adsorption isotherms (chapters 9 and 11).

8.2 The soil:solution ratio is defined as the oven-dry equivalent mass of adsorbent in grams (section 7.5) per volume in milliliters of solution.

8.3 Recommended soil:solution ratios are 1:4, 1:10, 1:20, 1:40, 1:60, 1:100, 1:200, 1:500. Ratios greater than 1:500 are rarely needed for most ionic solutes. In circumstances requiring soil:solution ratios greater than 1:500 that meet the criteria outlined in section 8.5.14, use the ratios 1:1000, 1:2000, 1:5000 and 1:10,000. The determination of a soil:solution ratio may be an iterative process, whereby the eight ratios between 1:4 and 1:500 are tested before attempting the extremely "dilute" systems (1:1000, and higher). Using an iterative process will reduce the amount of solute solution used, and will help ensure that enough solution will exist to complete the entire procedure. Ratios less than 1:4 should not be used because of limitations in mixing.

8.4 An example of how different soil:solution ratios are made is given below for an air-dried sample with a moisture content of 3%:

Soil:solution ratio (g/mL)	Air-dry weight (g)	Oven-dry equivalent of adsorbent (g)	Volume of solution containing solute (mL)
1:4	51.5	50.0	200
1:10	20.6	20.0	200
1:20	10.3	10.0	200
1:40	5.15	5.00	200
1:60	3.43	3.33	200
1:100	2.06	2.00	200
1:200	1.03	1.00	200
1:500	0.412	0.400	200

8.5 Soil:solution procedure

8.5.1 Calculate the masses of adsorbent samples for the various soil:solution ratios based on an oven-dried equivalent weight (section 7.5), such that for nonvolatile solutes, the volume of adsorbent plus solution occupies 80% to 90% of the container and for volatile solutes 100%.

8.5.2 Weigh the samples of adsorbent to be used in the soil:solution series. If handling anaerobic adsorbent-solute systems, conduct steps 8.5.2 to 8.5.7 in a glove box or bag before placing the containers on the rotary extractor.

8.5.3 Place the weighed samples into clean, labeled containers.

8.5.4 Pipette the solution containing the solutes (stock solution) into each container holding the adsorbent. The volume of solution should be identical in all containers.

8.5.5 Pipette the stock solution into a container holding no adsorbent. This sample will be the "blank" and designated as C_B. For each set of tests a minimum of one blank, and preferably three blanks, should be tested simultaneously and under identical conditions as the samples.

8.5.6 Close the bottles, ensuring a watertight seal, and place on a rotary tumbler for mixing.

8.5.7 Collect, preserve, and analyze an aliquot of the stock solution to determine the initial concentration of the solute(s) before contact with reaction containers, adsorbent, phase separation materials, and other surfaces. This sample will be designated as C_0. The volume and preservation techniques of the aliquot will vary depending on the solute and analytical method.

8.5.8 Continuously agitate samples at 29 ± 2 rpm for 24 ± 0.5 hours at room temperature (22 ± 3°C).

8.5.9 After 24 hours of agitation, open containers. If the suspensions are anaerobic, return the containers to a glove box or bags prior to opening the containers and make all measurements in the inert atmosphere of the glove box or bag. Observe and record the solution temperature, pH, and any changes in the adsorbent or solution.

8.5.10 Separate the solid and liquid phases of each sample, using either centrifugation or filtration (section 5.2). Determine the electrical conductivity of an aliquot of each supernate (see chapter 6). Collect and preserve aliquots of each supernate of sufficient volume to determine the solute concentration.

8.5.11 After analysis of all the solutions generated by the soil:solution procedure, compare the initial solute concentration(s) and blank samples to determine whether there was adsorption or desorption of the solute onto or from surfaces other than the adsorbent. If the difference between the blank and initial solute concentrations is greater than 3%, the adsorption data must be corrected. To make this assessment, determine the percent difference between the initial concentration and the blank solute concentration:

$$\%D = \frac{(C_0 - C_B)}{C_0} \times 100$$

where $\%D$ = percent difference,
C_0 = initial solute concentration (mg/L, µg/L), and
C_B = solute concentration (mg/L, µg/L) in blank solution.

If $\%D$ is a negative value, the solute concentration in the blank was greater than the initial solute concentration. Subtract the difference in concentration from all adsorption data, excluding the stock or initial concentration value.

8.5.12 Using the analyzed initial solute concentration and the final solute concentration for the various soil:solution ratios tested, calculate the percent of solute adsorbed:

$$\%A = \frac{(C_0 - C\,)}{C_0)} \times 100$$

where $\%A$ = percent adsorbed,
C_0 = initial solute concentration (mg/L, µ/L), and
C = solute concentration after contact with the adsorbent.

A negative value implies a contamination problem. Examine the laboratory technique and/or cleaning procedures. The adsorbent may contain previously adsorbed constituents that are desorbing into solution.

8.5.13 Select a soil:solution ratio indicating between 10% and 30% adsorption of the highest solute concentration. Use this ratio to determine the equilibration time (chapter 10) and to generate data for construction of a constant soil:solution isotherm (CSI). Often, several soil:solution ratios will generate between 10% and 30% solute adsorption. Selection of a specific soil-to-solution ratio is the investigator's prerogative, with the limitation that it be one listed in section 8.3 (chapters 9 and 11).

9 Determination of Soil:Solution Ratios for Nonionic Solutes

9.1 For ionic solutes, a suitable soil:solution ratio must be determined empirically, but a useful soil:solution ratio for nonionic solutes (hydrophobic organics) can be calculated if the organic carbon content of the adsorbent and the water solubility of the solute are known. The equations and their derivations for determining the soil:solution ratios for nonionic solutes are given in chapter 10.

9.2 The soil:solution ratios listed in section 8.3 most closely matching the calculated soil:solution ratio shall be used throughout this procedure. If the calculated ratio is in the middle of two ratios listed in section 8.3, the lower ratio (greatest mass of absorbent per milliliter of solute) is recommended to obtain the highest precision and accuracy.

10 Determination of Equilibration Time

10.1 To determine equilibration time, use the soil:solution ratio as determined in section 8.5.13 for inorganic solutes and in section 9 for hydrophobic organic solutes.

10.2 Use a minimum of four agitation intervals to determine the equilibration time. Recommended intervals are 1, 24, 48, and 72 hours, and represent the amount of time the solution and adsorbent are in contact.

10.3 Weigh the adsorbent on an oven-dry basis (section 7.5) and place into clean, labeled containers. If handling anaerobic systems, perform steps 10.3 and 10.8 in a glove box or bag before placing the containers on the rotary extractor.

10.4 Pipette the solute solution into the various containers at the times designated in step 10.2. Immediately cap the container and place on the rotary extractor and agitate at 29 ± 2 rpm at room temperature (22 ± 3°C).

10.5 Pipette the solute solution into a container containing no adsorbent. Agitate this blank sample for 72 hours.

10.6 Collect, preserve, and analyze an aliquot of the stock solute solution.

10.7 Remove the containers at the designated times from the rotary extractor and record the solution temperature, pH, and any changes in the adsorbent or solution. If handling anaerobic suspensions, return the containers to a glove box or bag before opening the containers.

10.8 Separate solid and liquid phases using centrifugation or filtration (section 5.2). Determine the electrical conductivity of an aliquot of each supernate. Collect and preserve aliquots of each supernate in sufficient quantity for determining the solute concentration.

10.9 Determine the rate of change in the solute concentrations at the various times by

$$\%\Delta C = \frac{(C_1 - C_2)}{C_1} \times 100$$

where
$\%\Delta C$ = percent change
C_1 = concentration of the solute at time t, and
C_2 = concentration of the solute after 1, 24, 48, or 72 hours.

10.10 The equilibrium time is defined as the minimum amount of time needed to establish a rate of change of the solute concentration equal to or less than 5% per a 24-hour interval (see chapter 13).

11 Construction of the Environmentally Conservative Isotherm (ECI)

11.1 Construction of an ECI requires that the soil:solution (sections 8 and 9) and equilibrium (section 10) procedures be completed.

11.2 If the equilibrium time as determined in section 10.9 is equal to or less than 24 hours, use the data obtained from the soil:solution procedure to construct an ECI. However, if the equilibrium time is greater than 24 hours, the soil:solution ratio determination procedure must be repeated at the equilibrium time determined by section 10.9. (Refer to chapter 12 for discussion of the advantages and limitations of the ECI.)

11.3 Because section 9 yields a single soil:solution ratio for nonionic solutes, select additional ratios that bracket the calculated ratio. Use a minimum of eight soil:solution ratios selected from those listed in section 8.3. Evaluate these ratios as outlined in section 8.5. When volatile solutes are under study, refer to section 6 for experimental considerations.

11.4 Use a minimum of five data points to construct an ECI. Solution ratios resulting in less than 10% adsorption of the solute should not be used to construct the ECI (refer to chapter 12 for justification). If less than five data points were obtained, vary the recommended soil:solution ratios to generate additional data.

11.5 Using the data generated by the soil:solution procedure, calculate the amount of solute adsorbed per mass of adsorbent.

11.5.1 Determine the amount of solute adsorbed per mass of adsorbent by

$$x/m = \frac{C_0 - C}{m}(V)$$

where x/m = amount of solute adsorbed per unit mass of adsorbent,
m = mass of adsorbent (oven-dried basis) in grams added to reaction container,
C_0 = initial solute concentration (determinedanalytically) before exposure to adsorbent,
C = solute concentration after exposure to adsorbent at equilibrium, and
V = volume of solute solution added to reaction container.

11.6 Construction of an ECI requires (1) an x/m value for each soil:solution ratio that meets the criteria in 11.2, and (2) the corresponding equilibrium concentration value (C) of the solute.

11.7 Construction of an ECI

11.7.1 Using linear graph paper, plot the equilibrium concentration (C), log C, or $C/x/m$ on the coordinate (x axis) and the corresponding x/m, log x/m, or C value as the dependent variable (y axis). Refer to chapter 12 for an example.

11.7.2 Fit an adsorption equation to the data plotted in 11.5.1. The Freundlich or a Langmuir-type equation may be applicable.

11.7.3 The linear expression of the Freundlich equation is

$$\log(x/m) = K_f + 1/n \log C$$

where x/m = amount of solute adsorbed per unit mass of adsorbent,
K_f = a constant,
$1/n$ = a constant (sometimes written as N), and
C = equilibrium concentration of solute after contact with adsorbent.

A linear regression can be used to fit a curve through the data plotted in 11.5.1, where the intercept equals log K_f and the slope equals $1/n$. An example in which the Freundlich equation is used is given in chapter 14.

11.7.4 A linear expression of the Langmuir-type equation is:

$$\frac{C}{x/m} = \frac{1}{K_L M} + \frac{C}{M}$$

where x/m = amount of solute adsorbed per unit mass of adsorbent,
K_L = a constant,
M = a constant, and
C = equilibrium concentration of the solute after exposure to adsorbent.

A linear regression can be used to fit a curve through the data plotted in 11.7.1, where the intercept equals $1/K_L M$ and the slope equals $1/M$. Examples using Langmuir-type equations are given in chapter 14.

11.7.5 Calculate the coefficient of determination (r^2) of the regression. Examples are given in chapter 15.

11.7.6 Use the equation that results in the coefficient of determination value closest to 1.0 to generate a curve through the data plotted in 11.7.1.

11.7.7 The data plotted in 11.7.1 and the curve of best fit from 11.7.6 represent an ECI.

11.7.8 Report the following information with the ECI:

- temperature at which the tests were conducted,
- pH and electrical conductivity (EC) of all solute solutions,
- concentrations of stock (C_0) and blank (C_B) solute solutions and the factor, if any, used to correct data,
- soil:solution ratios, corresponding quantity of solute solution and mass of adsorbent, initial (C_0) and final (C) solute concentration, and the percent of solute adsorbed,
- $\%\Delta C$ for each equilibration time,
- equation for the line of best fit and corresponding r^2 value, and
- complete description of the adsorbent.

12 Construction of the Constant Soil:Solution Ratio Isotherm (CSI)

12.1 The CSI requires the initial solute concentration to vary and the mass of adsorbent to remain constant—unlike the ECI, which holds the initial concentration of the solute constant and varies the mass of adsorbent in each containers. (Chapter 12 presents advantages and limitations of both techniques.)

12.2 Use the recommended soil:solution ratio, $\%A$ between 10% and 30% (section 8), and equilibrium time, $\%\Delta C < 5\%$ per 24-hour interval (section 10), in the construction of a CSI.

12.3 Weigh the adsorbent (mass prescribed by the soil:solution ratio) into clean, labeled containers. If handling anaerobic adsorbent-solute systems, conduct steps 12.3 to 12.5 in a glove box or glove bag.

12.4 Make a series of approximately eight dilutions of the stock solute solution so that the series shows a progressive decrease in solute concentration. In the most dilute solution, the solute concentration should be sufficient so that the amount remaining in solution is above detection limits after contact with the adsorbent. The volume of each diluted solution necessary for construction of the CSI will depend upon the size of the reaction container used.

12.4.1 The dilution of complex solutions may cause changes in pH and/or redox potential with the subsequent precipitation of the solute(s) (see chapter 11). Try to limit such reactions, or if not possible, use the procedures in section 11 to create adsorption isotherms.

12.5 Immediately after the dilutions of the stock solute solution, pipette the diluted solutions into the containers holding the adsorbent. Each solution should have a corresponding container and the volume of solution in all containers should be equal.

12.6 Place the containers on the rotary extractor at 29 ± 2 rpm at room temperature (22 ± 3°C). Agitate for the time determined in section 10. Collect and preserve aliquots of the stock solute solution, *and all dilutions* using accepted techniques (e.g., *Standard Methods for the Examination of Water and Wastewater*, American Public Health Association, 1985, 16th ed., Washington, DC, p. 38-45).

12.7 After the agitation period, remove the containers from the rotary extractor and open. If the suspensions are anaerobic, return the containers to a glove box or bag, then open the containers. Observe and record the solution temperature, pH, and any changes in the adsorbent or solution.

12.8 Separate the solid and liquid phases using either centrifugation or filtration (section 5.2). Determine the electrical conductivity of an aliquot of each supernate. Collect and preserve aliquots of each supernate of sufficient volume for the solute concentration determinations.

12.9 Determine the solute concentration in the stock solution, the dilute solutions before (C_0 in equation 11.5.1) and after (C in equation 11.5.1) exposure to the adsorbent. If significant differences in the blank solutions (section 8.5.11) are ascertained, the adsorption data must be corrected.

12.10 Using the data generated where the various solute concentrations were exposed to the same mass of adsorbent, calculate the amount of solute adsorbed per mass of adsorbent (x/m). Refer to equation 11.5.1 for calculation of x/m.

12.11 Construction of the CSI requires (1) an x/m value for each solute concentration, and (2) the corresponding equilibrium concentration value (C) of the solute.

12.12 For constructing the CSI, follow the same procedure and reporting requirements as the ECI. Refer to section 11.5 for directions on construction of the ECI/CSI.

Veritas Laboratories

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DETERMINATION OF SPECIFIC GRAVITY (RELATIVE DENSITY) OF AQUEOUS SAMPLES

ASTM D1429-13

STANDARD OPERATING PROCEDURE 2040VL

Effective Date: May 6, 2015
Revision No.: 0.00

APPROVED BY:

5/8/15
Bruce Cunningham — Date
Laboratory Director/QA Manager

5/8/15
Stan Van Wagenen — Date
Technical Director/QA Manager

Determination of Density (Relative) of Aqueous Samples
SOP #2040VL

1.0 SCOPE AND APPLICATION

1.1 This method is applicable to surface, ground, and saline waters, domestic and industrial waste waters and acid rain (atmospheric deposition). It is not intended for the determination of the specific gravity (relative density) of aqueous matrices with mud or sludge or for solid materials.

2.0 METHOD SUMMARY

2.1 This method describes the determination of apparent specific gravity (apparent relative density) of a water sample. It is determined using a cylindrical vessel (Digitube) and an analytical balance. The weights of identical volumes of the water sample and reference solution are measured; the temperatures of the reference solution and the sample must be the same at the time of measurement. The quantitative difference between specific gravity and apparent specific gravity, at 20°C, is approximately 0.01% for a substance with a specific gravity of 1.100.

3.0 DEFINITIONS

3.1 Specific gravity (relative density) – the ratio of the density of a substance to the density (mass of the same unit volume) of a reference substance, generally determined at 20°C and 4°C, respectively, in the United States.

3.2 Specific Gravity, True (SG_V) – Specific Gravity measured in vacuum

3.3 Conversion of SG_A to SG_V: $SG_V = SG_A - [\rho_a \div \rho_w (SG_A - 1)]$ *Where,* ρ_a *= the density of air at the temperature measured and* ρ_w *= the density of water at the temperature measured*

4.0 SAMPLE PRESERVATION, CONTAINERS, HANDLING AND STORAGE

4.1 Samples should be collected in a clean, unpreserved, HDPE or glass container.

5.0 INTERFERENCES AND POTENTIAL PROBLEMS

5.1 If solid material is present in a sample, the sample must be filtered using a 0.45µm filter.

5.2 Oils in the sample will also interfere.

6.0 EQUIPMENT/APPARATUS

6.1 50mL HDPE Digitube

6.2 Oxford BenchMte II 1-10mL Pipettor

6.3 Analytical balance (Denver Instruments M-120) accurate to 0.0001 grams.

6.4 NIST-traceable digital thermometer

7.0 REAGENTS AND STANDARDS

7.1 Reference solution: Laboratory reagent water at ambient room temperature

8.0 PROCEDURE

8.1 Allow a 100mL volume of the reference solution (in a clean plastic or glass container) and all samples to reach room temperature. Measure and record the temperatures, ensuring that the reference solutions and all samples have reached room temperature.

8.2 Place an empty 50mL HDPE Digitube on the top-loading balance and tare.

8.3 Withdraw a 10mL aliquot of the reference solution using a calibrated 10mL pipettor and place it into the Digitube.

8.4 Record the weight of the current aliquot of reference solution contained in the Digitube (g/10mL).

8.5 Tare the Digitube containing 10mL of the reference solution and repeat steps 8.3 and 8.4 (total volume in Digitube will be 20mL).

8.6 Tare the Digitube containing 20mL of the reference solution and repeat steps 8.3 and 8.4 (total volume in Digitube will be 30mL).

8.7 For each water sample, repeat steps 8.2 through 8.6, replacing "reference solution" with "water sample", and record the temperature and the three measured weights. The temperature of each sample must be the same as the temperature of the reference solution.

9.0 QUALITY ASSURANCE/QUALITY CONTROL

9.1 Ensure analytical balance has been checked for accuracy, using a certified 5.0 gram weight.

9.2 A laboratory control standard (LCS), or Quality Control Sample, may be analyzed with each batch at a frequency of one per day or every twenty (20) samples, whichever is more frequent. Acceptable limits for percent recovery are 85% - 115% of the known value.

9.3 A duplicate analysis must be performed with each sample batch at a frequency of one per day or every twenty (20) samples, whichever is more frequent. The Relative Percent Difference (RPD) for duplicate results must be 15% or less.

10.0 CORRECTIVE ACTIONS

10.1 If the LCS for the batch is unacceptable, the entire analytical batch must be re-analyzed. If there is insufficient sample for re-analysis, the results may be reported but must be flagged with the "S" data qualifier.

10.2 If the RPD is exceeded for a sample, the sample should be re-analyzed in duplicate. A second RPD failure requires that the result be reported with a "R" data qualifier, while an acceptable RPD allows the re-analysis results to be reported without a data qualifier.

11.0 CALCULATIONS

11.1 Calculate the average weight of the three aliquots for each sample and the reference solution.

11.2 Calculate the apparent specific gravity (apparent relative density) of the aqueous sample to the nearest 0.0001 using the following equation:

$$SG_A = \frac{\text{average weight of the sample, g/10mL}}{\text{average weight of reference solution, g/10mL}}$$

where:

SG_A = apparent specific gravity (apparent relative density)

Note: The samples and reference solution are at the same temperature at the time of their weight measurements.

12.0 DATA REVIEW AND VALIDATION

12.1 Data is reviewed by the analyst and by the Laboratory Director prior to reporting to the client. This review includes ensuring that the results comply with the QC acceptance criteria for this method.

13.0 REPORTING RESULTS

13.1 Final results are entered in the Laboratory Information Management System (LIMS) and final reports are printed from the LIMS. Reports are generated by the Laboratory Director, reviewed, signed and sent (electronically or by mail) to the client.

14.0 HEALTH AND SAFETY

14.1 Safe laboratory practices must be followed at all times. Safety glasses are required and gloves may be needed dependent on the samples be handled.

15.0 WASTE MANAGEMENT

15.1 Surface and saline waters may be disposed of in the laboratory sink.

15.2 Domestic and industrial wastes may be disposed of in the laboratory sink provided they are known not to be characteristically hazardous or if they do not contain substances prohibited by the laboratory's Waste Water Permit.

16.0 REFERENCES

16.1 ASTM D1429-13, *Standard Test Methods for Specific Gravity of Water and Brine*