June 20, 2017

Margaret Brunette
Wisconsin Department of Natural Resources
2300 N Dr Martin Luther King Jr Dr
Milwaukee, WI 53212
Margaret.brunette@wisconsin.gov

Subject: Groundwater Sampling Work Plan
Burnham Canal, Milwaukee, WI
BRRTS# 02-41-552940
NRT Project No. 2117

Dear Ms. Brunette:

On behalf of Miller Compressing Company (Miller), Natural Resource Technology, Inc., an OBG Company (NRT), is submitting this Groundwater Sampling Work Plan (Work Plan) for the Burnham Canal Site (Site) located in Milwaukee, WI (Figure 1). The Site consists of Miller's former wire reclamation furnace area and a portion of the Canal from the western terminus to the 11th Street Bridge. The southwest part of the Site is partially owned by Miller. Other portions of the south bank are owned by third parties, including by a foundry and an automobile scrap yard (not owned by Miller). Regional groundwater flow is towards Lake Michigan (i.e., west to east) and varies locally as influenced by utilities and the Canal system. The property mildly slopes towards the Canal on all sides. This Work Plan focuses on characterizing groundwater quality immediately downgradient of the former wire reclamation operations at the west end of the Canal (Figure 2).

Site investigation information required by Wisconsin Administrative Code Chapter NR 716 was previously documented in the Remedial Investigation (RI) Report (NRT, 2010), Preliminary Design Report (NRT, 2012), and Final Design Report (NRT, 2016). The proposed groundwater sampling in this Work Plan supplements the prior work.

TEMPORARY MONITORING WELL INSTALLATION

Three temporary monitoring wells will be installed at the locations shown on Figure 2 to evaluate groundwater quality within close proximity and downgradient of the former wire reclamation operations. The proposed locations will allow for an assessment of effects on groundwater associated with this former operation. The planned field activities will be completed in accordance with established NRT Standard Operating Procedures (Attachment 1), and are discussed further below.

Prior to drill rig mobilization, Site utilities will be identified and located. If necessary, the locations of the temporary monitoring wells shown on Figure 2 may be shifted to avoid local utilities or access constraints. The temporary monitoring wells will be installed using hollow stem auger drilling methods following NRT SOP 07-05-03. The wells will be drilled between 13 and 15 feet below ground surface (bgs), and will be installed and developed in accordance with NRT SOP 07-05-05. This protocol meets Wisconsin Administrative Code Chapter NR 141 requirements. The wells will be drilled to approximately 13 to 15 feet bgs to provide sufficient distance to the top of the well screen (ten foot screen) while also collecting the upper groundwater, documented at approximately 5 ft bgs (NRT, 2010). During drilling, the boring will be continuously logged in accordance with NRT SOP 07-06-03, meeting Wisconsin Administrative Code Chapter NR 141. Soil samples will not be collected from the boring.

If required by the disposal facility, a waste characterization sample will be collected from the cuttings and soil borings. Investigation derived waste (i.e., soil cuttings and well purge water) will be containerized in 55-gallon drums, labeled, and staged at a secure location at the facility pending disposal.

GROUNDWATER QUALITY SAMPLING

The purpose of the temporary wells is to establish the presence or absence of contaminants in groundwater that may be associated with prior releases from the former wire reclamation operations. Due to the historical industrial nature of the area, the sampling will focus on specific contaminants of concern. These contaminants are dissolved copper, dissolved lead, and polycyclic aromatic hydrocarbons (PAH).

Two groundwater sampling events will be conducted, the first no earlier than at least ten (10) days after well development to allow for the wells to stabilize. Preliminary sampling dates are provided in the Schedule section of this Work Plan. Water levels will be measured with an electronic water level indicator as outlined in NRT SOP 07-07-05 and then sampled using low-flow sampling methods in accordance with NRT SOP 07-07-07. A water level measurement will also be taken from the adjacent Canal. Field equipment will be calibrated prior to use as outlined in NRT SOP 07-11-01. Quality assurance/quality control samples will be collected at each event, as outlined in NRT SOP 07-04-07. Samples will be labeled and packaged in accordance with NRT SOP 07-03-01 and documented using chain-of-custody procedures outlined in NRT SOP 07-03-03. The samples will be picked up and transported via courier service for the analytical laboratory. Results of the groundwater sampling activities will be compiled and compared to the relevant Wisconsin Public Health Groundwater Quality Standards as outlined in Table 1 of Wisconsin Administrative Code Chapter NR 140. Field parameters will also be recorded during sample events and will include temperature, field conductivity, pH, dissolved oxygen, turbidity, and oxidation/reduction potential.

DOCUMENTATION

Upon receipt of initial laboratory data, NRT will perform Level II Data Verification in accordance with NRT SOP 01-03-01 to check for completeness, accuracy, and inconsistencies that may affect data quality and usability. This review includes requested parameters, hold times, correct methods, and laboratory QA/QC supporting data. Based on the review, revisions may be requested from the laboratory reports or qualifying flags may be added to the data.

In accordance with Wisconsin Administrative Code Chapter NR 716, the results collected from the temporary monitoring wells will be transmitted to WDNR within 10 days of receipt of the final lab reports. The transmittal will include a summary of field activities, soil boring logs, well construction and development forms, and analytical results.

SCHEDULE

The three temporary wells will be installed following approval of this Work Plan. Following the installation of the three temporary wells, the initial sampling round will take place no sooner than ten (10) days after successful installation and development. The second round of groundwater sampling will take place no sooner than thirty (30) days after the first sampling event. Following the second round of sampling, the temporary wells will be abandoned in accordance with NRT SOP 07-05-07, which meets Wisconsin Administrative Code Chapter NR 141. A preliminary schedule is provided below.

Work Task	Schedule
Temporary Well Installation and Development	July 2017
Collect and analyze groundwater samples (Round 1)	August 2017
Collect and analyze groundwater samples (Round 2)	September/October 2017

REFERENCES

Natural Resource Technology, November 2010, Remedial Investigation Report – Final. Burnham Canal Site, Milwaukee, Wisconsin.

Natural Resource Technology, November 2012, Preliminary Design Report. Burnham Canal Superfund Alternative Site, Milwaukee, Wisconsin.

Natural Resource Technology, July 2016, Final Design Report – Revision 2. Burnham Canal Superfund Alternative Site, Milwaukee, Wisconsin.

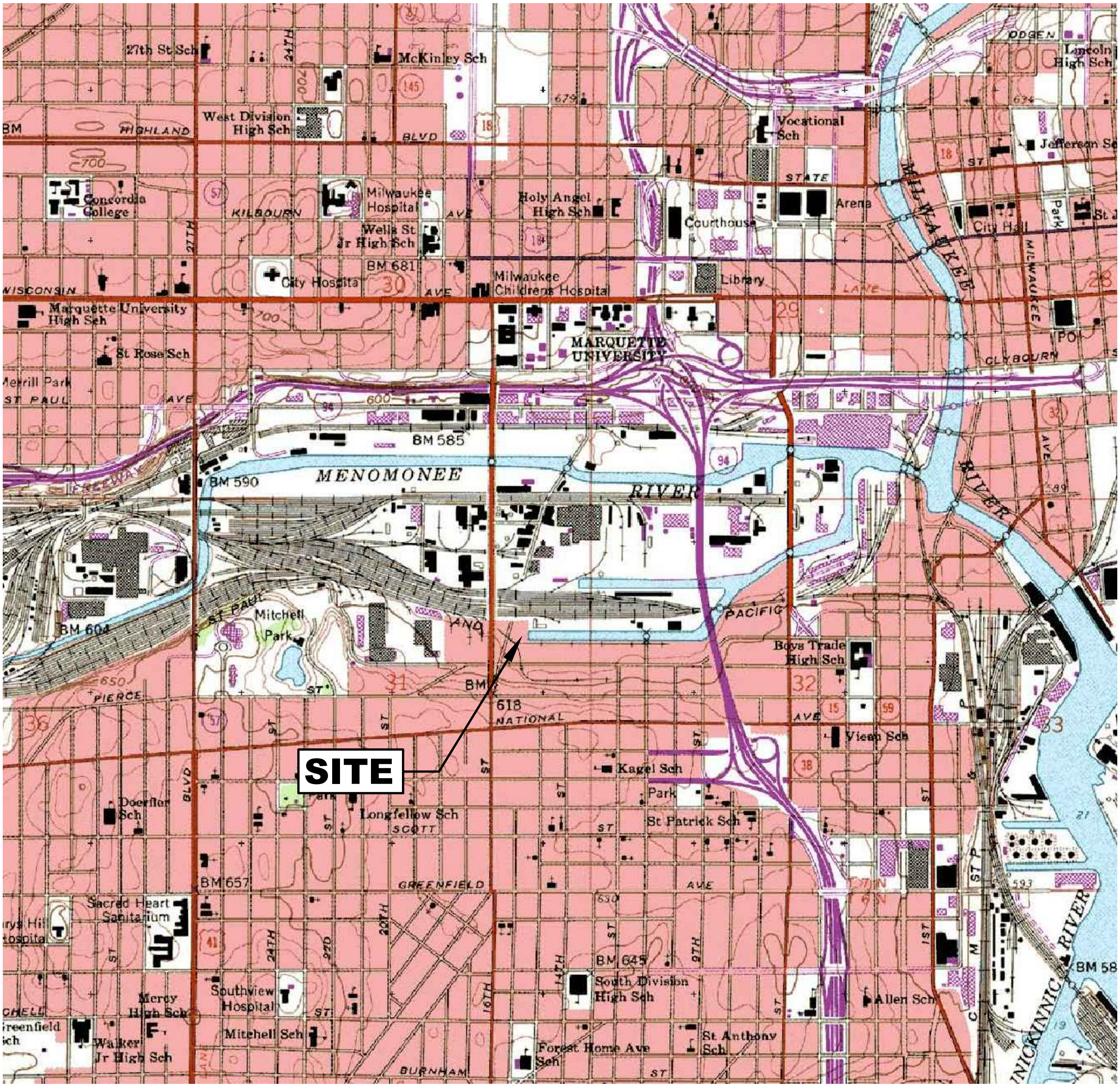
Sincerely,
NRT | An OBG Company

Andrew M. Millspaugh, PE
Environmental Engineer

Laurie L. Parsons, PE, PH
Principal Engineer/Hydrogeologist

Attachments: Figure 1 – Site Location
Figure 2 – Proposed Well Locations
Attachment 1 - NRT Standard Operating Procedures

FIGURES



SOURCE: EARTHVISIONS U.S. TERRAIN SERIES, © EARTHVISIONS, INC. 603-433-8500. USGS 7.5 MINUTE QUADRANGLE, MILWAUKEE. DATED 1958. PHOTOREVISED 1971.

QUADRANGLE LOCATION

N

0 2000 4000

SCALE IN FEET

CONTOUR INTERVAL 10 FEET

SITE LOCATION MAP

NATURAL RESOURCE TECHNOLOGY

BURNHAM CANAL
GROUNDWATER SAMPLING WORK PLAN
MILLER COMPRESSING COMPANY
MILWAUKEE, WISCONSIN

PROJECT NO. 2117/8.1

DRAWING NO. 2117-8.1-A01

FIGURE NO. 1

DRAWN: AMM DATE: 05/08/17 CHK'D: KJB DATE: 05/09/17 APP'D: AMM DATE: 05/09/17

May 09, 2017 2:45pm PLOTTED BY: MillspAM SAVED BY: MillspAM
Y:\Mapping\Projects\21\2117\CAD\8\2117-8.1-A01.dwg Layout1
IMAGES: Y:\Mapping\Projects\21\2117\CAD\SOURCE\MILWAUKEE.jpg; Y:\Mapping\Projects\21\2117\CAD\SOURCE\QUAD.jpg
XREFS:

DRAWN BY: AMM DATE: 05/04/17
CHECKED BY: KJB DATE: 05/09/17
APPROVED BY: AMM DATE: 05/09/17
DRAWING NO: 2117-8.1-B01
REFERENCE: See Info Block

PROPOSED SCREENING WELL LOCATIONS

BURNHAM CANAL
GROUNDWATER SAMPLING WORK PLAN
MILLER COMPRESSING COMPANY
MILWAUKEE, WISCONSIN

NATURAL RESOURCE TECHNOLOGY

PROJECT NO.
2117/8.1

FIGURE NO.
2

ATTACHMENT 1

NRT STANDARD OPERATING PROCEDURES

Prepared By:	JTB/SGW	Date Prepared:	02-13-2015
Corporate Officer:	DPK	Date Approved:	4-1-2015

DATA FLOW

1.1 Scope and Application

Natural Resource Technology, Inc. (NRT) is committed to continually improving the data flow process to make it efficient and consistent. This Standard Practice establishes policies and procedures concerning streamlining the flow, dissemination, and storage of field and laboratory analytical data, and outlines the roles and responsibilities of NRT staff.

1.2 Data Flow System

The Data Flow System was established for streamlining the process of receiving and filing field and analytical data and producing data deliverables. The benefit of this process is the ability to perform quality control checks at several steps during data processing, as well as standardization of electronic and hard copy filing. The data team is in part responsible for the quality control checks, electronic and hard copy filing, data import and production of data tables. The data team is responsible for the implementation of new standards as they apply to data management. Refer to Attachment A for a graphical representation of the Data Flow System.

1.3 Definitions

Several terms used in this Standard Practice may not be familiar to all staff that will use this document. The following terms are defined as follows:

- Super Tracker Table – Project-specific table of field and laboratory data compiled by the data group for tracking and importing data.
- Project–specific sampling documents – Documents compiled by the project team used to complete specific tasks. These may include but are not limited to the site-specific work plan, quality assurance project plan (QAPP), construction quality assurance project plan (CQAPP), and sampling summary.

- Import Summary – Report generated by the data group and includes a summary of the laboratory data sample designation groups that were brought into the NRT Enviro Data database.

- Quality Control – Set of procedures to ensure the quality of a service or product. It is a means of checking that samples were collected, analyzed and reported correctly.

- Quality Assurance - Maintenance of a desired level of quality in a service or product, especially by means of attention to every stage of the process of delivery or production.

- Level 2 Data Verification – Review of analytical data that includes holding times, analytical methods, surrogate recoveries, laboratory control sample recoveries, matrix spike and matrix spike duplicate recoveries and relative percent differences, method blank concentrations and reporting limits.

- Level 4 Data Validation – Comprehensive review of analytical data. This includes all of the Level 2 review items and recalculation of results, review of laboratory raw data, reconstructed ion chromatograms, initial and continuing calibration recoveries, initial and continuing blank concentrations, and other method-specific quality control data.

1.4 Roles and Responsibilities

Numerous individuals have roles and responsibilities in the collection and management of field, analytical and geotechnical data. No roles are more or less important than others and each contribute to the accurate and seamless approach to data management. Quality control is an especially important aspect of the data flow process and each staff member is responsible for some form of quality control. Staff and their responsibilities are described below.

1.4.1 Project Manager (PM)

PMs (or their designee) have responsibilities during all phases of data management which include the following:

- Generate a sampling summary form with a sampling summary matrix and server pathway for the project-specific sampling documents prior to the sampling event.

- Provide sample summary and anticipated level of QC necessary to Data Team.

- Review updated Super Tracker table (Attachment B) for conformance with the project-specific sampling documents:

    - Within 10 days of the completion of sample collection

    - Again when all analytical data is in-house
    - Bi-weekly for long-duration projects
- Coordinate third-party level 4 validation, if required, with the Data team and validation firm.
- Save level 4 validation files to project folder and review validation report. Data Team can assist with review.
- Review import summary report from the data team.
- Generate and send requests for data deliverables and mapping to the appropriate support team during any phase of the project.
- Review and finalize tables and figures.
- Define data quality objectives during kick-off meeting to explain roles/responsibilities, data schedules and sampling requirements.
- Return the GPS unit to the Mapping Team for post-processing (if required) of the sample coordinates information.
- If NRT did not collect any location information, submit a request to the company/individual who did the GPS data collection or survey and transmit it to the Mapping Team immediately upon receipt.

1.4.2 Field Staff

The field staff members for a given sampling event have the following responsibilities:

- Achieve a thorough and complete understanding of sampling and data requirements for the given project prior to mobilizing.
- Collect samples according to the sample summary provided by the PM, project-specific sampling documents, and the appropriate NRT standard field operating procedures. (NRT field operating procedures for sample collection and documentation are located at: W:\Operations\Standard Practices\Standard Operating Procedures\07 Field Procedures.)
- Complete field forms, chain of custody (COC), and sample control logs.
    - As a quality control (QC) check, the COC will be back-checked and initialed in the field by field staff who did not complete the COC, typically a team lead or other staff identified by PM in sampling event kick-off meeting.
- Send samples and completed COC to the laboratory according to NRT field SOPs.

- Provide the PM with a copy of the field documentation when samples are being submitted for analysis or as soon as is possible (within 10 days of sample submission).
- Complete field documentation of the PDF formats (i.e. field forms, field notes, copy of COC) and of the electronic version of the sample control log (SCL).
    - Provide server locations (links) of completed documents to PM and Data Team:
        - Within 10 days of the end of the field sampling event
        - Bi-weekly for long-duration projects

1.4.3 Data Team

The data team members have the following responsibilities:

- Create folders on the server according to the following structure:

- #### (Project Number)
    - Electronic Data Submittal
        - **2015**
        - **2016**
            - 01 January
            - 02 February
            - 06 June
            - 12 December
                - Air
                - Groundwater
                - Sediment
                - Soil
        - **Tables**
            - Data Team
            - Final
        - **Tracking**
            - **Project X Super Tracker.xlsx** *(spreadsheet)*

Contents of each media folder (e.g. Air):

- *COC (Chain of Custody).pdf*
- *Coordinates.xlsx*
- *Field Notes.pdf*
- *Lab report EDD file.xlsx*
- *Lab Report PDF document.pdf*
- *Lab SAF (Sample Acknowledgement Form).pdf*
- *RNA Field Data.xlsx*
- *SCL from project team (Sample Control Log).xlsx*
- Validation Report

- Create and maintain a Super Tracker table spreadsheet (Attachment B) according to project-specific sampling documents when the sample acknowledgment form is received from the laboratory and/or when field documentation is received. Update with electronic Sample Control Log (SCL) information and GPS coordinate data when available. The Super Tracker table is intended to capture all the information required to store data on the server.

- Receive electronic data deliverable (EDD) and lab report from laboratory, update Super Tracker table, save files on server and communicate the status of the data with the PM.

- Perform initial QC check on field data and notify project manager and field staff via e-mail of initial quality control check results.

- Perform Level 2 data verification (if requested) and communicate results to PM.

- Assist PM with Level 4 data validation coordination, if requested.

- Review level 4 validation reports and validated EDD for accuracy and completeness according to the USEPA National Functional Guidelines for Data Review and project-specific documents.

- Perform 10% check of EDD against the laboratory report. If errors are found, additional checking will be performed until the Data Team is confident the data is correct.

- Import data to the NRT Enviro Data database.

- Send import summary report to the PM. This report is generated by the Enviro Data system and is used to track what data has been loaded into the database.

- Generate requested data deliverables.

1.4.4 Mapping Team

The Mapping Team will work with the PM, field staff and the Data Team in the following capacities:

- Download GPS sample coordinates and perform data correction, if applicable.

- Provide corrected GPS coordinates to the data team or directly update Super Tracker table.

- Work with the project teams to clarify location / sample names / IDs.

- Generate requested figures.

1.4.5 Quality Control

Quality control is very important in the data flow process and:

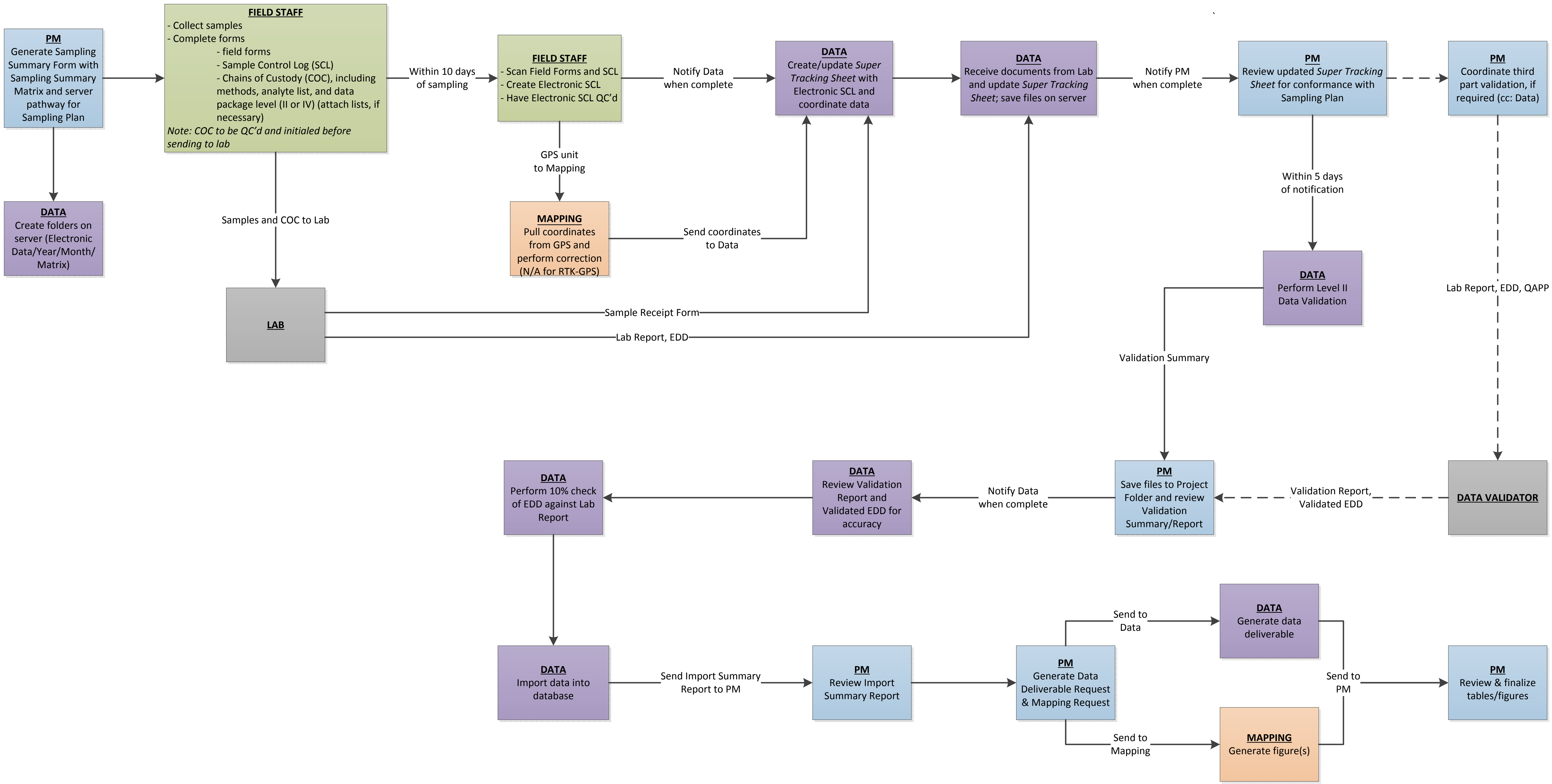
- Is not the responsibility of any one person or group
- Is required of all staff members in some form
- Begins at the planning stages of the project and continues until a final report is issued

The Data Team will perform quality control on all field documentation and laboratory analytical results with the following steps:

- Reconcile the laboratory analytical report, the field data, with the provided project-specific sampling documents. Any discrepancies with field documentation or scope of work will be brought to the attention of the appropriate project level (i.e. field staff, project manager) for clarification.
- Perform Level 2 data verification (if requested by PM) of laboratory data integrity and its usability for its intended purpose. Issues regarding laboratory analysis and reporting will be brought to the attention of the project manager and the data team will work directly with the laboratory to resolve the issues.
- Log data discrepancies (i.e. missing field documentation, missing or late analytical data) into a publicly available Super Tracker table for project manager and staff to review.
- Complete quality control on the data before import into the analytical database to assure all NRT and project-specific standards are being met.

ATTACHMENT A

DATA FLOW CHART



Attachment A - Data Flow Process

ATTACHMENT B

SUPER TRACKER TABLE SPREADSHEET

Attachment B - Super Tracker

Please read Comments for more info →	**Job Number**	Task Number	**Site Name**	QA Plan Number	**Sample Purpose Code**	Sample Event Name	Sample Event ID (number)	**Unique Sample ID (9 digits)**	**Station Name** (MW01, QC01 SB002)	**Station Type** (well, boring)	**Sample Date** (mm/dd/yyy)	**Sample Time** (hh:mm am/pm)	**Matrix (1)**	**Top of Soil or Sediment Interval**	**Bottom of Soil or Sediment Interval**	**Depth Units**	**Groundwater Filtered?**	**QC info** (MS/MSD, DUP)	Duplicate
Example	*2094*		*Integrys-Throop Street Station*		*ar - Assessment Routine*				*QC005*	*sb*	*5/22/2014*	*10:15 PM*	*SE*	*5*	*8*	*ft*	*F1*	*RB*	*1*

Notes:

(1) Air = AA, soil vapor = GS, sediment = SE, soil = SO, groundwater = WG, surface water = WS, waste = W (see Data team for additional abbreviations)
(2) VOCs= list compounds requested
(3) PVOCs = typically BTEX, or BTEX + naphthalene, or BTEX + styrene and TMBs
(4) PAHs 13, 16, 17 or 18 compounds
(5) Alkylated PAHs = 34 compounds
(6) SVOCs = list compounds requested (typically phenols)
(7) Filtered metals = list requested metals
(8) Total metals = non-filtered or soils = list metals requested
(9) Typical TAT for level 2 data and EDD = 10 business days
(10) Typical TAT for level 4 data and EDD = 20 business days
(11) Level II Review
(12) For additional information about the comments please see the *Geotech Data Transfer Standard Enviro Data Version 2012.*
(13) Bold headers indicate a field that is required for the data system.

Attachment B - Super Tracker

Parent Sample ID (Duplicate) *(MW004, SB526)*	**Sample Type (Grab, composite)**	Sampling Process Result	**Sampling Method**	**Geologic Unit Code**	**Lithology Code**	X coordinate	Y coordinate	Coordinate Description	Elevation GS	Elevation TOC	Datum (UOM for elevation)	Company doing Sampling	Field Sampler (initials)	CoC Witness (initials)	Chain of custody Number	**Project Team Sign off on Field Information**	Laboratory	Lab Report Number	Sample Delivery Group (Lab EDD #)
MW004	*u*	*Well Dry*	*pe*	*BED*	*LS*			*TBD 3*			*NAVD88*	*BMD*	*ANS*	*CCD*			*Lancaster Laboratories*		

Attachment B - Super Tracker

Lab Sample ID	VOCs -8260B [2]	PVOCs-8260B [3]	PAHs-8270 SIM [4]	Alkylated PAHs-8270 SIM [5]	SVOCs-8270C [6]	Dissolved metals-6010 or 6020 [7]	Total metals-6010 or 6020 [8]	DissolvedMercury-7470A	Total Mercury-7470A/7471A	PCBs-8082	TOC-Lloyd Kahn	TOC-Black carbon-Lloyd Kahn	Cyanide	tbd	tbd	tbd	tbd	tbd	tbd	tbd	tbd	tbd	tbd	Lab Received Date	Sample Receipt/ Condition Form from Lab
																								03/01/15	*acceptable*

Attachment B - Super Tracker

Expected Results Date [9]	Expected Date for Level 2 and EDD	Date Rcvd Level 2 data and EDD	Days Late/Days Ahead (-early / +later)	**Project Team Notified Data Set Complete DATE**	Level 2 Review[11]	Level 2 comments	Level 2 Import Date	**Project Team Notified (Level II Import) DATE**	Expected Date for Level 4 Data [10]	Date Received Level 4 Data	Days Late/Days Ahead	Data Team Notified Level IV Complete DATE	Level 4 Review	Level 4 Import Date	**Project Team Notified (Level IV Import) DATE**
03/10/15	*03/10/15*	*03/12/15*	*2*		*03/14/15*		*03/20/15*				*--*		*n/a*		
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Reviewed By:	KJB	Date Reviewed:	10-29-2012
Corporate Officer:	BRH	Date Approved:	06-25-13

CHAIN-OF-CUSTODY

1.1. Scope and Application

This field procedure outlines chain-of-custody procedures to record sample data and maintain sample integrity. A chain-of-custody (COC) form is a legal document used to track sample custody from sample collection to sample delivery at the laboratory. The procedures ensure the integrity of the sample from collection to data reporting. Refer to the project-specific documents for variances to this SOP.

1.2. Health and Safety Warnings

Follow Natural Resource Technology, Inc. (NRT) Health and Safety standard operating procedures when working with potentially hazardous material or with material of unknown origin. Project Health and Safety Plans will contain additional practices, if necessary, to mitigate site-specific hazards.

1.3. Sample Custody

Samples collected must be maintained under secure conditions and documented through COC procedures. As few people as possible should be part of the COC. A sample is under a person's custody if the following requirements are met:

- The sample is in the person's possession.
- The sample is in the person's view after being in the person's possession.
- The sample is in a secured location after being in the person's possession.

1.4. Chain-of-Custody Procedures

Field staff are responsible for the custody of samples until custody is transferred. Sample containers will be identified, tagged, handled, and transported in accordance with SOP 07-03-05. All samples must be accompanied by a COC form at all times and a separate COC will be generated for each sampling event and site.

When transferring the possession of samples, the individual relinquishing the sample will sign the “relinquished from” line on the COC. If a team is involved in the sample collection, only one team member is required to sign the COC. The receiving individual will then sign the COC, noting the date and time the samples were received. This record documents the transfer of sample custody from the sampler to another person.

The original record must accompany the sample shipment. A copy of the COC will be retained to document the transfer of custody. The hard copy will be scanned and saved in the master project file under Electronic Data Submittals (e.g., P:/1549/Electronic Data Submittals/October 2112).

1.4.1. Chain-of-Custody Errors

Erroneous information may not be erased on the COC. Errors will be lined out and initialed, and the correction written in a manner to not obscure the error.

1.5. Commercial Shipping

The COC will be maintained when using a commercial shipper (e.g., Fedex, UPS) without the carrier signing the COC. The COC will be signed for release custody, sealed in a plastic bag (e.g., one-gallon freezer Ziploc® bag), taped to the inside of the cooler lid, and seal inside. Note that nothing is written in the “received by” section of the COC at this time. The carrier’s established custody documentation procedure is used to verify custody during transportation. Shipping receipts, including tracking numbers, should be scanned and saved in the project file.

A minimum of two custody seals on the outside of the coolers are required. Custody seals shall be affixed to the top and side of the cooler and contain the following information: date, signature, and unique ID number. The unique ID numbers are recorded on the COC associated with the same container. The custody seal should be secured beneath the shipping tape so the container cannot be opened without breaking the seals. The shipping containers should be marked "THIS END UP," and arrow labels indicating the proper upward position of the container should be affixed to the container. A label containing the name and address of the shipper and receiving laboratory shall be placed on the outside of the container.

1.5.1. Multiple Cooler Shipments

If the samples are shipped in more than one container, a separate COC is required for each container. The COC must only list the samples that are within the associated container.

1.6. References

ASTM D4840-99(2010) Standard Guide for Sampling Chain-of-Custody Procedures.

ASTM D6911-03(2010) Standard Guide for Packaging and Shipping Environmental Samples for Laboratory Analysis

USEPA, Field Branches Quality System and Technical Procedures, Region 4, Science and Ecosystem Support Division, Athens, Georgia, http://www.epa.gov/region4/sesd/fbqstp/

Reviewed By:	JJW/SLM	Date Reviewed:	08/21/2012
Corporate Officer:	BRH	Date Approved:	06/25/2013

QUALITY CONTROL SAMPLES

1.1 Scope and Application

This procedure describes the collection of quality control (QC) samples. QC samples are used to evaluate field and laboratory quality control procedures and the precision, accuracy, representativeness, and comparability of data obtained during investigative activities. Refer to the project-specific documents for variances to this SOP.

1.2 Health and Safety Warnings

Follow Natural Resource Technology, Inc. (NRT) Health and Safety standard operating procedures when working with potentially hazardous material or with material of unknown origin. Project Health and Safety Plans will contain additional practices, if necessary, to mitigate site-specific hazards.

1.3 Equipment and Materials

Equipment and materials for the collection and analysis of quality control samples shall be identical to those used for the collection and analysis of the investigative samples of the same medium and collection method.

1.4 Types of Quality Control Samples

QC samples include field duplicate samples, matrix spike (MS) and matrix spike duplicate (MSD) samples, trip blanks, field blanks, and equipment blanks.

1.4.1 Field Duplicate Samples

Field duplicate samples are collected from various media to evaluate the representativeness and comparability of data obtained during investigative activities. Field duplicate samples shall be collected at the same time, using the same procedures and equipment, and in the same types of containers as the original samples. They shall also be preserved in the same manner and submitted for the same analyses as the original samples. The minimum/required frequency of field duplicate sample collection for each sample media shall be specified in the Quality Assurance Project Plan (QAPP), Field Sampling Plan (FSP), and/or other site-specific documents.

1.4.2 Matrix Spike and Matrix Spike Duplicate Samples

Matrix Spike and Matrix Spike Duplicate (MS/MSD) samples are collected to evaluate the effect of sample matrix on analytical results and the precision and accuracy of laboratory procedures. As with field duplicate samples, MS/MSD samples shall be collected at the same time, using the same procedures and equipment, and in the same types of containers as the original samples. They shall also be preserved in the same manner and submitted for the same analyses as the original samples. The minimum/required frequency of MS/MSD sample collection for each sample media shall be specified in the QAPP, FSP, and/or other site-specific documents.

1.4.3 Trip Blanks

Trip blanks are used to detect contamination that may be introduced in the field or during transit, bottle preparation, sample log-in, or sample storage within the laboratory. Trip blanks also reflect contamination that may occur during the analytical process. Trip blanks are samples of reagent-free water, properly preserved, which are prepared by the analytical laboratory in a controlled environment prior to field mobilization. Trip blanks are kept with the laboratory-provided containers through the sampling process and returned to the laboratory with the other samples being submitted for volatile organic compound (VOC) analysis. Trip blanks must be used for samples intended for VOC analysis and are preserved and analyzed for VOCs. One trip blank will accompany each cooler containing samples for VOC analysis or as specified in the QAPP, FSP, and/or other site-specific documents.

1.4.4 Equipment Blanks

Equipment blanks are also referred to as rinsate blanks or equipment rinsates. Equipment blanks are used to determine if non-dedicated equipment decontamination procedures are sufficient and there is no "carryover" from one sample to another, and may be used to determine if dedicated equipment is free of measurable concentrations of constituents of potential concern. Equipment blanks shall be collected by pouring distilled or deionized (DI) water onto or into the sampling equipment and directly filling the appropriate sample containers with the water that has contacted the sampling equipment. Equipment blanks are always collected after sampling equipment has been decontaminated and may be performed prior to collecting the first sample, after collecting highly impacted samples, and/or at the conclusion of sampling. After collection, equipment blanks are handled and treated in the same manner as investigative samples, unless noted otherwise in site-specific documents. The minimum/required frequency of equipment blanks for each sample media shall be specified in the QAPP, FSP, and/or other site-specific documents.

1.4.5 Field Blanks

Field blanks are used to determine potential for contamination of a sample by site contaminants from a source not associated with the sample collected (e.g. air-borne dust or high concentration volatiles in air from a source not related to the samples). Field blanks shall be collected by pouring distilled or ultrapure/DI water directly into the appropriate sample containers at pre-designated locations at the site. They shall also be preserved in the same manner and submitted for the same analyses as investigative samples. After collection, equipment blanks are handled and treated in the same manner as investigative samples, unless otherwise noted in the site-specific documents. The minimum/required frequency of equipment blanks for each sample media shall be specified in the QAPP, FSP, and/or other site-specific documents.

1.5 Evaluation of Quality Control Samples

Data generated by quality control samples and how they relate to the precision, accuracy, representativeness, and comparability of other data obtained during an investigation will be evaluated by the project team according to procedures defined in the QAPP, FSP, and/or other site-specific documents.

1.6 References

USEPA, 1990, Quality Assurance/Quality Control Guidance for Removal Activities, Sampling QA/QC Plan and Data Validation Procedures, Interim Final, EPA/540/G-90/004.

USEPA, 2002a, Quality Management Plan for the Superfund Division, Region 5, Chicago, Illinois.

USEPA, 2002b, Guidance for Quality Assurance Project Plans, EPA QA/G-5/ EPA/240/R-02/009.

USEPA, April 2007, Guidance for Preparing Standard Operating Procedures (SOPs), EPA/600/B-07/001.

USEPA, October 2010, Field Sampling Quality Control, Region 4, Operating Procedure, SESDPROC-011-R3, SESD, Athens, Georgia, http://www.epa.gov/region4/sesd/fbqstp/Field-Sampling-Quality-Control.pdf

USEPA, August 2011, Field-based Analytical Methods, Summary of Quality Control Samples and the Information They Provide, http://www.epa.gov/superfund/programs/dfa/download/qctable.pdf

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DRILLING METHODS GENERAL

1.1. Scope and Application

This standard is applicable to subsurface drilling techniques through unlithified, lithified, and fill materials. This standard operating procedure (SOP) does not address specific drilling methods, which are implemented by the drilling contractor, rather this SOP summarizes drilling methods available for use at environmental sites. It is important for technical staff to be familiar with available drilling methods for discussions with drilling contractors (who can offer additional insight and advice when planning for and scoping a project). In addition, ASTM D6286 is a standard guide that also provides additional information regarding applicability of drilling methods when planning an environmental drilling project. Refer to the project-specific documents for variances to this SOP.

1.2. Health and Safety Warnings

Follow Natural Resource Technology, Inc. (NRT) Health and Safety SOPs when working with potentially hazardous material or with material of unknown origin. Project Health and Safety Plans will contain additional practices, if necessary, to mitigate site-specific hazards.

Clear all underground utilities in accordance with SOP 07-05-01 prior to commencing sampling activities. Some states require the firm completing the drilling make the locate request for it to be valid and defensible, so check applicable state laws before clearing a site for underground utilities.

1.3. Drilling Types

1.3.1. Augers

Hollow-stem and solid-stem auger methods can be used in unconsolidated and semi-consolidated (weathered rock) materials, but not in competent rock. Each method can be used without introducing foreign materials into the borehole (such as drilling fluids), thus minimizing the potential for cross-contamination, an important consideration when selecting the drilling method(s) for a project.

1.3.1.1 Hollow-Stem Auger

A hollow-stem auger consists of a hollow steel stem or shaft with a continuous spiraled steel flight welded onto the exterior of the drill stem, connected to an auger bit, which when rotated, transports cuttings to the surface. This method is best suited in materials such as sand that have a tendency to collapse when drilled.

A monitoring well can be installed inside hollow stem augers with little concern for potential caving of the surrounding material. A center-rod bottom plug or pilot bit assembly can be used to keep most material out of the bottom of the auger during drilling. Potable water may be used inside the augers (where applicable) to equalize pressure if sand or other flowing material (“heaving sands” or “blow-in”) enters the auger from the bottom. Watertight center plugs are not acceptable because they create suction when extracted from the augers, which can compound heaving sand issues. Auguring without a center plug or pilot bit assembly is permitted, provided the soil plug in the bottom of the auger is removed when sampling or constructing a well. Removing the soil plug from augers can be accomplished by introducing water into the auger. Retracting augers after constructing monitoring wells in lose soils that are prone to caving can be difficult because the augers are typically extracted without being rotated to avoid damage to the well; thus, a drill rig with sufficient power must be used to extract the augers without rotation. Boreholes can be augured to depths of 150 feet or more (depending on the auger and drill rig size), but generally boreholes are augured to depths less than 100 feet. ASTM D5784 is a standard for the performance of hollow-stem auger drilling and well installation which should be referred to if this method if drilling is being considered. Field personnel performing soil sampling or well construction with this method should read this guidance to ensure work is done in accordance with industry standards.

1.3.1.2 Solid-Stem Auger

Solid-stem augers have a solid stem or shaft with a continuous spiraled steel flight, welded onto the stem, and connected to an auger bit. This auger method is used in cohesive and semi cohesive soils that do not have a tendency to collapse when disturbed. Boreholes can be augured to depths of 200 feet or more (depending on the auger and drill rig size), but generally boreholes are augured to depths less than 150 feet.

1.3.2. Rotary Methods

This method consists of a drill stem coupled to a bit that rotates and cuts through soils and/or competent rock. The cuttings produced from the rotating drill bit are transported to the surface by the selected drilling fluid (water, drilling mud, or air) in all cases except for sonic rotary. Rotary sonic methods only require the addition of drilling fluid (typically water) to cool the drill bit.

For non-sonic rotary drilling, the water, drilling mud, or air is pumped down through the drill stem, out through the drill bit and is forced, along with the drill cuttings, to the surface between the borehole wall and drill stem. The drilling fluids also cool the drill bit. When considering this method, it is important to evaluate the potential for contamination when fluids and/or air are introduced into the borehole.

Sonic rotary is the preferred rotary drilling method, followed by water rotary, direct wireline rotary, air rotary, mud rotary, and dual-wall reverse circulation air rotary.

1.3.2.1. Rotary Sonic

This method advances two concentric drill stems using rotation in conjunction with axial vibration. After advancing the drill stem, the inner string is removed with a core of drill cuttings while the outer string remains in place to maintain an open borehole. The cuttings (generally intact) can be removed from the inner casing for examination of stratigraphy prior to disposal. Compared to hollow stem augurs,
1) the quantity of cuttings is minimized because the borehole diameter is reduced and 2) smearing of the formation materials on the borehole walls is reduced as well. This drilling method is useful in a variety of materials, from flowing sands to heavily consolidated formations.

In flowing sands, the drill casings can be filled and/or pressurized with potable water to prevent excess entry of formation materials into the drill string. The same QA/QC requirements for sampling of material introduced to the borehole apply as in other drilling methods. Because the amount of water introduced into the borehole can be significant, an approximation of the water used in the drilling process should be logged for use in estimating appropriate well development withdrawal.

Sonic drilling allows a larger diameter temporary casing to be set into a confining layer while drilling proceeds into deeper aquifers. This temporary casing is then removed during the grouting operation.
In many cases this will be acceptable technique. However, the level of contamination in the upper aquifer, the importance of the lower aquifers for drinking water uses, the permeability and continuity of the

confining layer, and state regulations should be taken into account when specifying this practice as opposed to permanent outer casing placed into the confining unit. Note that when using the temporary casing practice, it is critical that grout be mixed and placed properly as specified elsewhere in this section.

Because the total borehole diameter in sonic drilling is only incrementally larger than the inner casing diameter, particular care should be taken that the well casing is placed in the center of the drill stem while placing the filter pack. Centralizers may be required to facilitate this in the case of deep wells with PVC casing.

1.3.2.2. Water Rotary

When using water rotary, potable water should be used whenever possible. If potable water is not available, then options for transporting potable water to the site or alternative drilling methods should be evaluated. Water rotary is the preferred rotary method because potable water is the only fluid introduced into the borehole during drilling. Water does not clog the formation materials, thus reducing well development time. The potable water will, however, flow into the surrounding formation materials (if permeable) and mix with the natural formation water. This mixing of the drilling and natural formation water should be evaluated when determining the drilling method. Generally, most of the drilling water will be recovered during well development. ASTM D5783 is a standard for the performance of water-based rotary drilling and well installation which should be referred to if this method if drilling is being considered.

1.3.2.3. Mud Rotary

Mud rotary is the least preferred rotary method because chemical changes can be introduced into the borehole from the constituents in the drilling mud, and it is very difficult to remove the drilling mud from the borehole after drilling and during well development. The drilling mud can also carry contaminants from a contaminated zone to an uncontaminated zone, thereby cross contaminating the borehole. However, it is a preferred method among some drilling contractors because the drilling mud allows easy removal of the cuttings, cools the bit properly, and generally makes drilling easiest since the mud acts as a casing to hold the borehole open during drilling operations.

If mud rotary is selected, potable water is recommended whenever possible, and drilling muds need to be reviewed for potential environmental and chemical ramifications. ASTM D5783 is a standard for the performance of water-based rotary drilling and well installation which should be referred to if this method if drilling is being considered.

1.3.2.4. Direct Wireline Rotary

As with the water rotary method, potable water should be used, and if it is not available then consideration needs to be given to transporting potable water to the site or an alternative drilling method. This is the preferred method for coring bedrock because potable water is the only fluid introduced into the formation and it shares the same advantages and considerations of water rotary drilling. The difference between the two is that a continuous core sample may be recovered with wireline drilling. In comparison to air rotary, additional time may be required for borehole construction due to the core sample collection. ASTM D5876 is a standard for the performance of direct rotary wireline drilling and well installation which should be referred to if this method if drilling is being considered.

1.3.2.5. Air Rotary

Air rotary utilizes compressed air to cool the bit and remove the drill cuttings. When using air rotary, the air compressor must have an in-line organic air filter system connected between the compressor and rig. The organic filter system removes potential contaminants (such as oil or grease required for proper compressor operation) and should be regularly inspected to insure it is functioning properly. Air compressors that do not have in-line organic filter systems are not acceptable for use during drilling.

A cyclone velocity dissipater or similar air containment system should also be used to funnel the cuttings to one location instead of allowing them to be blown uncontrolled out of the borehole. An air rotary rig that allows cuttings to blow uncontrolled out of the borehole and does not direct them to a discharge point with minimal disturbance is not preferred. Air rotary that employs the dual tube (reverse circulation) drilling system is acceptable since the cuttings are contained in the drill stems and blown to the surface through the cyclone velocity dissipater and to the ground with little surface disturbance. ASTM D5782 is a standard for the performance of air rotary drilling and well installation which should be referred to if this method if drilling is being considered.

1.3.2.6. Dual-Wall Reverse Circulation Air Rotary

Dual-wall reverse circulation drilling air rotary is similar to regular air rotary with the exception that the flow of drill cuttings is from the casing into and through the drill bit rod. The method is extremely useful when ground-water sampling of an unconsolidated formation is desired during drilling. Samples can be collected while drilling proceeds and shipped to a laboratory for fast-turnaround to assess contaminant concentrations with depth. ASTM D5781 is a standard for the performance of dual-wall reverse circulation drilling and well installation which should be referred to if this method if drilling is being considered.

1.3.2.7. Other Methods

Other types of drilling procedures are also available, such as the cable-tool, the jetting method, and the boring (bucket auger) method. These methods are not common site investigation methods. Use of these methods may be appropriate based on site circumstances, if approved by the project manager before fieldwork is initiated.

1.4. Cased Boreholes

Casings are used to prevent cross-contamination when boreholes are drilled through contaminated intervals. A pilot borehole is bored through the overburden and/or contaminated zone into the underlying uncontaminated strata. An outer casing (sometimes called surface or pilot casing) is then placed into the borehole and sealed with grout. The borehole and outer casing extend a minimum of 5 feet into lower strata or 2 feet into competent bedrock. The total depths into underlying strata or bedrock will vary, depending on the physical characteristics of the underlying material and the extent of weathering and/or fracturing of the bedrock.

The size of the outer casing is of sufficient inside diameter (ID) to contain drilling equipment. The outer casing is grouted by the tremie method or pressure grouting to within 2 feet of the ground surface. The grout mixture used to seal the outer casing typically consists of Type I Portland cement/bentonite or cement/sand mixture to ensure the bottom plug is rigid enough to withstand drilling stresses. A minimum of 24 hours is allowed for grout curing before continuing drilling activities.

1.5. References

ASTM D2113-08 Standard Practice for Rock Core Drilling and Sampling of Rock for Site Investigation

ASTM D5781-95(2006) Standard Guide for Use of Dual-Wall Reverse-Circulation Drilling for Geoenvironmental Exploration and the Installation of Subsurface Water-Quality Monitoring Devices

ASTM D5782-95(2006) Standard Guide for Use of Direct Air-Rotary Drilling for Geoenvironmental Exploration and the Installation of Subsurface Water-Quality Monitoring Devices

ASTM D5783-95(2006) Standard Guide for Use of Direct Rotary Drilling with Water-Based Drilling Fluid for Geoenvironmental Exploration and the Installation of Subsurface Water-Quality Monitoring Devices

ASTM D5784-95(2006) Standard Guide for Use of Hollow-Stem Augers for Geoenvironmental Exploration and the Installation of Subsurface Water-Quality Monitoring Devices

ASTM D5875-95(2006) Standard Guide for Use of Cable-Tool Drilling and Sampling Methods for Geoenvironmental Exploration and Installation of Subsurface Water-Quality Monitoring Devices

ASTM D6151-08 Standard Practice for Using Hollow Stem Augers for Geotechnical Exploration and Soil Sampling

ASTM D1452-09 Practice for Soil Investigation and Sampling by Auger Borings

ASTM D2113-08 Practice for Rock Core Drilling and Sampling of Rock for Site Investigation

ASTM D5872-95(2000) Guide for Use of Casing Advancement Drilling Methods for Geoenvironmental Exploration and Installation of Subsurface Water-Quality Monitoring Devices

ASTM D6282-98(2005) Standard Guide for Direct Push Soil Sampling for Environmental Site Characterizations

ASTM D6286-98(2006) Standard Guide for Selection of Drilling Methods for Environmental Site Characterization

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MONITORING WELL CONSTRUCTION AND DEVELOPMENT

1.1. Scope and Application

This standard is applicable to construction and development of groundwater monitoring wells. Refer to the project-specific documents for variances to this standard operating procedure (SOP).

1.2. Health and Safety Warnings

Follow Natural Resource Technology, Inc. (NRT) Health and Safety standard operating procedures when working with potentially hazardous material or with material of unknown origin. Project Health and Safety Plans will contain additional practices, if necessary, to mitigate site-specific hazards. Clear all underground utilities in accordance with SOP 07-05-01 prior to commencing sampling activities.

1.3. Considerations

Design and installation of permanent monitoring wells involves drilling boreholes into various geologic formations with differing subsurface conditions and may require several drilling methods and installation procedures (NRT SOP 07-05-03). State well construction methods and requirements should be reviewed and incorporated into scope development to ensure applicable regulations are satisfied.

Selection of drilling methods and installation procedures shall be based on field data collected during a hydrogeologic site investigation and/or a search of existing data. Each permanent monitoring well will be designed and installed to function properly throughout the entire anticipated life of the monitoring program.

When designing monitoring wells the following issues need to be considered:

- Short- and long-term objectives
- Potential length of the monitoring program
- Contaminants to be monitored/analyzed

- Type of well construction materials to be used and size of borehole required
- Surface and subsurface geologic conditions
- Aquifer(s) to be monitored
- Length and placement of the well screen(s) and anticipated depth of the well(s)
- General site conditions and drill rig accessibility
- Potential health and safety hazards
- Whether the wells will serve more than one purpose (e.g., monitoring, pump test, extraction)

Each issue can be expanded into many subtopics depending on the project complexity. The drilling method(s) is selected once the data have been assembled and reviewed.

1.4. Drilling Methods for Monitoring Well Installation

For many sites, hollow-stem auger is the preferred drilling procedure for installing wells (typically based on cost, depth, and well constructability). However, site conditions may require other methods and alternate methods will be review/selected that will perform acceptably under anticipated or known site conditions. It is advisable to consider several different drilling alternatives and be prepared to use them if problems occur that warrants a drilling method change.

The following drilling methods are available for monitoring well construction purposes. Selection of a drilling method should consider how the drilling method will affect well development and quality of connection to the aquifer. Refer to SOP 07-05-03 for a summary of specific drilling procedures.

- Hollow-Stem Auger
- Solid-Stem Auger
- Rotary Sonic
- Water Rotary
- Mud Rotary
- Direct Wireline Rotary
- Air Rotary

- Dual-Wall Reverse Circulation Air Rotary
- Hydraulic Push
- Cable-Tool (not recommended)
- Jetting Method (not recommended)
- Bucket Auger (not recommended)
- The project manager in consultation with a senior staff geologist if necessary shall approve the use of non-recommended methods before fieldwork is initiated. In addition, it is anticipated the drilling subcontractor will procure the appropriate materials based on the number of boreholes and the expected depths.

1.5. Borehole Requirements

1.5.1. Borehole Diameter

The borehole will be of sufficient diameter to 1) satisfy state regulations and 2) so well construction can proceed as needed. For example, regulations for many states require a borehole diameter of at least 4 inches greater than the well casing (e.g., a 6-inch borehole is required to install a 2-inch outside diameter (OD) casing). A borehole diameter less than 4 inches larger than the well casing will not be acceptable in these states. This “4-inch” requirement allows an annular space around the well casing large enough to install the required filter pack and annular seal. In addition, this annular space will allow up to a 1.5-inch diameter tremie pipe for placing the filter pack, seal, and/or grout at the appropriate intervals. In addition, the borehole(s) shall be advanced as close to vertical as possible and checked with a plumb bob or level. Slanted boreholes are not acceptable unless specified in the design.

1.5.2. Overdrilling the Borehole

Sometimes it is necessary to overdrill the borehole (drill deeper than required to set the well) to set the well screen and filter pack at the target depth or to place a sump beneath the well. Typically, overdrilling by just a few feet is sufficient for this purpose. If the borehole is overdrilled it can be backfilled to the designed depth, either with bentonite pellets or the filter pack. The need to overdrill a borehole or use bentonite below the well screen should only be done in consultation with a Senior Geologist.

1.6. Monitoring Well Construction Methods

1.6.1. Monitoring Well Construction and Installation

Following borehole completion, the well string is constructed by securing the PVC riser to the well screen by flush-jointed threads. Lubricating oils and grease are not to be used on casing threads. Teflon tape can be used to wrap the threads to insure a tight fit and minimize leakage. No glue of any type shall be used to secure casing joints. Teflon® O-rings can also be used to insure a tight fit and minimize leakage; however, O-rings made of other materials are not acceptable if the well is going to be sampled for organic compounds.

Six to twelve inches of clean filter pack sand is placed at the bottom of the borehole before the well string is lowered into the borehole. The well string is placed into the borehole through the hollow-stem auger or temporary casing. Centralizers can be used to plumb a well, but may interfere with filter pack or annular space seal placement or may cause bridging during material placement. Monitoring wells less than 50 feet deep usually do not need centralizers. If centralizers are used they should be placed below the well screen and above the bentonite pellet seal. The specific placement intervals are determined based on site conditions.

When installing the well string through hollow-stem augers, the augers are slowly extracted as the sand pack, bentonite seal (if necessary), and annular space seal are tremied and/or poured into place. The extraction of the augers allows the materials being placed through the augers to flow below the augers, rather than up into the augers causing the augers to become stuck in the borehole.

After the well string is plumb, the filter material is poured or tremie-piped around the well screen up to the designated depth (generally six inches to two feet above the well screen). After the filter pack has been installed, six inches to two feet of fine sand is typically placed on top of the filter pack as a filter pack seal unless the well is too shallow to allow placement of this fine sand layer. Next, the bentonite seal, consisting of bentonite chips, bentonite pellets, or bentonite granules, depending on site conditions, is placed, if necessary. The bentonite seal extends from the top of the filter pack seal to the bottom of the annular space seal, typically two to five feet above the filter pack seal. The annular space seal, consisting of bentonite granules, chips, grout, or slurry, depending on site conditions, is then pumped by the tremie method or poured into the annular space around the PVC casing up to one foot bgs for a flush-mounted protective cover or two inches bgs for a stick-up protective cover. Bentonite is not placed between the well casing and protective cover pipe; sand or native soil is used to allow water to drain away from the well. If grout is used, it is allowed to set for a minimum of 24 hours before the surface seal and protective cover pipe are installed.

Following placement of the annular space seal, the protective cover pipe is installed. A stick-up protective cover pipe will have a lockable cap. The stick-up protective cover extends at least two feet bgs, and does not extend below the annular space seal into the filter pack. The protective cover has a weep hole (minimum ¼ inch diameter) for drainage placed just above the top of the well pad or ground surface to prevent water from remaining inside the cover. A protective cover made of aluminum or other soft metals is not acceptable because it is not strong enough to resist tampering. Concrete or soil is placed on top of the bentonite annular space seal/ surface seal to prevent drying and cracking, depending on site conditions and state requirements.

A flush-mounted protective cover pipe extends at least one foot bgs. It is made of material that will withstand traffic and have a watertight seal. The PVC well casing is cut low enough so a lockable cap may be secured over the casing to prevent tampering with or filling of the well. Concrete surface seals are installed around flush-mounted protective covers, and extend to the bottom of the cover. The flush-mounted cover is installed slightly (1/2 to 1 inch) above the surrounding ground surface and the concrete pad installed sloping away from the cover to facilitate drainage away from the well and reduce ponding of water over the well, especially if there is a potential for it to freeze in winter.

After the surface pad and protective cover are installed, bumper posts may be installed (if needed). Bumper posts are typically steel pipes of 3- to 4-inch diameter and a minimum 5-foot length. They are installed to a minimum depth of 2 feet below ground surface, extend a minimum of 3 feet above ground surface, and are filled with either sand or concrete once installed (to provide additional strength). The bumper posts are placed around the monitoring wells in a configuration that provides maximum protection for the well.

After the wells have been installed, they are permanently marked with the well number on either the cover or an appropriate place that will not be easily obscured by weather, damaged, or vandalized.

1.6.2. Cased Wells

Double cased wells are constructed when:

- There is reason to believe interconnection of two aquifers by well construction may cause cross-contamination.
- Flowing sands make it impossible to install a monitoring well using conventional methods.
- In special areas designated by a governmental agency.

A pilot borehole is drilled through the overburden and/or contaminated zone to a pre-determined depth. An outer casing is then placed into the borehole and sealed with grout. The outer casing diameter is of sufficient diameter to contain the inner casing and the required minimum annular space. The outer casing is grouted by the tremie method or pressure grouting to within 2 feet of the ground surface. The grout is pumped into the annular space between the outer casing and the borehole wall by placing the tremie tube in the annular space and pumping the grout from the bottom of the borehole to the surface, or placing a grout shoe or plug inside the casing at the bottom of the borehole and pumping the grout through the bottom grout plug and up the annular space on the outside of the casing. If the outer casing is set into very tight clay, both of the above methods might have to be used, because the clay usually forms a tight seal in the bottom and around the outside of the casing preventing grout from flowing freely during injection. Conversely, outer casing set into bedrock normally will have space enough to allow grout to flow freely during injection.

The grout mixture used to seal the outer annular space can be neat cement, cement/bentonite, or cement/sand. The seal or plug at the bottom of the borehole and outer casing consists of a Type I Portland cement/bentonite or cement/sand mixture. The use of a pure bentonite grout for a bottom plug is not acceptable because the bentonite grout cures to a gel and is not rigid enough to withstand the stresses of drilling. At least 24 hours are required for the grout plug to cure before attempting to drill through it.

When drilling through the seal, care must be taken to avoid cracking, shattering, and/or washing out the seal. Removal of outer casings, which are sometimes called temporary surface casings, after well screens and casings have been installed and grouted is not performed. Trying to remove outer surface casings after the inner casings have been grouted may jeopardize the structural integrity of the well.

Potentially contaminated zones can also be isolated by telescoping smaller diameter hollow stem augers inside larger ones. However, this is typically limited by the large diameters required at the surface, which make use of rotary drilling methods advantageous based on costs and generation of drilling spoils.

1.6.3. Bedrock Wells

The preferred method of advancing the borehole into the bedrock is rock coring. Rock coring makes a smooth, round hole through the seal and into the bedrock without cracking and/or shattering the seal. Roller cone bits are used in soft bedrock, but caution must be taken when using a roller cone bit to advance through the grout seal in the bottom of the borehole because excessive water and "down" pressure can cause cracking, eroding(washing), and/or shattering of the seal. Low volume air hammers have been used to advance the borehole, but they have a tendency to shatter the seal because of the hammering action. Any proposed method will be evaluated on its own merits, and will have to be approved by a senior staff geologist before drilling activities begin.

The installation of monitoring wells into bedrock can be accomplished in at least two ways:

1 Open Bedrock Well: The finished well consists of an open borehole from the base of the surface casing to the well bottom. The surface casing extends from the ground surface into bedrock and prevents the hole from collapsing. If the protective casing integrity is compromised, the well is open to direct contamination and will have to be repaired or abandoned. A limitation to the open bedrock well is the entire bedrock interval serves as the monitoring zone. In this situation, it is very difficult or even impossible to monitor a specific zone and contaminants, if present, could be diluted. The use of open bedrock wells is generally not acceptable in the Superfund and RCRA programs because of the uncontrolled monitoring intervals. However, some site-specific conditions or objectives may warrant open bedrock wells.

2. Cased Monitoring Well: This well has an inner well screen and casing with filter pack, bentonite seal, and annular grout like monitoring wells constructed in unlithified materials. This well installation method gives the flexibility of isolating the monitoring zone(s) and minimizing inter-aquifer flow. The filter pack also serves as a barrier between the bentonite seal and the screened interval. Rubber inflatable packers are not acceptable alternatives to filter packs because the packers have to remain in the well permanently and, over a period of time, will decompose and possibly contribute contaminants to the monitoring zone.

1.6.4. Placing Well Materials

Acceptable methods for placing well materials, including the filter pack and annular seal, include positive displacement and the tremie method. Use of the tremie method minimizes the risk of bridging in the borehole and ensures the placement at the proper intervals. Pouring materials (filter pack and bentonite seal) is acceptable in shallow boreholes less than 50 feet where the annular space is large enough to prevent bridging and allow measuring (with a tape measure) to ensure the materials are placed at the proper intervals. The proper placement depth is documented by measuring and not by estimating. Also, to insure the materials are placed at the proper intervals, they should be tamped with an appropriate tool while measuring. Tamping minimizes the potential for bridging by forcing the materials that have lodged against the borehole wall and/or the well casing to the proper interval.

1.7 Well Development

Completed monitoring wells can be developed immediately unless constructed and sealed with a liquid grout seal. Wells constructed with grout seals, (and all other wells, if possible), should not be developed for at least 12 hours after they are installed. This allows sufficient time for the well materials to set and cure before development procedures are initiated. The purpose of developing new wells is to remove residual materials remaining in the wells after installation has been completed, and to try to re-establish the natural hydraulic flow conditions of the formation around the immediate vicinity of the well. New wells are developed until the column of water in the well is free of visible sediment, and the pH, temperature, and specific conductivity have stabilized. Refer to ASTM Standard Practices D5521/D5521M for more details on development criteria.

In most cases the above criteria can be satisfied; however, in some cases the pH, temperature, and specific conductivity stabilize while the water remains turbid. In this case the well may still contain well construction materials, such as drilling mud in the form of a mud cake and/or formation soils that have not been washed out of the borehole. Excessive or thick drilling mud cannot be flushed out of a borehole with one or two well volumes of purge water, agitation and continuous flushing for several days may be necessary to complete the well development under this condition. Repeated cycles of development over several hours or days may also be necessary for low-yield wells which pump dry or nearly dry during development.

Caution should be taken when using high rate pumps and/or large volume air compressors during well development because excessive pumping or high air pressures can damage the well screen and filter pack. The on-site geologist will make the decision as to the development completion of each well. All field decisions will be documented in the field logbook.

The following methods are used to develop monitoring wells:

- Pumping
- Compressed air (with the appropriate organic filter system)
- Bailing
- Surging
- Backwashing ("rawhiding")
- Jetting

These methods can be used, both individually and in combination, to achieve effective well development. The selected development method(s) will be approved by a senior staff geologist before well installation activities are initiated.

1.8 References

ASTM D5092-04(2010)e1 Standard Practice for Design and Installation of Ground Water Monitoring Wells in Aquifers

D5521/D5521M-13 Standard Guide for Development of Groundwater Monitoring Wells in Granular Aquifers

ASTM D6001-05 Standard Guide for Direct-Push Ground Water Sampling for Environmental Site Characterization

ASTM D6724-04(2010) Standard Guide for Installation of Direct Push Ground Water Monitoring Wells

ASTM D6725-04(2010) Standard Practice for Direct Push Installation of Prepacked Screen Monitoring Wells in Unconsolidated Aquifers

USEPA, Field Branches Quality System and Technical Procedures, Region 4, Science and Ecosystem Support Division, Athens, Georgia, http://www.epa.gov/region4/sesd/fbqstp/

Prepared By:	RJC	Date Prepared:	05/31/2013
Corporate Officer:	BRH	Date Approved:	02-27-14

BOREHOLE AND MONITORING WELL ABANDONMENT

1.1. Scope and Application

This standard is applicable to abandonment of monitoring wells and boreholes. The objective of this standard operating procedure (SOP) is to assure that the monitoring well or borehole is abandoned such that it cannot act as a conduit for migration of water from the ground surface to the water table or between aquifers. Many states have requirements for well abandonment; however, these requirements are sometimes not explicit. A technically sound well abandonment method is based on the site geology, well casing materials, and general condition of the well(s). To comply with state requirements, the appropriate state agency must be notified (if applicable) of well abandonment. Refer to the project-specific documents for specific requirements for well and borehole abandonment and variances to this SOP.

1.2. Health and Safety Warnings

Follow Natural Resource Technology, Inc. (NRT) Health and Safety standard operating procedures when working with potentially hazardous material or with material of unknown origin. Project Health and Safety Plans will contain additional practices, if necessary, to mitigate site-specific hazards.

1.3. Abandonment

When feasible, the preferred well abandonment method is to completely remove the well casing and screen from the borehole. This may be accomplished by auguring with a hollow stem auger over the well casing down to the bottom of the borehole, thereby removing the grout and filter pack materials from the hole. The well casing is then removed from the hole with the drill rig. The borehole is then backfilled with the appropriate grout material. The backfill material is placed into the borehole from the bottom to the top by pressure grouting with the positive displacement method (e.g., tremie method). The top two feet of the borehole is filled with concrete or material similar to surrounding features (e.g., asphalt or topsoil) to ensure a secure surface seal. If the area has heavy traffic use, and/or the well locations need to be permanently marked, then a protective surface pad(s) and/or steel bumper guards may be installed.
The concrete surface plug can be recessed below ground surface if the potential for construction activities

exists. This abandonment method is appropriate for one to four inch diameter wells. Planning is required for wells having six-inch or larger diameters and the abandonment of these wells should only be completed after review of the appropriate state regulations and discussions with the well driller that will be retained for the abandonment.

Wells constructed of PVC may be more difficult to remove from the borehole than metal casings because of its brittleness. If the PVC well casing breaks during removal it may be abandoned if cut off (or broken) below the required depth for abandonment. However, if state regulations require the entire well string to be removed, then these wells can be abandoned by using a drag bit or roller cone bit with the wet rotary method to grind the casing into small cuttings that will be flushed from the borehole by the drilling fluid. Another method is to use a solid-stem auger with a carbide auger head to grind the PVC casing into small cuttings that will be brought to the surface on the rotating flights. After the casing materials have been removed from the borehole, the borehole is cleaned out and pressure grouted with the approved grouting materials.

1.4. References

ASTM International, D5299 Standard Guide for Decommissioning of Ground Water Wells, Vadose Zone Monitoring Devices, Boreholes, and Other Devices for Environmental Activities

USEPA, Field Branches Quality System and Technical Procedures, Region 4, Science and Ecosystem Support Division, Athens, Georgia, http://www.epa.gov/region4/sesd/fbqstp/

Prepared By:	NDK/RJC	Date Prepared:	04-20-2014
Corporate Officer:	RHW	Date Approved:	4-22-2014

FIELD LOGGING OF SOIL AND SEDIMENT

1.1. Scope and Application

This standard operating procedure (SOP) is applicable to field logging of subsurface explorations of soil and sediment. This standard is established to indicate the process of logging in the field, to improve comprehension of the logging process, and to improve overall efficiency within the office when working with logging field notes. Refer to project-specific documents for variances from this SOP.

1.2. Health and Safety Warnings

Follow Natural Resource Technology, Inc. (NRT) Health and Safety (H&S) standard operating procedures (SOPs) when working with potentially hazardous material or with material of unknown origin. Project-specific H&S plans will contain additional practices, if necessary, that are necessary to mitigate project- or site-specific hazards.

Clear all underground utilities, private, commercial, and public in accordance with SOP 07-05-01 prior to commencing sampling activities. Screen each sample location with a metal detector or magnetometer prior to sampling to verify the absence buried metal, such as underground pipes.

1.3. Logging Procedure

Soil descriptions will be completed in accordance with ASTM Standard Practice for the Description and Identification of Soils (Visual-Manual Procedure), which is ASTM Standard D2488 – 09a. A copy of ASTM Standard D2488 – 09a is attached along with two summary sheets developed from this SOP. These two summary sheets describe in tabulated format how to identify fine- and course-grained soils in the field in accordance with ASTM SOP and they are entitled “Fine-Grained Soils Field Identification” and “Coarse-Grained Soils Field Identification”, respectively.

When logging soils, all contact depth shall be recorded in tenths of a foot. The general criteria for logging fine-grained and coarse-grained soils are listed below. Soil descriptions will be documented on field borehole logs and will describe material percentages of individual components that constituent the matrix of the soil sample and the soil classification guideline is based on ASTM D2488.

1.3.1. Sediment Classes

Granular sediment is comprised of three classes of material, biogenic, mineral/lithic, and glass. Glass is likely to be only a minimal component so it does not warrant further discussion. The descriptive classification for both mineral and biogenic types is based upon grain-size and sediment constituents.

1.3.1.1. Biogenic (Organic) Sediments

Biogenic sediments (organic origin) are those that contain remains or traces of once-living organisms in a concentration of greater than 50 percent. This class of sediment is often flocculent at the sediment/water interface and has a “pudding-like” texture due to its high content of organic material. Biogenic sediments are often dark brown to black in color, and have an organic odor. Basic components of those sediments include; shell fragments, fish parts, plant material, and fecal pellets.

1.3.1.2. Mineral Sediments

Mineral sediments consist of mineral grains derived from physically weathered rocks, precipitates, and antigenic sources in a concentration of greater than 50 percent (ASTM D2488 Section 3). If there are enough biogenic/organic constituents present to influence the soil properties (ASTM D2488 Section 14.8). Common components of mineral sediments include; quartz, feldspars, clay minerals, micas, and rock fragments.

1.4. Lithologic Description

A continuous log of encountered geologic materials from borehole cuttings, samples, and core should be recorded on a borehole field Log. Prior to creating a continuous log of geologic materials some terms, definitions, and descriptors are important to be aware while logging soil and sediment.

Physical descriptions derived from visual observation and manual testing can be used to classify soil and sediment origin (biogenic or mineral) as well as physical properties of the material. The physical soil and sediment description includes the following parameters:

- Color
- Odor

- Obvious materials
- Structure
- Consistency (including particle size, shape and angularity for course grained-soils/sediments)
- Gradation
- Dry Strength (manual test)
- Dilatency (manual test)
- Toughness (physical description)
- Plasticity (physical description)

The soil color should be identified using a Munsell soil color chart. Often organic sediments (biogenic) turn color after exposure to air, any such color change should be noted as well.

Any obvious material in samples, such as coal fines, metallic chips, wood, etc. should be noted, and depth of material recorded. Further, any sheen soil or water within the sample container should be recorded.

The odor of a sample needs to be described. The following table summarizes the terms that may be used to describe the strength or pungency of odors:

Strength of Odor	Comment
No odor	No detectable odor at close proximity
Faint	Barely perceptible under close proximity, may be difficult to characterize
Moderate	Perceptible odor under close proximity
Strong	Clearly perceptible odor from several feet, (e.g., standing over sample)

The following is a list of common odor characterizations (remember "-like" will follow each descriptor):

- Diesel
- Mothball
- Petroleum-gasoline
- Petroleum-diesel

- Petroleum-kerosene
- Sulfur
- Gasoline
- MGP
- Coal tar
- Creosote
- Paint
- Tar
- Solvent
- Oil-based Varnish
- Vinegar
- Rubber
- Kerosene
- Burnt
- Earthy
- Smokey
- Sour
- Sweet
- Fishy
- Fruity

Consider the following when classifying odors:

- Be safe! Use your hand to waft odors from the sample toward your nose initially. If you don't smell anything, then you can get closer. It may be helpful to take short quick breaths through the nose to help describe odors. DO NOT get your nose right up to a sample and take a deep breath as the contents of the sample is unknown and this work needs to be performed in a safe manner.

- Provide the sample interval(s) that the odor describes.

- Include negatives (i.e., descriptions of "No Odor"). The lack of odors can be just as important as the presence of odors. If there is no description of odor in the log, we cannot assume that there was no odor.

- Some samples may have very strong odors (saturate the nose) and make it difficult to discern the strength of the odors in later samples. Do not need to try and compensate for this, describe the odor as you perceive it at that time.

Structure of the soil should be described utilizing the following table taken from ASTM D2488.

Table 1: Criteria for Describing Structure

Description	Criteria
Stratified	Alternating layers of varying material or color with layers at least 6 millimeters thick
Laminated	Alternating layers of varying material or color with layers less than 6 millimeters thick
Fissured	Breaks along definite planes of fracture with little resistance to fracturing
Slickensided	Fracture planes appear polished or glossy, sometimes striated
Blocky	Cohesive soil that can be broken into small angular lumps resisting further breakdown
Lensed	Inclusion of small pockets of different soils, note thickness
Homogeneous	Same color and appearance throughout sample

Consistency for fine-grained soils (50% or more fines) of biogenic or mineral sources should be described as very soft to very hard utilizing the following table taken from ASTM D2488.

Table 2: Criteria for Describing Consistency

Description	Criteria
Very soft	Thumb will penetrate soil more than 1 in. (25 mm)
Soft	Thumb will penetrate soil about 1 in. (25 mm)
Firm	Thumb will indent soil about ¼ in. (6mm)
Hard	Thumb will not indent soil but readily indented with thumbnail
Very Hard	Thumbnail will not indent soil

Consistency for course-grained soils (less than 50 percent fines) should include several descriptive observations including particle size, particle shape, and angularity. Particle size differentiates between sand, silt, and clay (ASTM D2488 Section 3.1).

Particle shape refers to the length, width, and thickness of the individual particles. The description of particle shape should only be used in cases where the particle shape is flat, elongated, or flat and elongated (ASTM D 2488, Table 2).

Table 3: Criteria for Describing Particle Shape

Description	Criteria
Flat	Particles with width/thickness >3
Elongated	Particles with width/length >3
Flat and elongated	Particles meet criteria for both flat and elongated

The angularity refers to the overall shape or outline of a particle. The description should be angular, sub-angular, sub-rounded or rounded (ASTM D2488, Table 1).

Table 4: Criteria for Describing Angularity of Coarse-Grained Particles

Description	Criteria
Angular	Particles have sharp edges and relatively plane sides with unpolished surfaces
Sub-angular	Particles are similar to angular description but have rounded edges
Sub-rounded	Particles have nearly plane sides but have well-rounded corners and edges
Rounded	Particles have smoothly curved sides and no edges

Gradation refers to the distribution of grain sizes present in a sample and should be used where course-grained soils are encountered. The description should be either well-graded or poorly-graded as defined in ASTM D2488 (Sections 15.31 and 15.32). Sorting which is a Geologic Interpretation can often be confused with Gradation. When sorting is included while logging it should be printed in parentheses near the end of the log.

Table 5: Criteria for Describing Gradation

Description	Criteria
Poorly Graded	Predominately one particle size, wide range of sizes with some intermediate sizes missing (gap or skip graded)
Well Graded	Wide range of particle sizes and substantial amounts of the intermediate particles sizes

For fine-grained mineral soils, dry strength, dilatency, toughness, and plasticity should be used to classify the material as lean clay, fat clay, silt, or elastic silt (ASTM D2488 Section 14) and/or the NRT Fine-Grained Soils Field Identification Sheet, which is based on the ASTM standards.

Table 6: Criteria for Describing Dry Strength

Description	Criteria
None	The dry specimen crumbles with mere pressure of handling.
Low	The dry specimen crumbles with some finger pressure.
Medium	The dry specimen breaks into pieces or crumbles with considerable finger pressure.
High	The dry specimen cannot be broken with finger pressure. Specimen will break into pieces between thumb and a hard surface.
Very High	The dry specimen cannot be broken between thumb and a hard surface.

Table 7: Criteria for Describing Dilatency

Description	Criteria
None	No visible change
Slow	Water appears/disappears slowly or does not disappear
Rapid	Water appears/disappears quickly

Table 8: Criteria for Describing Toughness

Description	Criteria
Low	Only slight pressure is required to roll the thread near the plastic limit. The thread and the lump are weak and soft.
Medium	Medium pressure is required to roll the thread to near the plastic limit. The thread and the lump have medium stiffness.
High	Considerable pressure is required to roll the thread to near the plastic limit. The thread and the lump have very high stiffness.

Table 9: Criteria for Describing Plasticity

Description	Criteria
Nonplastic	A 3-mm thread cannot be rolled at any water content.
Low	The thread can barely be rolled, and the lump cannot be formed when drier than the plastic limit.
Medium	The thread is easy to roll, and not much time is required to reach the plastic limit. The thread cannot be rerolled after reaching the plastic limit. The lump crumbles when drier than the plastic limit.
High	It takes considerable time rolling and kneading to reach the plastic limit. The thread can be rolled several times after reaching the plastic limit. The lump can be formed without crumbling when drier than the plastic limit.

1.4.1. Fine-Grained Sediment Description Format

The following format should be followed when logging fine-grained soil or sediment:

> **Group Name:** Soil color, preszence of organic material, particle descriptions, geotechnical description**,** dry strength, dilatency, toughness, plasticity, consistency, cementation, structure, odor, moisture, additional comments (geologic origin and/or descriptions).

Fine-Grained Sediment Description Example:

> **LEAN CLAY WITH SAND (CL)s**, reddish brown (5YR 4/4), few mottles greenish gray (10Y 5/1), 15% subrounded fine to medium sand, few subangular fine gravel, slow dilatency, medium toughness, medium plasticity, homogenous, blocky, no odor, moist, trace fine root material [TILL].

All geologic descriptions will be record as noted in the above examples when logging Fine-Grained Soil or Sediment. List below are more details on the noted criteria necessary for a complete description:

- Color - Soil color is coded using the Munsell Soil Color chart. The code should be in parentheses immediately following the written description. Presence of mottling and banding is also recorded; for example, “reddish brown (5YR 4/4)”.
- Class type (Biogenic or Mineral)
- Size Distribution - approximate percentage of gravel, sand, fines (if possible, distinguish between silt and clay). Percentages should add up to 100%. For example, “80% silt, 20% f-sand”.
- Geotechnical Description-recording the blow counts for a specific split spoon while working with a Hollow Stem Auger, performing pocket penotrometer test, or a Torvane shear strength test (when applicable and available). Field Guides for testing soil strength using a pocket penetrometer or field vane are attached.
- Dry Strength, Dilatency, Toughness, and Plasticity tests should be completed to determine the fine-s] grained soil characteristics and type.
- Textural Classification - example “Sandy Silt”
- Group Symbol - USCS group symbol is written in parentheses after the textural classification. For example, “(sML)”
- Consistency/Penetration Resistance - use very soft, soft, medium, stiff, very stiff, and hard. These are estimated from drive sample hammer blows or other field tests. Blow counts may also be used, if reliable.
- Moisture Content - Dry, damp, moist, wet (saturated)
- Miscellaneous - odor, contact, and/or bedding dip, bedding features, cementation, structures, fractures, fracture fillings, fossils, formation name, minerals, oxidation, etc.

1.4.2. Coarse-Grained Sediment Description Format

The following format should be followed when logging coarse-grained soil or sediment:

Group Name: Soil color, presence of organic material, particle descriptions, geotechnical description**,** fine-grained soils, consistency, cementation, structure, odor, moisture, additional comments (geologic origin and/or descriptions).

Coarse-Grained Sediment Description Example:

POORLY GRADED SAND WITH SILT, (SP-SM) reddish brown (5YR 4/4), subrounded fine to medium sand, few subangular fine gravel, no cementation, homogenous no odor, moist.

All geologic descriptions will be record as noted in the above examples when logging Coarse-Grained Soil or Sediment. List below are more details on the noted criteria necessary for a complete description:

- Color - Soil color is coded using the Munsell Soil Color chart. The code should be in parentheses immediately following the written description. Presence of mottling and banding is also recorded; for example, “reddish brown (5YR 4/4)”.
- Class type (Biogenic or Mineral)
- Size Distribution - approximate percentage of gravel, sand, fines (if possible, distinguish between silt and clay). Percentages should add up to 100%. For example, “80% silt, 20% fine sand”.
- Grain shape (angular, subangular, subrounded, rounded, or well-rounded)
- Geotechnical Description-recording the blow counts for a specific split spoon while working with a Hollow Stem Auger, performing pocketpenotrometer test, or a Torvane shear strength test (when applicable and available).
- Textural Classification - example “Sandy Silt”
- Group Symbol - USCS group symbol is written in parentheses after the textural classification. For example, “(sML)”
- Moisture Content - Dry, damp, moist, wet (saturated)
- Miscellaneous - odor, contact, and/or bedding dip, bedding features, cementation, structures, fractures, fracture fillings, fossils, formation name, minerals, oxidation, etc.

1.4.3. SOP Attachments

The following attachments are herein made part of the SOP for the purposes of logging soil and sediment samples appropriately and in accordance with this SOP:

- ASTM D2488
- NRT Fine-Grained Soils Field Identification Summary
- NRT Coarse-Grained Soils Field Identification Summary
- NRT Field Guide 001 Pocket Penetrometer (June 2012)
- NRT Field Guide 002 Field Vane (June 2012)

1.5. References

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

ASTM D5715, Test Method for Estimating the Degree of Humification of Peat and Other Organic Soils (Visual/Manual Method).

ASTM D4083, Practice for Description of Frozen Soils (Visual-Manual Procedure).

ASTM D5079, Practices for Preserving and Transporting Rock Core Samples.

ASTM D5434, Guide for Field Logging of Subsurface Explorations of Soil and Rock.

ASTM D4543, Practices for Preparing Rock Core Specimens and Determining Dimensional and Shape Tolerances.

ASTM D6236, Guide for Coring and Logging Cement - or Lime-Stabilized Soil.

ASTM D7099 ,Terminology Relating to Frozen Soil and Rock.

ASTM D0653, Terminology Relating to Soil, Rock, and Contained Fluids.

Johnson, R. B., and J. V. DeGraff, 1988, Principles of Engineering Geology, John Wiley and Sons, New York.

ASTM International, D2488-00 Standard Practice for Description and Identification of Soils (Visual-Manual Procedure).

USEPA, 2001, Sediment Sampling guide and Methodologies (2nd Edition), Division of Surface Water, Cincinnati, Ohio, 2001.

USEPA, 2001, Environmental Investigations Standard Operating Procedures and Quality Assurance Manual (EISOPQAM), Region 4, Enforcement and Investigations Branch, SESD, Athens, Georgia, www.epa.gov/region4/sesd/eisopqam/eisopqam.html.

USEPA, 2002, Ecological Assessment Standard Operating Procedures and Quality Assurance Manual, SESD, Region 4, Ecological Assessment Branch, Athens, Georgia.

ATTACHMENT 1

COARSE-GRAINED SOILS FIELD IDENTIFICATION

Coarse-Grained Soils Field Identification
(Particles are less than 50% silt and/or clay (< No. 200 sieve)
<u>DO NOT</u> include particles > 3" diameter to estimate particle %

(Description guidelines follow ASTM D2488 Standard, reference standard for additional detail on performance for soil descriptions)

<u>GROUP NAME</u>, soil color, particle descriptions, consistency, cementation, structure, odor, moisture, additional comments [geologic origin].

<u>POORLY GRADED SAND WITH SILT</u>,(SP-SM), reddish brown (5YR 4/4), subrounded fine to medium sand, few subangular fine gravel, no cementation, homogeneous, no odor, moist.

1

Group Name – Determine <u>after</u> completion of tests.

2

Soil Color (in moist condition) – Color name followed by Hue, Value, & Chroma (eg., Brown (7.5YR 5/3))
<u>Mottled</u> – Identify the percentage mottled and color
(e.g., Brown (7.5YR 5/3) 5% Gray (10YR 5/1) mottling)

3

Particle Descriptions (comments not required when not applicable)
1)**Percent cobbles/boulders** volume %
2)**Coarse Particle Size Range** (Maximum size, and range)
3)**Particle Shape and Angularity**
4)**% gravel/sand/fines** - % particle < 3" by <u>dry weight</u> basis
- Estimate percentage to the closest 5%.
- sum of % gravel/sand/fines must equal 100 (except trace)

General Particle ranges:

Trace	**< 5%**
Few	**5–10 %**
Little	**15–25 %**

Some	**30–45 %**
Mostly	**50–100 %**

5

Consistency Geotechnical Guide (not in ASTM)

Relative Density	SPT Blows/Foot
Very Loose	0-4
Loose	4-10
Medium Dense	10-30
Dense	30-50
Very Dense	>50

6

Describe Fine Grained Material – follow fine-grained description sheet.

7

Cementation Drop dilute HCl onto the soil, describe

None	No visible reaction
Weak	Some reaction; with bubbles forming slowly
Strong	Violent reaction, with bubbles forming immediately

8

Structure- note thickness for stratified, laminated, lensed.

Stratified	Alternating layers of material/color ≥ 6 mm
Laminated	Alternating layers of material/color < 6 mm
Fissured	Breaks on fracture(s) with little resistance
Lensed	Small pockets of different material
Homogeneous	Same color and appearance throughout

9

Odor –Appropriate terms listed on back.

10

Moisture -

Dry	Dry to touch, dusty.
Moist	Damp, but no visible water
Wet	Visible free water, usually soil is below water table

11

Additional Comments – presence of roots or root holes, surface coatings on coarse-grained particles, etc.

GRADING

poorly graded	- Predominately one particle size (uniform) - Wide range of sizes with some intermediate sizes missing (gap or skip graded)
well graded	Wide range of particle sizes and substantial amounts of the intermediate particle sizes

Sorting entered under *Geologic Interpretation*
The geologic interpretation (including sorting) should printed in parentheses near the end of the log.

Sorting Class	
very well sorted	1 Wentworth size class
well sorted	1 Wentworth size class
moderately well sorted	2 Wentworth size classes
moderately sorted	3 Wentworth size classes
poorly sorted	4 Wentworth size classes
very poorly sorted	5-8 Wentworth size classes

Wentworth size classes are the geologic grain sizes shown on the next page.

FIELD IDENTIFICATION PROCEDURES (excluding particles > 3” and basing fractions on weights)			Group Symbol	NAMES
GRAVEL > 50% > No. 4 Sieve Size	Clean Gravel (little or no fines)	Wide range in grain size and substantial amounts of intermediate particle sizes	**GW**	WELL-GRADED GRAVEL (GW) WELL-GRADED GRAVEL WITH SAND (GWs)
		Predominately one size of range of sizes w/ some intermediate sizes missing	**GP**	POORLY-GRADED GRAVEL (GP) POORLY-GRADED GRAVEL WITH SAND (GPs)
	Well-Graded	fines = ML or MH	**GW-GM**	WELL-GRADED GRAVEL WITH SILT (GW-GM) WELL-GRADED GRAVEL WITH SILT AND SAND (GW-
		fines = CL or CH	**GW-GC**	WELL-GRADED GRAVEL WITH CLAY (GW-GM) WELL-GRADED GRAVEL WITH CLAY AND SAND (GW-
	Poorly-Graded	fines = ML or MH	**GP-GM**	POORLY-GRADED GRAVEL WITH SILT (GP-GM) POORLY-GRADED GRAVEL WITH SILT AND SAND (GP-
		fines = CL or CH	**GP-GC**	POORLY-GRADED GRAVEL WITH CLAY (GP-GC) POORLY-GRADED GRAVEL WITH CLAY AND SAND (GP-
	Gravel with Fines (Appreciable Fines)	Non-plastic fines (for identification, see ML)	**GM**	SILTY GRAVEL (GM) SILTY GRAVEL WITH SAND (GMs)
		Plastic fines (for identification, see CL)	**GC**	CLAYEY GRAVEL (GC) CLAYEY GRAVEL WITH SAND (GCs)
SAND 50% or more is < No. 4 Sieve Size	Clean Sand (little or no fines)	Wide range in grain size and substantial amounts of intermediate particle sizes	**SW**	WELL-GRADED SAND (SW) WELL-GRADED SAND WITH GRAVEL (SWg)
		Predominately one size or a range of sizes w/ some intermediate sizes missing	**SP**	POORLY-GRADED SAND (SP) POORLY-GRADED SAND WITH GRAVEL (SPg)
	Well-Graded	fines = ML or MH	**SW-SM**	WELL-GRADED SAND WITH SILT (SW-SM) WELL-GRADED SAND WITH SILT AND GRAVEL (SW-SMg)
		fines = CL or CH	**SW-SC**	WELL-GRADED SAND WITH CLAY (SW-SC) WELL-GRADED SAND WITH CLAY AND GRAVEL (SW-
	Poorly-Graded	fines = ML or MH	**SP-SM**	POORLY-GRADED SAND WITH SILT (SP-SM) POORLY-GRADED SAND WITH SILT AND GRAVEL (SP-
		fines = CL or CH	**SP-SC**	POORLY-GRADED SAND WITH CLAY (SP-SC) POORLY-GRADED SAND WITH CLAY AND GRAVEL (SP-
	Sand with Fines (Appreciable Amount of Fines)	Non-plastic fines (for identification, see ML)	**SM**	SILTY SAND (SM) SILTY SAND WITH GRAVEL (SMg)
		Plastic fines (for identification, see CL)	**SC**	CLAYEY SAND (SC) CLAYEY SAND WITH GRAVEL (SCg)

Borderline Symbols:
Make every effort to place the soil in a single group. Use a borderline symbol when a soil falls in to one of two possible basic groups (i.e. SC/CL, CL/CH). A borderline symbol may be used under the following circumstances:

1) Fines 45-55%, one symbol represents coarse-grained soil with fines and the other a fine-grained soil (i.e. GM/ML, SC/CL).
2) % sand & gravel estimated to be approximately the same. GP/SP, SC/GC, GM/SM (it is practically impossible to have GW/SW).
3) If a soil could be well or poorly graded (GW/GP, SW/SP)

The order of the borderline symbols should reflect similarity to surrounding or adjacent soils. (i.e. if surrounding soil is GM and your sample could be GM/ML or ML/GM, then GM/ML should be chosen.

Group Name for borderline symbols is the first symbol (i.e. GM/ML is (Silty Gravel or Silty Gravel With Sand (as appropriate)). The only exceptions are for fine-grained material.

Particle Sizes

UNIFIED SOIL CLASSIFICATION SYSTEM (USCS - ASTM D****)				
Grain Size	**Relative Size**	**Inches**	**Millimeters**	**Sieve Size (mm, unless noted)**
Boulders	Basketball or larger	> 11.8“	> 300	Pass – n/a Retained on a 300
Cobbles	lemon to basketball	>3” - 11.8”	75 – 300	Pass a 300 mm sieve Retained on a 75
Coarse Gravel	grape to lemon	0.76” - 3”	19 – 75	Passes a 75 Retained on a 19
Fine Gravel	pea to grape	0.19” - 0.75”	5 – 19	Pass a 19 Retained on 4.75 (No. 4)
Coarse Sand	rock salt	0.08-0.19	2.00 - 4.75	Pass a 4.75 (No. 4) Retained on 2.00 (No. 10)
Medium Sand	sugar to table salt	0.02-.008	0.425 – <2.00	Pass a 2.00 (No. 10) Retained on 0.425 (No 40.)
Fine Sand	Fine sugar to sugar	0.003-0.02	0.075 – <0.425	Pass a 425 µm (No. 40) Retained on 0.075 (No. 200)
Silt			0.005 – 0.074	Pass a 0.075 (No. 200) Non-plastic
Clay			< 0.005	Pass a 0.075 (No. 200) Plastic

GEOLOGIC	
Grain Size	**Millimeters**
Boulder	> 256
Cobble	64 - 256
Pebble	4 - 64
Granule	2 - 4
Very Coarse Sand	1 - 2
Coarse Sand	0.5 - 1
Medium Sand	0.25 - 0.5
Fine Sand	0.125 - 0.25
Very Fine Sand	0.0625 - 0.125
Coarse Silt	0.031 - 0.0625
Medium Silt	0.016 - 0.031
Fine Silt	0.008 - 0.016
Very Fine Silt	0.004 - 0.008
Clay	< 0.004

Fine-Grained Soils Field Identification
(Particles are 50% or more silt and/or clay (< No. 200 sieve)
DO NOT include particles > 3" diameter to estimate particle %

Description guidelines follow ASTM D2488-00 Standard, reference standard for additional detail on performance for soil descriptions. Geologic descriptions may be added to the end of the description in brackets.

GROUP NAME, soil color, particle descriptions, dilatency, toughness, plasticity, consistency, cementation, structure, odor, moisture, additional comments, [geologic origin and/or descriptions].

LEAN CLAY WITH SAND (CL)s, reddish brown 5YR 4/4, few mottles greenish gray 10Y 5/1, 15 % subrounded fine to medium sand, few subangular fine gravel, slow dilatency, medium toughness, medium plasticity, homogenous, blocky, no odor, moist, trace fine root material [TILL].

1

Group Name: Determine after completion of tests listed below. Flow Chart for group names is on the back of this sheet.

2

Soil Color (moist condition) Color name with Hue, Value, & Chroma (e.g., Brown (7.5YR 5/3))
Mottled – Identify mottling percentage and color (e.g., Brown (7.5YR 5/3) 5% Gray (10YR 5/1) mottles)

3

Peat: Composed primarily of vegetable tissue in ranges of decomposition. Do not subject samples to field test procedures described beyond Item #4.
Color - Usually dark brown to black
Texture - Ranges from fibrous to amorphous
Consistency - Usually spongy

4

Particle Descriptions (comments not required when not applicable)
1)**Percent cobbles/boulders** volume %
2)**Coarse Particle Size Range** (Maximum size, and range)
3)**Particle Shape and Angularity**
4)**% gravel/sand/fines** - % particle < 3" by dry weight basis
Estimate percentage to the closest 5%. Sum of gravel/sand/fine %s must equal 100 % (except trace) - General Particle ranges:

Trace	**< 5%**	**Little**	**15–25 %**	**Mostly**	**50–100 %**
Few	**5–10 %**	**Some**	**30–45 %**		

Grain Size	Inch	Millimeter	relative size
Boulders	>11.8	>300	basketball or larger
Cobbles	2.9-11.8	75-300	Lemon - basketball
Coarse Gravel	0.75-2.9	19-75	grape to lemon
Fine Gravel	0.19-0.75	4.8-19	pea to grape
Coarse Sand	0.08-0.19	2.0-48	rock salt
Medium Sand	0.02-.008	0.43-2.0	sugar to table salt
Fine Sand	0.003-0.02	0.08-0.43	fine sugar to sugar
Silt / Clay	<0.003	<0.08	

5

Dilatency – Mold ½"diameter ball (remove all medium sand or larger), add water until soft (not sticky). Smooth ball into palm of one hand; vigorously shake hand horizontally, striking against other hand. Note water appearing on surface. Squeeze sample by closing the hand or pinching soil – note disappearance of water.

None	No visible change
Slow	Water appears/disappears slowly or does not disappear
Rapid	Water appears/disappears quickly

6

Toughness – Shape dilatency ball into a thread (1/8" (3 mm) diameter). Fold and re-roll until thread crumbles (near plastic limit). Note strength of thread. Lump pieces together and knead until lump crumbles.

Low	Slight pressure required to roll near plastic limit. Thread and lump are weak and soft.
Medium	Medium pressure required to roll near plastic limit. Thread and lump have medium stiffness.
High	Considerable pressure needed to roll near plastic limit.

7

Plasticity: On the basis of toughness test observations

Non	Thread cannot be rolled at any water content
Low	Thread is barely rolled, lump cannot be formed when drier than the plastic limit
Medium	Easily rolled thread, little time to reach plastic limit. Cannot re-roll. Lump crumbles when drier than plastic limit.
High	Considerable time to reach plastic limit. Thread can be re-rolled several times. Can form lump without crumbling when drier than plastic limit.

7

Geo-Technical	Pocket Penet	Blows / foot	ASTM Consistency	ASTM Criteria (press thumb/thumbnail)
Very soft	0-0.25	0-2	Very soft	Penetrates > 1"
Soft	0.25-0.5	2-4	Soft	Penetrates about 1"
Firm	0.5-1.0	4-8	Firm	Indents about ¼"
Stiff	1.0-2.0	8-15	- -	No ASTM Description
Very Stiff	2.0-4.0	15-30	Hard	Thumbnail only indents
Hard	>4.0	>30	Very hard	Thumbnail will not indent

8

Cementation Drop dilute HCl onto the soil, describe

None	No visible reaction
Weak	Some reaction; with bubbles forming slowly
Strong	Violent reaction, with bubbles forming immediately

9

Structure- note thickness for stratified, laminated, lensed.

Stratified	Alternating layers of material/color ≥ 6 mm
Laminated	Alternating layers of material/color < 6 mm
Fissured	Breaks on fracture(s) with little resistance
Slickensided	Polished/glossy fracture plane(s), sometimes striated
Blocky	Can be broken into small angular lumps which resist further breakdown
Lensed	Small pockets of different material
Homogeneous	Same color and appearance throughout

10

Odor –Appropriate terms listed on back.

11

Moisture -

Dry	Dry to touch, dusty.
Moist	Damp, but no visible water
Wet	Visible free water, usually soil is below water table

12

Comments – diamicton, roots or root holes, surface coatings, etc…

13

Geologic Interpretations

Deposition add *possible* if unsure	alluvial, lacustrine, colluvial, sediment flow, mass slump, subglacial, supraglacial, glaciaofluvial, glaciolacustrine, aeolian (loess), outwash, proglacial

Dilatency	Toughness	Plasticity	Soil Identification
No	Low	Low	Elastic Silt (MH)
	Low / Medium	Low / Medium	Elastic Silt (MH)
	Medium	Medium	Lean Clay (CL) or Elastic Silt (MH)
No	High	High	Fat Clay (CH)
Slow	Medium	Medium	Lean Clay (CL)
	Low	Non / Low	Silt (ML)
	Low / Medium	Low / Medium	Elastic Silt (MH)
Rapid	Low	Non / Low	Silt (ML)

If properties do not flow, texture again.

- Use borderline texture if soil cannot be differentiated after multiple texture procedures
- MH / CL properties are similar. If MH / CL are indistinguishable use MH/CL or CL/MH.

Note - MH will dry quickly with a smooth, silky feel on your hands.

	Dilatency	Toughness	Plasticity
ML	slow - rapid	low	non - low
CL	no - slow	medium	medium
MH	no - slow	low - medium	low - medium
CH	no	high	high

				GROUP NAME	
CL	<30% sand / gravel	<15% sand / gravel		Lean Clay	(CL)
		%sand ≥ %gravel		Lean Clay With Sand	(CL)s
		%sand < %gravel		Lean Clay With Gravel	(CL)g
	≥ 30% sand / gravel	%sand ≥ %gravel	<15% gravel	Sandy Lean Clay	s(CL)
			≥15% gravel	Sandy Lean Clay With Gravel	s(CL)g
		%sand < %gravel	<15% sand	Gravelly Lean Clay	g(CL)
			≥15% sand	Gravelly Lean Clay With Sand	g(CL)s
ML	<30% sand / gravel	<15% sand / gravel		Silt	(ML)
		%sand ≥ %gravel		Silt With Sand	(ML)s
		%sand < %gravel		Silt With Gravel	(ML)g
	≥ 30% sand / gravel	%sand ≥ %gravel	<15% gravel	Sandy Silt	s(ML)
			≥15% gravel	Sandy Silt With Gravel	s(ML)g
		%sand < %gravel	<15% sand	Gravely Silt	g(ML)
			≥15% sand	Gravely Silt With Sand	g(ML)s
CH	<30% sand / gravel	<15% sand / gravel		Fat Clay	(CH)
		%sand ≥ %gravel		Fat Clay With Sand	(CH)s
		%sand < %gravel		Fat Clay With Gravel	(CH)g
	≥ 30% sand / gravel	%sand ≥ %gravel	<15% gravel	Sandy Fat Clay	s(CH)
			≥15% gravel	Sandy Fat Clay With Gravel	s(CH)g
		%sand < %gravel	<15% sand	Gravelly Fat Clay	g(CH
			≥15% sand	Gravelly Fat Clay With Sand	g(CH)s
MH	<30% sand / gravel	<15% sand / gravel		Elastic Silt	(MH)
		%sand ≥ %gravel		Elastic Silt With Sand	(MH)s
		%sand < %gravel		Elastic Silt With Gravel	(MH)g
	≥ 30% sand / gravel	%sand ≥ %gravel	<15% gravel	Sandy Elastic Silt	s(MH)
			≥15% gravel	Sandy Elastic Silt With Gravel	s(MH)g
		%sand < %gravel	<15% sand	Gravely Elastic Silt	g(MH)
			≥15% sand	Gravely Elastic Silt With Sand	g(MH)s
OL/ OH					
OL					
OH					
PT				Peat	(PT)

"**Sandy**" indicates coarse particles are =/> 30% and less than 50%.

"**Sandy**" indicates sand % > gravel %

"**with Gravel**" indicates the % of gravel is =/> 15%.

Borderline Symbols:
Every effort shall be made to place the soil in a single group. A borderline symbol is used when a soil that may fall in to one of two possible basic groups (e.g., SC/CL, CL/CH). A borderline symbol may be used under the following circumstances:

1) Fines 45-55%, one symbol represents coarse-grained soil with fines and the other a fine-grained soil (e.g., GM/ML, CL/SC).
2) If a soil could either be a silt or clay (CL/ML, CH/MH)
3) Fine-grained soil at low/high compressibility boundary (CL/CH, MH/ML)

The order of the borderline symbols should reflect similarity to surrounding or adjacent soils. (e.g., if surrounding soil is GM and your sample could be GM/ML or ML/GM, then GM/ML should be chosen.
<u>Group Names</u> for borderline symbols are the group name for the first symbol except:

CL/CH – <u>LEAN TO FAT CLAY</u>
ML/CL – <u>CLAYEY SILT</u>
CL/ML – <u>SILTY CLAY</u>

Designation: D2488 – 09a

Standard Practice for Description and Identification of Soils (Visual-Manual Procedure)[1]

This standard is issued under the fixed designation D2488; 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.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope*

1.1 This practice covers procedures for the description of soils for engineering purposes.

1.2 This practice also describes a procedure for identifying soils, at the option of the user, based on the classification system described in Test Method D2487. The identification is based on visual examination and manual tests. It must be clearly stated in reporting an identification that it is based on visual-manual procedures.

1.2.1 When precise classification of soils for engineering purposes is required, the procedures prescribed in Test Method D2487 shall be used.

1.2.2 In this practice, the identification portion assigning a group symbol and name is limited to soil particles smaller than 3 in. (75 mm).

1.2.3 The identification portion of this practice is limited to naturally occurring soils (either intact or disturbed).

NOTE 1—This practice may be used as a descriptive system applied to such materials as shale, claystone, shells, crushed rock, etc. (see Appendix X2).

1.3 The descriptive information in this practice may be used with other soil classification systems or for materials other than naturally occurring soils.

1.4 The values stated in inch-pound units are to be regarded as standard. The values given in parentheses are mathematical conversions to SI units that are provided for information only and are not considered standard.

1.5 *This standard does not purport to address all of the safety problems, 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.* For specific precautionary statements see Section 8.

1.6 *This practice offers a set of instructions for performing one or more specific operations. This document cannot replace education or experience and should be used in conjunction with professional judgment. Not all aspects of this practice may be applicable in all circumstances. This ASTM standard is not intended to represent or replace the standard of care by which the adequacy of a given professional service must be judged, nor should this document be applied without 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
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
D2113 Practice for Rock Core Drilling and Sampling of Rock for Site Investigation
D2487 Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System)
D3740 Practice for Minimum Requirements for Agencies Engaged in Testing and/or Inspection of Soil and Rock as Used in Engineering Design and Construction
D4083 Practice for Description of Frozen Soils (Visual-Manual Procedure)

3. Terminology

3.1 *Definitions*—Except as listed below, all definitions are in accordance with Terminology D653.

NOTE 2—For particles retained on a 3-in. (75-mm) US standard sieve, the following definitions are suggested:
Cobbles—particles of rock that will pass a 12-in. (300-mm) square opening and be retained on a 3-in. (75-mm) sieve, and

[1] This practice is under the jurisdiction of ASTM Committee D18 on Soil and Rock and is the direct responsibility of Subcommittee D18.07 on Identification and Classification of Soils.

Current edition approved June 15, 2009. Published July 2009. Originally approved in 1966. Last previous edition approved in 2009 as D2488 – 09. DOI: 10.1520/D2488-09A.

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

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

Boulders—particles of rock that will not pass a 12-in. (300-mm) square opening.

3.1.1 *clay*—soil passing a No. 200 (75-μm) sieve that can be made to exhibit plasticity (putty-like properties) within a range of water contents, and that exhibits considerable strength when air-dry. For classification, a clay is a fine-grained soil, or the fine-grained portion of a soil, with a plasticity index equal to or greater than 4, and the plot of plasticity index versus liquid limit falls on or above the "A" line (see Fig. 3 of Test Method D2487).

3.1.2 *gravel*—particles of rock that will pass a 3-in. (75-mm) sieve and be retained on a No. 4 (4.75-mm) sieve with the following subdivisions:

coarse—passes a 3-in. (75-mm) sieve and is retained on a ¾-in. (19-mm) sieve.

fine—passes a ¾-in. (19-mm) sieve and is retained on a No. 4 (4.75-mm) sieve.

3.1.3 *organic clay*—a clay with sufficient organic content to influence the soil properties. For classification, an organic clay is a soil that would be classified as a clay, except that its liquid limit value after oven drying is less than 75 % of its liquid limit value before oven drying.

3.1.4 *organic silt*—a silt with sufficient organic content to influence the soil properties. For classification, an organic silt is a soil that would be classified as a silt except that its liquid limit value after oven drying is less than 75 % of its liquid limit value before oven drying.

3.1.5 *peat*—a soil composed primarily of vegetable tissue in various stages of decomposition usually with an organic odor, a dark brown to black color, a spongy consistency, and a texture ranging from fibrous to amorphous.

3.1.6 *sand*—particles of rock that will pass a No. 4 (4.75-mm) sieve and be retained on a No. 200 (75-μm) sieve with the following subdivisions:

coarse—passes a No. 4 (4.75-mm) sieve and is retained on a No. 10 (2.00-mm) sieve.

medium—passes a No. 10 (2.00-mm) sieve and is retained on a No. 40 (425-μm) sieve.

fine—passes a No. 40 (425-μm) sieve and is retained on a No. 200 (75-μm) sieve.

3.1.7 *silt*—soil passing a No. 200 (75-μm) sieve that is nonplastic or very slightly plastic and that exhibits little or no strength when air dry. For classification, a silt is a fine-grained soil, or the fine-grained portion of a soil, with a plasticity index less than 4, or the plot of plasticity index versus liquid limit falls below the "A" line (see Fig. 3 of Test Method D2487).

4. Summary of Practice

4.1 Using visual examination and simple manual tests, this practice gives standardized criteria and procedures for describing and identifying soils.

4.2 The soil can be given an identification by assigning a group symbol(s) and name. The flow charts, Fig. 1a and Fig. 1b for fine-grained soils, and Fig. 2, for coarse-grained soils, can be used to assign the appropriate group symbol(s) and name. If the soil has properties which do not distinctly place it into a specific group, borderline symbols may be used, see Appendix X3.

NOTE 3—It is suggested that a distinction be made between *dual symbols* and *borderline symbols.*

Dual Symbol—A dual symbol is two symbols separated by a hyphen, for example, GP-GM, SW-SC, CL-ML used to indicate that the soil has been identified as having the properties of a classification in accordance with Test Method D2487 where two symbols are required. Two symbols are required when the soil has between 5 and 12 % fines or when the liquid limit and plasticity index values plot in the CL-ML area of the plasticity chart.

Borderline Symbol—A borderline symbol is two symbols separated by a slash, for example, CL/CH, GM/SM, CL/ML. A borderline symbol should be used to indicate that the soil has been identified as having properties that do not distinctly place the soil into a specific group (see Appendix X3).

5. Significance and Use

5.1 The descriptive information required in this practice can be used to describe a soil to aid in the evaluation of its significant properties for engineering use.

5.2 The descriptive information required in this practice should be used to supplement the classification of a soil as determined by Test Method D2487.

5.3 This practice may be used in identifying soils using the classification group symbols and names as prescribed in Test Method D2487. Since the names and symbols used in this practice to identify the soils are the same as those used in Test Method D2487, it shall be clearly stated in reports and all other appropriate documents, that the classification symbol and name are based on visual-manual procedures.

5.4 This practice is to be used not only for identification of soils in the field, but also in the office, laboratory, or wherever soil samples are inspected and described.

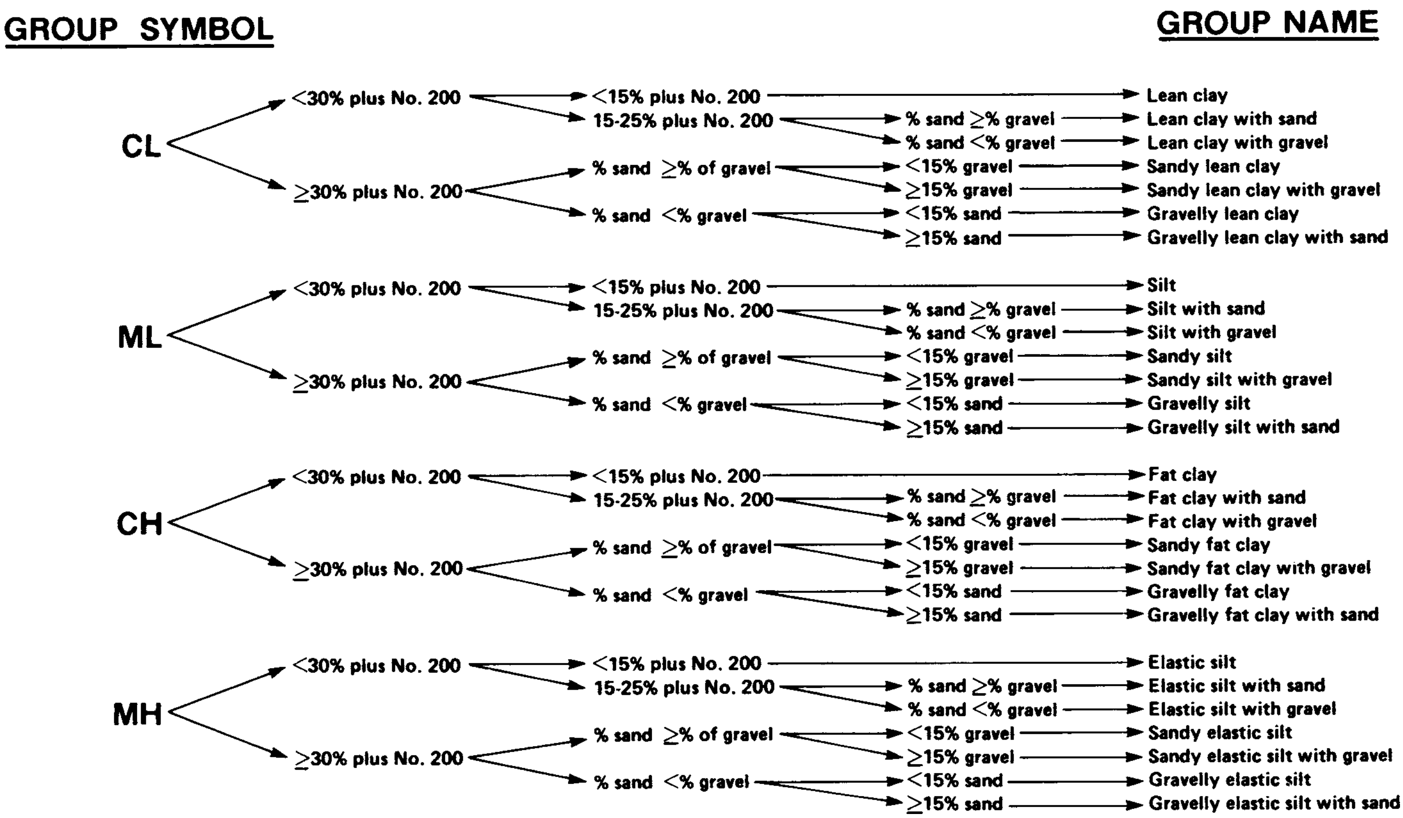
5.5 This practice has particular value in grouping similar soil samples so that only a minimum number of laboratory tests need be run for positive soil classification.

NOTE 4—The ability to describe and identify soils correctly is learned more readily under the guidance of experienced personnel, but it may also be acquired systematically by comparing numerical laboratory test results for typical soils of each type with their visual and manual characteristics.

5.6 When describing and identifying soil samples from a given boring, test pit, or group of borings or pits, it is not necessary to follow all of the procedures in this practice for every sample. Soils which appear to be similar can be grouped together; one sample completely described and identified with the others referred to as similar based on performing only a few of the descriptive and identification procedures described in this practice.

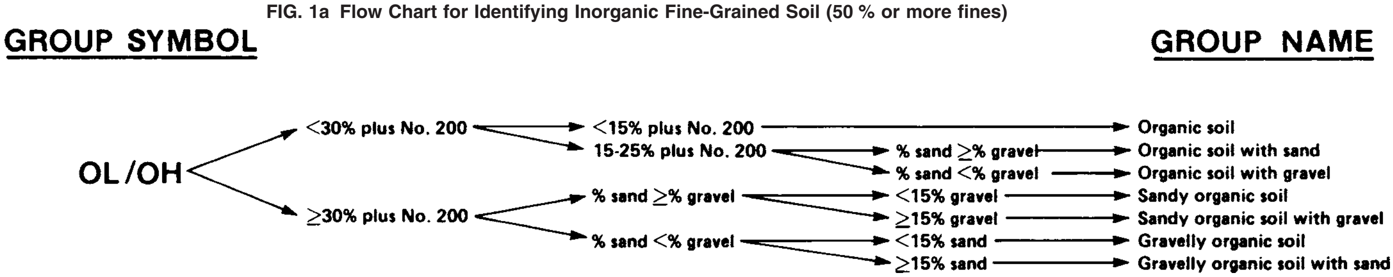
5.7 This practice may be used in combination with Practice D4083 when working with frozen soils.

NOTE 5—Notwithstanding the statements on precision and bias contained in this standard: The precision of this test method 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. Users of this test method are cautioned that compliance with Practice D3740 does not in itself assure reliable testing. Reliable testing depends on several factors; Practice D3740 provides a means for evaluating some of those factors.



NOTE 1—Percentages are based on estimating amounts of fines, sand, and gravel to the nearest 5 %.

FIG. 1a Flow Chart for Identifying Inorganic Fine-Grained Soil (50 % or more fines)



NOTE 1—Percentages are based on estimating amounts of fines, sand, and gravel to the nearest 5 %.

FIG. 1 b Flow Chart for Identifying Organic Fine-Grained Soil (50 % or more fines)

6. Apparatus

6.1 *Required Apparatus*:

6.1.1 *Pocket Knife or Small Spatula*.

6.2 *Useful Auxiliary Apparatus*:

6.2.1 *Test Tube and Stopper* (or jar with a lid).

6.2.2 *Hand Lens*.

7. Reagents

7.1 *Purity of Water*—Unless otherwise indicated, references to water shall be understood to mean water from a city water supply or natural source, including non-potable water.

7.2 *Hydrochloric Acid*—A small bottle of dilute hydrochloric acid, HCl, one part HCl (10 *N*) to three parts water (This reagent is optional for use with this practice). See Section 8.

8. Safety Precautions

8.1 When preparing the dilute HCl solution of one part concentrated hydrochloric acid (10 *N*) to three parts of distilled water, slowly add acid into water following necessary safety precautions. Handle with caution and store safely. If solution comes into contact with the skin, rinse thoroughly with water.

8.2 **Caution**—Do not add water to acid.

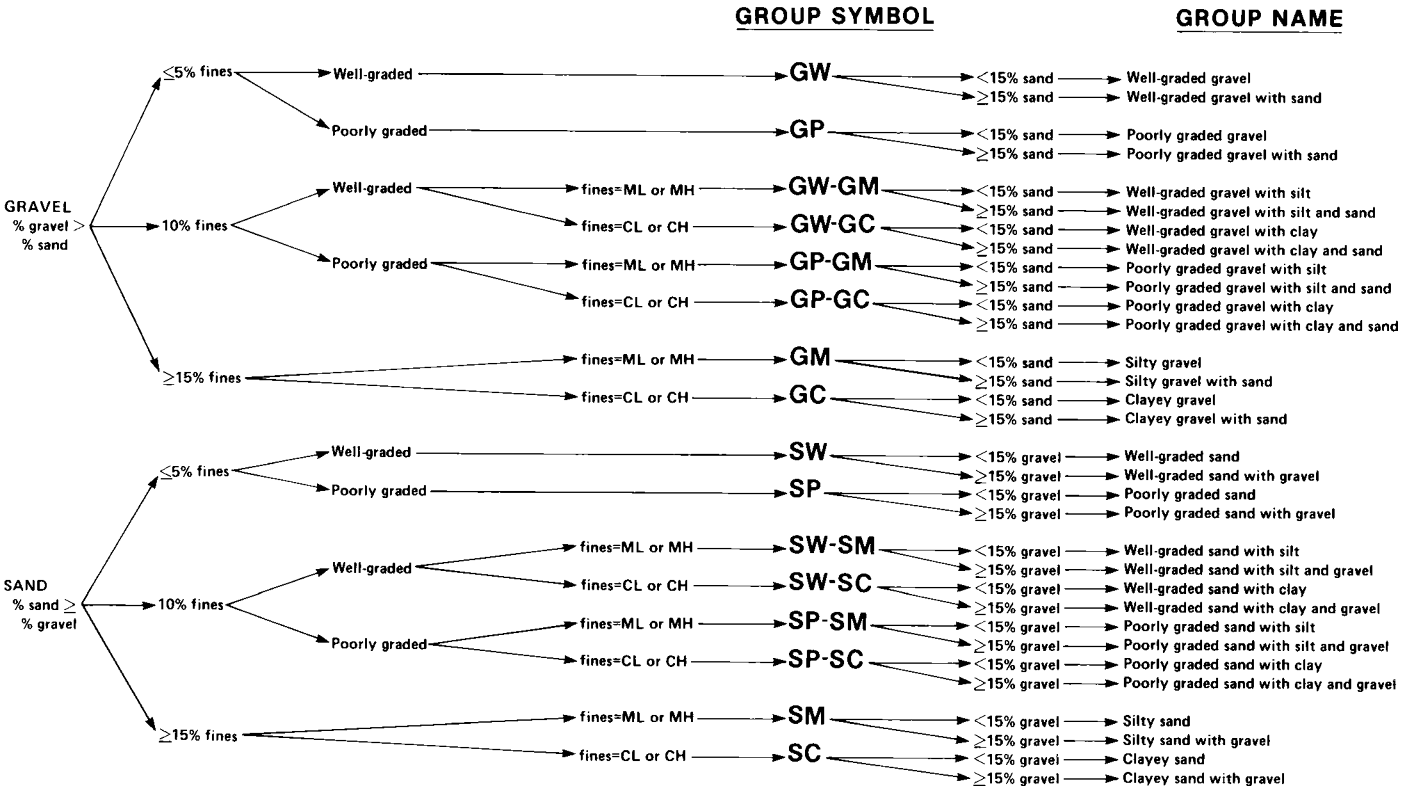
9. Sampling

9.1 The sample shall be considered to be representative of the stratum from which it was obtained by an appropriate, accepted, or standard procedure.

NOTE 6—Preferably, the sampling procedure should be identified as having been conducted in accordance with Practices D1452, D1587, or D2113, or Test Method D1586.

9.2 The sample shall be carefully identified as to origin.

NOTE 7—Remarks as to the origin may take the form of a boring number and sample number in conjunction with a job number, a geologic stratum, a pedologic horizon or a location description with respect to a permanent monument, a grid system or a station number and offset with respect to a stated centerline and a depth or elevation.



NOTE 1—Percentages are based on estimating amounts of fines, sand, and gravel to the nearest 5 %.

FIG. 2 Flow Chart for Identifying Coarse-Grained Soils (less than 50 % fines)

9.3 For accurate description and identification, the minimum amount of the specimen to be examined shall be in accordance with the following schedule:

Maximum Particle Size, Sieve Opening	Minimum Specimen Size, Dry Weight
4.75 mm (No. 4)	100 g (0.25 lb)
9.5 mm (3⁄8 in.)	200 g (0.5 lb)
19.0 mm (3⁄4 in.)	1.0 kg (2.2 lb)
38.1 mm (1½ in.)	8.0 kg (18 lb)
75.0 mm (3 in.)	60.0 kg (132 lb)

NOTE 8—If random isolated particles are encountered that are significantly larger than the particles in the soil matrix, the soil matrix can be accurately described and identified in accordance with the preceeding schedule.

9.4 If the field sample or specimen being examined is smaller than the minimum recommended amount, the report shall include an appropriate remark.

10. Descriptive Information for Soils

10.1 *Angularity*—Describe the angularity of the sand (coarse sizes only), gravel, cobbles, and boulders, as angular, subangular, subrounded, or rounded in accordance with the criteria in Table 1 and Fig. 3. A range of angularity may be stated, such as: subrounded to rounded.

10.2 *Shape*—Describe the shape of the gravel, cobbles, and boulders as flat, elongated, or flat and elongated if they meet the criteria in Table 2 and Fig. 4. Otherwise, do not mention the shape. Indicate the fraction of the particles that have the shape, such as: one-third of the gravel particles are flat.

TABLE 1 Criteria for Describing Angularity of Coarse-Grained Particles (see Fig. 3)

Description	Criteria
Angular	Particles have sharp edges and relatively plane sides with unpolished surfaces
Subangular	Particles are similar to angular description but have rounded edges
Subrounded	Particles have nearly plane sides but have well-rounded corners and edges
Rounded	Particles have smoothly curved sides and no edges

10.3 *Color*—Describe the color. Color is an important property in identifying organic soils, and within a given locality it may also be useful in identifying materials of similar geologic origin. If the sample contains layers or patches of varying colors, this shall be noted and all representative colors shall be described. The color shall be described for moist samples. If the color represents a dry condition, this shall be stated in the report.

10.4 *Odor*—Describe the odor if organic or unusual. Soils containing a significant amount of organic material usually have a distinctive odor of decaying vegetation. This is especially apparent in fresh samples, but if the samples are dried, the odor may often be revived by heating a moistened sample. If the odor is unusual (petroleum product, chemical, and the like), it shall be described.

10.5 *Moisture Condition*—Describe the moisture condition as dry, moist, or wet, in accordance with the criteria in Table 3.

10.6 *HCl Reaction*—Describe the reaction with HCl as none, weak, or strong, in accordance with the critera in Table

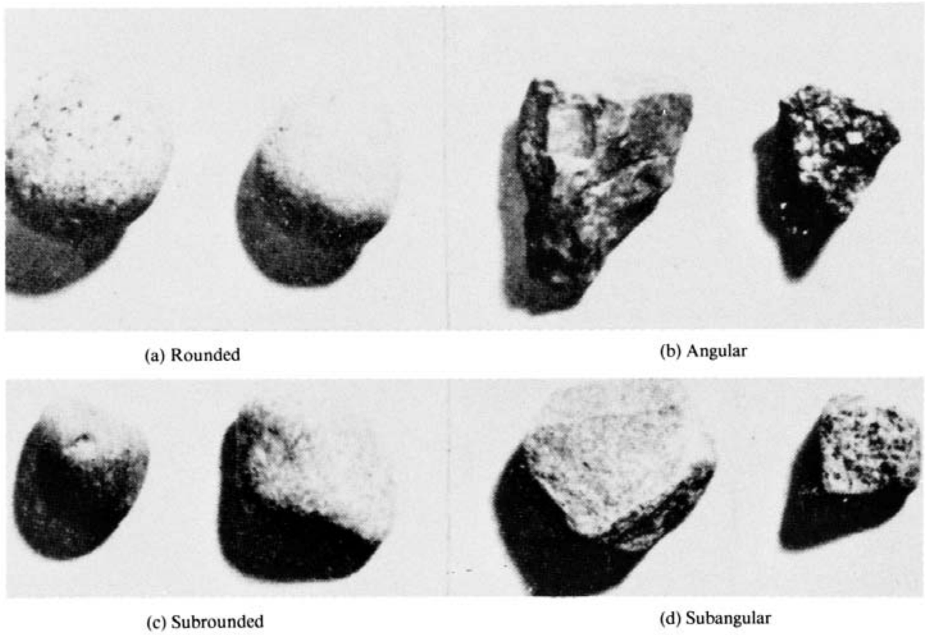


FIG. 3 Typical Angularity of Bulky Grains

TABLE 2 Criteria for Describing Particle Shape (see Fig. 4)

The particle shape shall be described as follows where length, width, and thickness refer to the greatest, intermediate, and least dimensions of a particle, respectively.

Flat	Particles with width/thickness > 3
Elongated	Particles with length/width > 3
Flat and elongated	Particles meet criteria for both flat and elongated

4. Since calcium carbonate is a common cementing agent, a report of its presence on the basis of the reaction with dilute hydrochloric acid is important.

10.7 *Consistency*—For intact fine-grained soil, describe the consistency as very soft, soft, firm, hard, or very hard, in accordance with the criteria in Table 5. This observation is inappropriate for soils with significant amounts of gravel.

10.8 *Cementation*—Describe the cementation of intact coarse-grained soils as weak, moderate, or strong, in accordance with the criteria in Table 6.

10.9 *Structure*—Describe the structure of intact soils in accordance with the criteria in Table 7.

10.10 *Range of Particle Sizes*—For gravel and sand components, describe the range of particle sizes within each component as defined in 3.1.2 and 3.1.6. For example, about 20 % fine to coarse gravel, about 40 % fine to coarse sand.

10.11 *Maximum Particle Size*—Describe the maximum particle size found in the sample in accordance with the following information:

10.11.1 *Sand Size*—If the maximum particle size is a sand size, describe as fine, medium, or coarse as defined in 3.1.6. For example: maximum particle size, medium sand.

10.11.2 *Gravel Size*—If the maximum particle size is a gravel size, describe the maximum particle size as the smallest sieve opening that the particle will pass. For example, maxi-

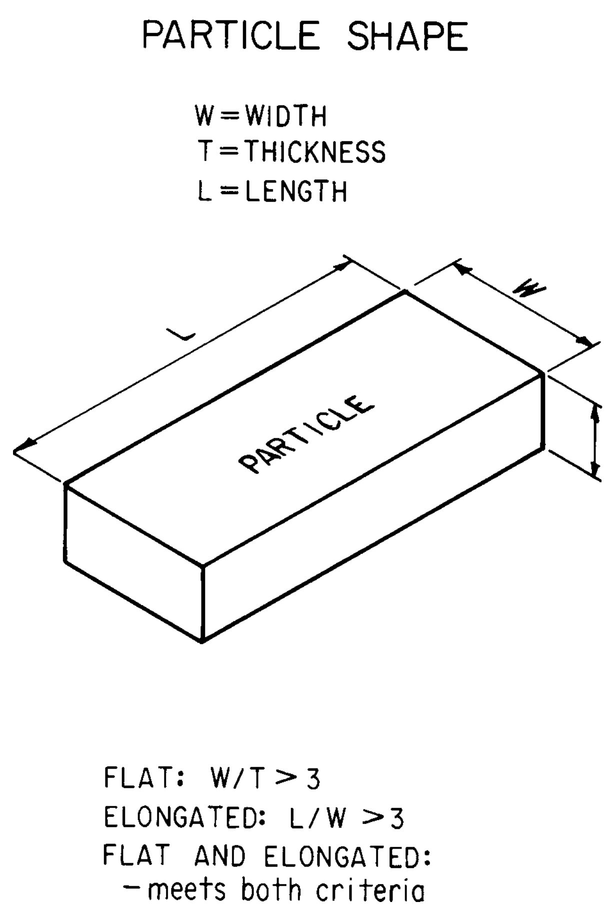


FIG. 4 Criteria for Particle Shape

TABLE 3 Criteria for Describing Moisture Condition

Description	Criteria
Dry	Absence of moisture, dusty, dry to the touch
Moist	Damp but no visible water
Wet	Visible free water, usually soil is below water table

TABLE 4 Criteria for Describing the Reaction With HCl

Description	Criteria
None	No visible reaction
Weak	Some reaction, with bubbles forming slowly
Strong	Violent reaction, with bubbles forming immediately

TABLE 5 Criteria for Describing Consistency

Description	Criteria
Very soft	Thumb will penetrate soil more than 1 in. (25 mm)
Soft	Thumb will penetrate soil about 1 in. (25 mm)
Firm	Thumb will indent soil about ¼ in. (6 mm)
Hard	Thumb will not indent soil but readily indented with thumbnail
Very hard	Thumbnail will not indent soil

TABLE 6 Criteria for Describing Cementation

Description	Criteria
Weak	Crumbles or breaks with handling or little finger pressure
Moderate	Crumbles or breaks with considerable finger pressure
Strong	Will not crumble or break with finger pressure

TABLE 7 Criteria for Describing Structure

Description	Criteria
Stratified	Alternating layers of varying material or color with layers at least 6 mm thick; note thickness
Laminated	Alternating layers of varying material or color with the layers less than 6 mm thick; note thickness
Fissured	Breaks along definite planes of fracture with little resistance to fracturing
Slickensided	Fracture planes appear polished or glossy, sometimes striated
Blocky	Cohesive soil that can be broken down into small angular lumps which resist further breakdown
Lensed	Inclusion of small pockets of different soils, such as small lenses of sand scattered through a mass of clay; note thickness
Homogeneous	Same color and appearance throughout

mum particle size, 1½ in. (will pass a 1½-in. square opening but not a ¾-in. square opening).

10.11.3 *Cobble or Boulder Size*—If the maximum particle size is a cobble or boulder size, describe the maximum dimension of the largest particle. For example: maximum dimension, 18 in. (450 mm).

10.12 *Hardness*—Describe the hardness of coarse sand and larger particles as hard, or state what happens when the particles are hit by a hammer, for example, gravel-size particles fracture with considerable hammer blow, some gravel-size particles crumble with hammer blow. "Hard" means particles do not crack, fracture, or crumble under a hammer blow.

10.13 Additional comments shall be noted, such as the presence of roots or root holes, difficulty in drilling or augering hole, caving of trench or hole, or the presence of mica.

10.14 A local or commercial name or a geologic interpretation of the soil, or both, may be added if identified as such.

10.15 A classification or identification of the soil in accordance with other classification systems may be added if identified as such.

11. Identification of Peat

11.1 A sample composed primarily of vegetable tissue in various stages of decomposition that has a fibrous to amorphous texture, usually a dark brown to black color, and an organic odor, shall be designated as a highly organic soil and shall be identified as peat, PT, and not subjected to the identification procedures described hereafter.

12. Preparation for Identification

12.1 The soil identification portion of this practice is based on the portion of the soil sample that will pass a 3-in. (75-mm) sieve. The larger than 3-in. (75-mm) particles must be removed, manually, for a loose sample, or mentally, for an intact sample before classifying the soil.

12.2 Estimate and note the percentage of cobbles and the percentage of boulders. Performed visually, these estimates will be on the basis of volume percentage.

NOTE 9—Since the percentages of the particle-size distribution in Test Method D2487 are by dry weight, and the estimates of percentages for gravel, sand, and fines in this practice are by dry weight, it is recommended that the report state that the percentages of cobbles and boulders are by volume.

12.3 Of the fraction of the soil smaller than 3 in. (75 mm), estimate and note the percentage, by dry weight, of the gravel, sand, and fines (see Appendix X4 for suggested procedures).

NOTE 10—Since the particle-size components appear visually on the basis of volume, considerable experience is required to estimate the percentages on the basis of dry weight. Frequent comparisons with laboratory particle-size analyses should be made.

12.3.1 The percentages shall be estimated to the closest 5 %. The percentages of gravel, sand, and fines must add up to 100 %.

12.3.2 If one of the components is present but not in sufficient quantity to be considered 5 % of the smaller than 3-in. (75-mm) portion, indicate its presence by the term *trace*, for example, trace of fines. A trace is not to be considered in the total of 100 % for the components.

13. Preliminary Identification

13.1 The soil is *fine grained* if it contains 50 % or more fines. Follow the procedures for identifying fine-grained soils of Section 14.

13.2 The soil is *coarse grained* if it contains less than 50 % fines. Follow the procedures for identifying coarse-grained soils of Section 15.

14. Procedure for Identifying Fine-Grained Soils

14.1 Select a representative sample of the material for examination. Remove particles larger than the No. 40 sieve (medium sand and larger) until a specimen equivalent to about a handful of material is available. Use this specimen for performing the dry strength, dilatancy, and toughness tests.

14.2 *Dry Strength*:

14.2.1 From the specimen, select enough material to mold into a ball about 1 in. (25 mm) in diameter. Mold the material until it has the consistency of putty, adding water if necessary.

14.2.2 From the molded material, make at least three test specimens. A test specimen shall be a ball of material about ½ in. (12 mm) in diameter. Allow the test specimens to dry in air, or sun, or by artificial means, as long as the temperature does not exceed 60°C.

14.2.3 If the test specimen contains natural dry lumps, those that are about ½ in. (12 mm) in diameter may be used in place of the molded balls.

NOTE 11—The process of molding and drying usually produces higher strengths than are found in natural dry lumps of soil.

14.2.4 Test the strength of the dry balls or lumps by crushing between the fingers. Note the strength as none, low, medium, high, or very high in accorance with the criteria in Table 8. If natural dry lumps are used, do not use the results of any of the lumps that are found to contain particles of coarse sand.

14.2.5 The presence of high-strength water-soluble cementing materials, such as calcium carbonate, may cause exceptionally high dry strengths. The presence of calcium carbonate can usually be detected from the intensity of the reaction with dilute hydrochloric acid (see 10.6).

14.3 *Dilatancy*:

14.3.1 From the specimen, select enough material to mold into a ball about ½ in. (12 mm) in diameter. Mold the material, adding water if necessary, until it has a soft, but not sticky, consistency.

14.3.2 Smooth the soil ball in the palm of one hand with the blade of a knife or small spatula. Shake horizontally, striking the side of the hand vigorously against the other hand several times. Note the reaction of water appearing on the surface of the soil. Squeeze the sample by closing the hand or pinching the soil between the fingers, and note the reaction as none, slow, or rapid in accordance with the criteria in Table 9. The reaction is the speed with which water appears while shaking, and disappears while squeezing.

14.4 *Toughness*:

14.4.1 Following the completion of the dilatancy test, the test specimen is shaped into an elongated pat and rolled by hand on a smooth surface or between the palms into a thread about ⅛ in. (3 mm) in diameter. (If the sample is too wet to roll easily, it should be spread into a thin layer and allowed to lose some water by evaporation.) Fold the sample threads and reroll repeatedly until the thread crumbles at a diameter of about ⅛ in. The thread will crumble at a diameter of ⅛ in. when the soil is near the plastic limit. Note the pressure required to roll the thread near the plastic limit. Also, note the strength of the thread. After the thread crumbles, the pieces should be lumped together and kneaded until the lump crumbles. Note the toughness of the material during kneading.

14.4.2 Describe the toughness of the thread and lump as low, medium, or high in accordance with the criteria in Table 10.

14.5 *Plasticity*—On the basis of observations made during the toughness test, describe the plasticity of the material in accordance with the criteria given in Table 11.

14.6 Decide whether the soil is an *inorganic* or an *organic* fine-grained soil (see 14.8). If inorganic, follow the steps given in 14.7.

14.7 *Identification of Inorganic Fine-Grained Soils*:

14.7.1 Identify the soil as a *lean clay*, CL, if the soil has medium to high dry strength, no or slow dilatancy, and medium toughness and plasticity (see Table 12).

14.7.2 Identify the soil as a *fat clay*, CH, if the soil has high to very high dry strength, no dilatancy, and high toughness and plasticity (see Table 12).

14.7.3 Identify the soil as a *silt*, ML, if the soil has no to low dry strength, slow to rapid dilatancy, and low toughness and plasticity, or is nonplastic (see Table 12).

14.7.4 Identify the soil as an *elastic silt*, MH, if the soil has low to medium dry strength, no to slow dilatancy, and low to medium toughness and plasticity (see Table 12).

NOTE 12—These properties are similar to those for a lean clay. However, the silt will dry quickly on the hand and have a smooth, silky feel when dry. Some soils that would classify as MH in accordance with the criteria in Test Method D2487 are visually difficult to distinguish from lean clays, CL. It may be necessary to perform laboratory testing for proper identification.

14.8 *Identification of Organic Fine-Grained Soils*:

14.8.1 Identify the soil as an *organic soil*, OL/OH, if the soil contains enough organic particles to influence the soil properties. Organic soils usually have a dark brown to black color and

TABLE 8 Criteria for Describing Dry Strength

Description	Criteria
None	The dry specimen crumbles into powder with mere pressure of handling
Low	The dry specimen crumbles into powder with some finger pressure
Medium	The dry specimen breaks into pieces or crumbles with considerable finger pressure
High	The dry specimen cannot be broken with finger pressure. Specimen will break into pieces between thumb and a hard surface
Very high	The dry specimen cannot be broken between the thumb and a hard surface

TABLE 9 Criteria for Describing Dilatancy

Description	Criteria
None	No visible change in the specimen
Slow	Water appears slowly on the surface of the specimen during shaking and does not disappear or disappears slowly upon squeezing
Rapid	Water appears quickly on the surface of the specimen during shaking and disappears quickly upon squeezing

TABLE 10 Criteria for Describing Toughness

Description	Criteria
Low	Only slight pressure is required to roll the thread near the plastic limit. The thread and the lump are weak and soft
Medium	Medium pressure is required to roll the thread to near the plastic limit. The thread and the lump have medium stiffness
High	Considerable pressure is required to roll the thread to near the plastic limit. The thread and the lump have very high stiffness

TABLE 11 Criteria for Describing Plasticity

Description	Criteria
Nonplastic	A ⅛-in. (3-mm) thread cannot be rolled at any water content
Low	The thread can barely be rolled and the lump cannot be formed when drier than the plastic limit
Medium	The thread is easy to roll and not much time is required to reach the plastic limit. The thread cannot be rerolled after reaching the plastic limit. The lump crumbles when drier than the plastic limit
High	It takes considerable time rolling and kneading to reach the plastic limit. The thread can be rerolled several times after reaching the plastic limit. The lump can be formed without crumbling when drier than the plastic limit

TABLE 12 Identification of Inorganic Fine-Grained Soils from Manual Tests

Soil Symbol	Dry Strength	Dilatancy	Toughness and Plasticity
ML	None to low	Slow to rapid	Low or thread cannot be formed
CL	Medium to high	None to slow	Medium
MH	Low to medium	None to slow	Low to medium
CH	High to very high	None	High

may have an organic odor. Often, organic soils will change color, for example, black to brown, when exposed to the air. Some organic soils will lighten in color significantly when air dried. Organic soils normally will not have a high toughness or plasticity. The thread for the toughness test will be spongy.

NOTE 13—In some cases, through practice and experience, it may be possible to further identify the organic soils as organic silts or organic clays, OL or OH. Correlations between the dilatancy, dry strength, toughness tests, and laboratory tests can be made to identify organic soils in certain deposits of similar materials of known geologic origin.

14.9 If the soil is estimated to have 15 to 25 % sand or gravel, or both, the words "with sand" or "with gravel" (whichever is more predominant) shall be added to the group name. For example: "lean clay with sand, CL" or "silt with gravel, ML" (see Fig. 1a and Fig. 1b). If the percentage of sand is equal to the percentage of gravel, use "with sand."

14.10 If the soil is estimated to have 30 % or more sand or gravel, or both, the words "sandy" or "gravelly" shall be added to the group name. Add the word "sandy" if there appears to be more sand than gravel. Add the word "gravelly" if there appears to be more gravel than sand. For example: "sandy lean clay, CL", "gravelly fat clay, CH", or "sandy silt, ML" (see Fig. 1a and Fig. 1b). If the percentage of sand is equal to the percent of gravel, use "sandy."

15. Procedure for Identifying Coarse-Grained Soils (Contains less than 50 % fines)

15.1 The soil is a *gravel* if the percentage of gravel is estimated to be more than the percentage of sand.

15.2 The soil is a *sand* if the percentage of gravel is estimated to be equal to or less than the percentage of sand.

15.3 The soil is a *clean gravel* or *clean sand* if the percentage of fines is estimated to be 5 % or less.

15.3.1 Identify the soil as a *well-graded gravel*, GW, or as a *well-graded sand*, SW, if it has a wide range of particle sizes and substantial amounts of the intermediate particle sizes.

15.3.2 Identify the soil as a *poorly graded gravel*, GP, or as a *poorly graded sand*, SP, if it consists predominantly of one size (uniformly graded), or it has a wide range of sizes with some intermediate sizes obviously missing (gap or skip graded).

15.4 The soil is either a *gravel with fines* or a *sand with fines* if the percentage of fines is estimated to be 15 % or more.

15.4.1 Identify the soil as a *clayey gravel*, GC, or a *clayey sand*, SC, if the fines are clayey as determined by the procedures in Section 14.

15.4.2 Identify the soil as a *silty gravel*, GM, or a *silty sand*, SM, if the fines are silty as determined by the procedures in Section 14.

15.5 If the soil is estimated to contain 10 % fines, give the soil a dual identification using two group symbols.

15.5.1 The first group symbol shall correspond to a clean gravel or sand (GW, GP, SW, SP) and the second symbol shall correspond to a gravel or sand with fines (GC, GM, SC, SM).

15.5.2 The group name shall correspond to the first group symbol plus the words "with clay" or "with silt" to indicate the plasticity characteristics of the fines. For example: "well-graded gravel with clay, GW-GC" or "poorly graded sand with silt, SP-SM" (see Fig. 2).

15.6 If the specimen is predominantly sand or gravel but contains an estimated 15 % or more of the other coarse-grained constituent, the words "with gravel" or "with sand" shall be added to the group name. For example: "poorly graded gravel with sand, GP" or "clayey sand with gravel, SC" (see Fig. 2).

15.7 If the field sample contains any cobbles or boulders, or both, the words "with cobbles" or "with cobbles and boulders" shall be added to the group name. For example: "silty gravel with cobbles, GM."

16. Report

16.1 The report shall include the information as to origin, and the items indicated in Table 13.

NOTE 14—*Example: Clayey Gravel with Sand and Cobbles, GC*—About 50 % fine to coarse, subrounded to subangular gravel; about 30 % fine to coarse, subrounded sand; about 20 % fines with medium plasticity, high dry strength, no dilatancy, medium toughness; weak reaction with HCl; original field sample had about 5 % (by volume) subrounded cobbles, maximum dimension, 150 mm.

In-Place Conditions—Firm, homogeneous, dry, brown

Geologic Interpretation—Alluvial fan

NOTE 15—Other examples of soil descriptions and identification are given in Appendix X1 and Appendix X2.

NOTE 16—If desired, the percentages of gravel, sand, and fines may be stated in terms indicating a range of percentages, as follows:

Trace—Particles are present but estimated to be less than 5 %

Few—5 to 10 %

Little—15 to 25 %

Some—30 to 45 %

Mostly—50 to 100 %

16.2 If, in the soil description, the soil is identified using a classification group symbol and name as described in Test Method D2487, it must be distinctly and clearly stated in log forms, summary tables, reports, and the like, that the symbol and name are based on visual-manual procedures.

TABLE 13 Checklist for Description of Soils

1. Group name
2. Group symbol
3. Percent of cobbles or boulders, or both (by volume)
4. Percent of gravel, sand, or fines, or all three (by dry weight)
5. Particle-size range:
   Gravel—fine, coarse
   Sand—fine, medium, coarse
6. Particle angularity: angular, subangular, subrounded, rounded
7. Particle shape: (if appropriate) flat, elongated, flat and elongated
8. Maximum particle size or dimension
9. Hardness of coarse sand and larger particles
10. Plasticity of fines: nonplastic, low, medium, high
11. Dry strength: none, low, medium, high, very high
12. Dilatancy: none, slow, rapid
13. Toughness: low, medium, high
14. Color (in moist condition)
15. Odor (mention only if organic or unusual)
16. Moisture: dry, moist, wet
17. Reaction with HCl: none, weak, strong

For intact samples:

18. Consistency (fine-grained soils only): very soft, soft, firm, hard, very hard
19. Structure: stratified, laminated, fissured, slickensided, lensed, homogeneous
20. Cementation: weak, moderate, strong
21. Local name
22. Geologic interpretation
23. Additional comments: presence of roots or root holes, presence of mica, gypsum, etc., surface coatings on coarse-grained particles, caving or sloughing of auger hole or trench sides, difficulty in augering or excavating, etc.

17. Precision and Bias

17.1 This practice provides qualitative information only, therefore, a precision and bias statement is not applicable.

18. Keywords

18.1 classification; clay; gravel; organic soils; sand; silt; soil classification; soil description; visual classification

APPENDIXES

(Nonmandatory Information)

X1. EXAMPLES OF VISUAL SOIL DESCRIPTIONS

X1.1 The following examples show how the information required in 16.1 can be reported. The information that is included in descriptions should be based on individual circumstances and need.

X1.1.1 *Well-Graded Gravel with Sand (GW)*—About 75 % fine to coarse, hard, subangular gravel; about 25 % fine to coarse, hard, subangular sand; trace of fines; maximum size, 75 mm, brown, dry; no reaction with HCl.

X1.1.2 *Silty Sand with Gravel (SM)*—About 60 % predominantly fine sand; about 25 % silty fines with low plasticity, low dry strength, rapid dilatancy, and low toughness; about 15 % fine, hard, subrounded gravel, a few gravel-size particles fractured with hammer blow; maximum size, 25 mm; no reaction with HCl (Note—Field sample size smaller than recommended).

In-Place Conditions—Firm, stratified and contains lenses of silt 1 to 2 in. (25 to 50 mm) thick, moist, brown to gray; in-place density 106 lb/ft^3; in-place moisture 9 %.

X1.1.3 *Organic Soil (OL/OH)*—About 100 % fines with low plasticity, slow dilatancy, low dry strength, and low toughness; wet, dark brown, organic odor; weak reaction with HCl.

X1.1.4 *Silty Sand with Organic Fines (SM)*—About 75 % fine to coarse, hard, subangular reddish sand; about 25 % organic and silty dark brown nonplastic fines with no dry strength and slow dilatancy; wet; maximum size, coarse sand; weak reaction with HCl.

X1.1.5 *Poorly Graded Gravel with Silt, Sand, Cobbles and Boulders (GP-GM)*—About 75 % fine to coarse, hard, subrounded to subangular gravel; about 15 % fine, hard, subrounded to subangular sand; about 10 % silty nonplastic fines; moist, brown; no reaction with HCl; original field sample had about 5 % (by volume) hard, subrounded cobbles and a trace of hard, subrounded boulders, with a maximum dimension of 18 in. (450 mm).

X2. USING THE IDENTIFICATION PROCEDURE AS A DESCRIPTIVE SYSTEM FOR SHALE, CLAYSTONE, SHELLS, SLAG, CRUSHED ROCK, AND THE LIKE

X2.1 The identification procedure may be used as a descriptive system applied to materials that exist in-situ as shale, claystone, sandstone, siltstone, mudstone, etc., but convert to soils after field or laboratory processing (crushing, slaking, and the like).

X2.2 Materials such as shells, crushed rock, slag, and the like, should be identified as such. However, the procedures used in this practice for describing the particle size and plasticity characteristics may be used in the description of the material. If desired, an identification using a group name and symbol according to this practice may be assigned to aid in describing the material.

X2.3 The group symbol(s) and group names should be placed in quotation marks or noted with some type of distinguishing symbol. See examples.

X2.4 Examples of how group names and symbols can be incororated into a descriptive system for materials that are not naturally occurring soils are as follows:

X2.4.1 *Shale Chunks*—Retrieved as 2 to 4-in. (50 to 100-mm) pieces of shale from power auger hole, dry, brown, no reaction with HCl. After slaking in water for 24 h, material identified as "Sandy Lean Clay (CL)"; about 60 % fines with medium plasticity, high dry strength, no dilatancy, and medium toughness; about 35 % fine to medium, hard sand; about 5 % gravel-size pieces of shale.

X2.4.2 *Crushed Sandstone*—Product of commercial crushing operation; "Poorly Graded Sand with Silt (SP-SM)"; about 90 % fine to medium sand; about 10 % nonplastic fines; dry, reddish-brown.

X2.4.3 *Broken Shells*—About 60 % uniformly graded gravel-size broken shells; about 30 % sand and sand-size shell pieces; about 10 % nonplastic fines; "Poorly Graded Gravel with Silt and Sand (GP-GM)."

X2.4.4 *Crushed Rock*—Processed from gravel and cobbles in Pit No. 7; "Poorly Graded Gravel (GP)"; about 90 % fine, hard, angular gravel-size particles; about 10 % coarse, hard, angular sand-size particles; dry, tan; no reaction with HCl.

X3. SUGGESTED PROCEDURE FOR USING A BORDERLINE SYMBOL FOR SOILS WITH TWO POSSIBLE IDENTIFICATIONS.

X3.1 Since this practice is based on estimates of particle size distribution and plasticity characteristics, it may be difficult to clearly identify the soil as belonging to one category. To indicate that the soil may fall into one of two possible basic groups, a borderline symbol may be used with the two symbols separated by a slash. For example: SC/CL or CL/CH.

X3.1.1 A borderline symbol may be used when the percentage of fines is estimated to be between 45 and 55 %. One symbol should be for a coarse-grained soil with fines and the other for a fine-grained soil. For example: GM/ML or CL/SC.

X3.1.2 A borderline symbol may be used when the percentage of sand and the percentage of gravel are estimated to be about the same. For example: GP/SP, SC/GC, GM/SM. It is practically impossible to have a soil that would have a borderline symbol of GW/SW.

X3.1.3 A borderline symbol may be used when the soil could be either well graded or poorly graded. For example: GW/GP, SW/SP.

X3.1.4 A borderline symbol may be used when the soil could either be a silt or a clay. For example: CL/ML, CH/MH, SC/SM.

X3.1.5 A borderline symbol may be used when a fine-grained soil has properties that indicate that it is at the boundary between a soil of low compressibility and a soil of high compressibility. For example: CL/CH, MH/ML.

X3.2 The order of the borderline symbols should reflect similarity to surrounding or adjacent soils. For example: soils in a borrow area have been identified as CH. One sample is considered to have a borderline symbol of CL and CH. To show similarity, the borderline symbol should be CH/CL.

X3.3 The group name for a soil with a borderline symbol should be the group name for the first symbol, except for:

CL/CH lean to fat clay
ML/CL clayey silt
CL/ML silty clay

X3.4 The use of a borderline symbol should not be used indiscriminately. Every effort shall be made to first place the soil into a single group.

X4. SUGGESTED PROCEDURES FOR ESTIMATING THE PERCENTAGES OF GRAVEL, SAND, AND FINES IN A SOIL SAMPLE

X4.1 *Jar Method*—The relative percentage of coarse- and fine-grained material may be estimated by thoroughly shaking a mixture of soil and water in a test tube or jar, and then allowing the mixture to settle. The coarse particles will fall to the bottom and successively finer particles will be deposited with increasing time; the sand sizes will fall out of suspension in 20 to 30 s. The relative proportions can be estimated from the relative volume of each size separate. This method should be correlated to particle-size laboratory determinations.

X4.2 *Visual Method*—Mentally visualize the gravel size particles placed in a sack (or other container) or sacks. Then, do the same with the sand size particles and the fines. Then, mentally compare the number of sacks to estimate the percentage of plus No. 4 sieve size and minus No. 4 sieve size present. The percentages of sand and fines in the minus sieve size No. 4 material can then be estimated from the wash test (X4.3).

X4.3 *Wash Test (for relative percentages of sand and fines)*—Select and moisten enough minus No. 4 sieve size material to form a 1-in (25-mm) cube of soil. Cut the cube in half, set one-half to the side, and place the other half in a small dish. Wash and decant the fines out of the material in the dish until the wash water is clear and then compare the two samples and estimate the percentage of sand and fines. Remember that the percentage is based on weight, not volume. However, the volume comparison will provide a reasonable indication of grain size percentages.

X4.3.1 While washing, it may be necessary to break down lumps of fines with the finger to get the correct percentages.

X5. ABBREVIATED SOIL CLASSIFICATION SYMBOLS

X5.1 In some cases, because of lack of space, an abbreviated system may be useful to indicate the soil classification symbol and name. Examples of such cases would be graphical logs, databases, tables, etc.

X5.2 This abbreviated system is not a substitute for the full name and descriptive information but can be used in supplementary presentations when the complete description is referenced.

X5.3 The abbreviated system should consist of the soil classification symbol based on this standard with appropriate lower case letter prefixes and suffixes as:

Prefix:	Suffix:
s = sandy	s = with sand
g = gravelly	g = with gravel
	c = with cobbles
	b = with boulders

X5.4 The soil classification symbol is to be enclosed in parenthesis. Some examples would be:

Group Symbol and Full Name	Abbreviated
CL, Sandy lean clay	s(CL)
SP-SM, Poorly graded sand with silt and gravel	(SP-SM)g
GP, poorly graded gravel with sand, cobbles, and boulders	(GP)scb
ML, gravelly silt with sand and cobbles	g(ML)sc

SUMMARY OF CHANGES

Committee D18 has identified the location of selected changes to this standard since the last issue (D2488 – 09) that may impact the use of this standard. (Approved June 15, 2009.)

(*1*) Revised Section 1.2.3.

Prepared By:	TBN	Date Prepared:	10/21/13
Corporate Officer:	BRH	Date Approved:	11/22/13

GROUNDWATER and NAPL ELEVATION MEASUREMENTS

1.1 Scope and Application

This standard is applicable to the collection of groundwater and non-aqueous phase liquid (NAPL) elevation measurements. Refer to project-specific documents (workplans) for variances to this SOP.

1.2 Health and Safety Warnings

Follow Natural Resource Technology, Inc. (NRT) Health and Safety standard operating procedures when working with potentially hazardous material or with material of unknown origin. Project Health and Safety Plans will contain additional practices, if necessary, to mitigate site-specific hazards.

1.3 Preliminary Procedures

Specific measurements during a sampling event, such as water level and depth of well, and observations of well condition should be documented in a field book or field form. The well shall be visually inspected and any damage that could permit surface water infiltration into the well must be noted and documented in accordance with Well Integrity Evaluation and Maintenance SOP 07-07-01.

1.4 Groundwater Level Measurements

Measurement of the static water level is taken prior to well purging and sample withdrawal. The elevation of the groundwater is determined by the following equation:

Groundwater Elevation = Top of Casing Elevation - Depth to Water

Measurements will be in units consistent with the units and datum used to survey the measurement point on the well.

All well measurements must be made from the point at which the elevation was measured (e.g., top of well casing). This point must be noted in the comments section of field notes or forms. Measurements shall not be made relative to protective casings, which are subject to frost heave.

1.4.1 Groundwater and NAPL Elevation Measurements

If wells have not been equipped with dedicated systems containing static head sensors (pressure transducers) or similar devices, then a water level indicator or oil/water interface probe shall be used to determine the static level of water in the well and to measure the total depth of the well. An oil/water interface probe should not be used to collect water level readings from wells that do not contain NAPL. Lead weight water level indicators should not be used.

When the indicator probe contacts the water, dependent upon the model, a series of beeps or a continuous beep will sound. If using an oil water interface probe a different sound will indicate the presence of NAPL. The following steps are for measuring groundwater and NAPL:

1. When groundwater elevation contour maps are to be prepared, collect synoptic depth to groundwater measurements (e.g. collect measurements consecutively at every site well in the shortest period of time possible and prior to any sampling activities).

2. Done PPE as required by the HASP.

3. Clean the water level indicator or oil/water interface probe and cable in accordance with SOP 07-04-09. As with other activities it is preferred to start collecting readings from the cleanest wells and end with the most contaminated wells to reduce the risk of cross-contamination. Decontaminate the water level indicator (probe) with laboratory-grade soap and potable or deionized water between each well location.

4. If NAPL is known to be present in the well, it is recommended to place a piece of plastic sheeting and absorbent pads adjacent to the well to use as a clean work area. Cut a hole in the center of sheeting and place the sheet around the well.

5. If light or dense non-aqueous phase liquid (LNAPL or DNAPL) and/or an absorbent sock is present in the well (based on a review historical data, if available), place enough absorbent pads on the plastic sheet beside the well to absorb oil that may be present when the absorbent sock and oil/water interface probe is removed from the well.

6. Unlock and open the well cover while standing upwind of the well. Remove well cap. If PID readings are required by the workplan, insert the PID probe approximately 4 to 6 inches into the casing of the well headspace and cover with gloved hand. Record the PID reading on the field log.

7. Locate the measuring reference point on the well casing. If one is not found, initiate a reference point by notching the inner and outer casings with a hacksaw or by using a waterproof marker. All down-hole measurements will be taken from the reference points.

8. Take time to monitor whether the measured depth to groundwater represents static groundwater elevation. If the well is not vented, then pressure caps may prevent some water columns from equilibrating with atmospheric pressure; be alert for this condition (sometimes indicated by an audible popping or hissing noise when the cap is removed) in non-vented wells. Record these observations in field notes and return to the well as needed to make additional measurements to determine whether or not the water level has equilibrated.

9. If an absorbent sock is already in the well, note the presence of the sock on the log, remove the absorbent sock, and make a qualitative estimate of the volume of LNAPL present in the absorbent sock. Proceed to Step 12 after the well has equilibrated (wait up to 1 hour before measuring LNAPL thickness and water level).

10. Record the inside diameter of the well casing on the field log.

11. For wells that do not contain NAPL, measure the depth to water to the nearest 0.01 foot using a water level indicator. Confirm the measurement by gently raising and lowering the water level indicator to collect several readings, record the confirmed depth to water in the field notes.

12. At all locations containing LNAPL, except those monitoring wells containing highly viscous LNAPL (see note below), lower the oil/water interface probe into the well to determine the existence of any light immiscible layer. Carefully record the depths of the air/light-phase and light-phase/water interfaces (to the nearest 0.01 foot) to determine the thickness of the light-phase immiscible layer (if present). If no light-phase immiscible layer is present, record the depth of the air/water interface and inspect the probe for NAPL residue and note the presence/absence of the residue on the probe in the field notes. In the absence of an oil/water interface probe, NAPL thickness can also be estimated using a bailer (glass or plastic). Slowly lower the bailer into the top of the water column. For LNAPL measurements, do not allow the bailer to fill completely. For dense non-aqueous phase liquid (DNAPL) measurements allow the bailer to drop to the bottom of the well. Retrieve the bailer, place on a bailer stand, and measure the thickness of product in the bailer. Record the measurement as an estimate.

    Note: Use extreme caution when gauging monitoring wells with highly viscous LNAPL. Highly viscous LNAPL is difficult to remove from sampling equipment. To gauge viscous LNAPL depths, mark a section of PVC pipe at 1-foot intervals to estimate location of the pipe within the well and slowly lower pipe into the well until reaching the fluid/air interface. Mark the PVC pipe at the top of casing (TOC) and slowly remove. Measure difference between the uppermost limit of

LNAPL on the pipe (if present) and the mark made at the TOC. The difference is the top of LNAPL. To get depth to water, use two sections of PVC pipe that when put one inside the other will also fit down the 2-inch diameter well (e.g., ¾" diameter pipe inside a 1½" diameter pipe). Make sure that the ¾" pipe is at least 6 inches longer than the 1½" pipe). Tape the bottom of the two pipes such that the tape can be easily removed–but not lost into the bottom of the well, and can be lowered through the LNAPL/water interface. Slowly lower the two pipes into the well until reaching the bottom of the well. Push the ¾" pipe through the 1½" pipe to remove the tape and allow groundwater to enter pipes. Remove the ¾" diameter pipe and allow the water level to equilibrate inside the 1½" pipe (wait up to 1 hour before measuring). After allowing the well to equilibrate, gauge the water level in the well as detailed above.

13. At locations known to contain DNAPL it may not be appropriate to use an oil/water interface probe because DNAPL tends to be difficult to remove from equipment. It is recommended to use dedicated or disposable equipment for recording DNAPL thickness to reduce decontamination time and reduce the risk of cross contamination. DNAPL measurements should be collected after a groundwater sample is collected, if any. It is recommended to collect DNAPL measurements using the following method:

    a. Purchase a stainless steel hex nut from the hardware store.

    b. Tie the nut to the end of some white nylon rope.

    c. Carefully lower the rope and nut into the well stop as soon as the nut reaches the bottom of the well. Mark the rope at the top of the casing and carefully remove the rope and nut.

    d. Record the thickness of DNAPL staining on the white rope (this is DNAPL thickness). The measurement from the mark at the top of the casing to the top of the DNAPL staining is the depth to DNAPL measurement. <u>Note that DNAPL may enter the well from any portion of the screened interval and accumulate in the bottom of the well, so this depth and thickness reading should not be used to make statements about the thickness and elevation of DNAPL in the formation around the well.</u>

    e. <u>The stainless steel nut and nylon rope should be disposed of as investigative derived waste along with gloves, paper towels, and oil absorbent materials in accordance with the HASP and/or workplan.</u>

1.4.2 Depth of Well Measurements

This measurement is required at well construction to determine purge volumes and at least annually to evaluate well integrity. If sampling is conducted less frequently than once a year, well depth will be measured during each sampling event. Wells with dedicated pumps are exempt from this measurement. The depth of well, when not field measured, should be obtained from the Well Construction Log and noted on the Well Purge form and also noted in the comments section, as being "from the Well Construction Log".

Measurement of depth to well bottom is made with a water level meter or with a measuring tape with a weighted bottom. Measure the depth to well bottom to nearest 0.01-ft relative to the reference point. Adjust measurements to account for the length of the water meter probe housing which extends below the water level sensor or for the length of weight below the bottom of the tape, if any. Depth to bottom measurements should be avoided in situations when performing the measurement stirs up sediment settled in the well sump. If possible, wait to take depth to well bottom measurement until after sampling is completed, and/or rely on past measurement of depth to well bottom to calculate well volumes.

1. After recording the static water level and collecting groundwater samples (if any), unroll the cable or tape until it hits the bottom of the well
2. Slowly pull up the slack until slight tension is felt on the cable
3. Slowly raise and lower until a feel for the bottom is obtained
4. Record the total well depth measurement in field notebook or forms
5. Decontaminate the indicator and length of measuring tape used to collect the reading in accordance with SOP 07-04-09

1.6 References

ASTM Standard D3415, 1998 (2011), “Standard Practice for Identification of Waterborne Oils,” ASTM International, West Conshohocken, PA, 2011, DOI: 10.1520/D3415-98R11, www.astm.org

USEPA, Field Branches Quality System and Technical Procedures, Region 4, Science and Ecosystem Support Division, Athens, Georgia, http://www.epa.gov/region4/sesd/fbqstp/

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GROUNDWATER SAMPLING

1.1 Scope and Application

This Standard Operating Procedure (SOP) describes commonly-used groundwater sampling methods and identifies routines to follow when collecting samples from monitoring wells. Guidance documents and SOPs published by the United States Environmental Protection Agency (USEPA) and ASTM International provide the foundation for this SOP. Procedures outlined below are intended to ensure that representative samples are collected in ways that are safe, technically defensible, easily replicated, appropriate for the selected analytical methods, and sensitive to site-specific conditions and hydrogeology. Refer to project-specific documents for variances from this SOP.

1.2 Summary of Methods

This SOP describes two methods that are most-commonly used to purge and sample groundwater from monitoring wells: 1) well volume method, and 2) low-flow (low-stress or micro-purge) method.

1.2.1 Well Volume Method

Using the well volume method, a pre-determined volume of groundwater is purged from the monitoring well to remove stagnant water from the well's casing (riser pipe). Typically a minimum of 3 well volumes of groundwater is removed; however, modification (reduction) of the minimum number of purge volumes is acceptable when water quality parameters (field parameters) are monitored at regular intervals during purging. Samples are collected when the minimum purge volume has been removed and/or when water quality parameters stabilize within acceptable limits.

1.2.2 Low-flow Method

Using the low-flow method, groundwater is purged (pumped) from a monitoring well at low flow rates that result in minimal drawdown. Depth to groundwater and groundwater quality parameters (field parameters) are monitored throughout the purging process. Pumping rates are adjusted to ensure groundwater entering the pump is from the screened formation and not from stagnant water in the well casing above the pump inlet. Samples are collected when drawdown and groundwater quality parameters stabilize within pre-determined criteria.

1.3 SOPs for Related Tasks

This SOP applies only to sampling groundwater from monitoring wells. Sampling methods for drinking water wells, surface water, pore water, leachate, and other liquid wastes are not described in this SOP.

However, this groundwater sampling SOP requires adherence to other SOPs for closely-related tasks, some of which are referenced herein:

- SOP 07-07-01 Well Integrity Evaluation
- SOP 07-07-05 Groundwater and Non-Aqueous Phase Liquid Elevation Measurement
- SOP 07-11-01 Equipment Calibration, Operation, and Maintenance
- SOP 07-04-09 Equipment Decontamination
- SOP 07-04-07 Quality Control Samples
- SOP 07-03-01 Sample Labeling and Storage
- SOP 07-03-03 Chain of Custody
- SOP 07-03-09 Shipping

2.1 Pre-mobilization Planning

Successful groundwater sampling requires planning for health and safety considerations, selecting and preparing sampling equipment, knowledge of laboratory analytical methods, field-sampling procedures, and attention to record-keeping requirements.

Planning for a groundwater sampling event includes the following basic components:

- Identify scope of work and project objectives
- Prepare a health and safety plan
- Coordinate laboratory analytical services
- Select purging and sampling methods and equipment
- Prepare field equipment
- Prepare necessary field documentation forms
- Coordinate disposal of investigative-derived waste (purge water)

2.1.1 Site-Specific Considerations

Knowledge of site conditions and previous sampling records/field notes is helpful. Select equipment and sampling methods to match the scope of work and site-specific data quality objectives.

When planning a sampling event, it is also important to understand the following site-specific information:

- Site access, security, and health and safety issues
- Known or unknown concentrations of compounds of concern
- Anticipated depth to water at individual wells
- Presence or absence of NAPLs and/or DNAPLs
- Purging methods (e.g. well volume, low flow, modified, other)
- Equipment selection (e.g. pumps, bailers, or a combination of both)
- Criteria for monitoring of field parameters
- Sampling order (typically from least to most contaminated wells)
- Requirements for field-filtering and field-preservation of samples

- Requirements for field and/or laboratory QA/QC samples
- Decontamination procedures
- Identification of short hold times or special sample handling requirements
- List of analytes and analytical methods
- Site-specific SOPs, methods, and/or record-keeping requirements

2.1.2 Health & Safety Plan, Personal Protective Equipment

Use of a site-specific Health and Safety Plan (HASP) and personal protection equipment (PPE) is mandatory for all sampling activities. NRT's Health & Safety Coordinator must approve the HASP and appropriate PPE prior to any on-site activities.

Level D protection, at minimum, is required for field activities involving groundwater sampling; however, PPE will vary according to possible levels of risk and exposure pathways. Additional protection, such as Tyvek® suits, splash guards, and/or respirators may be necessary. Use of field-screening devices, such as a photoionization detector (PID), for monitoring breathing zones and/or decontamination zones may also be appropriate.

Attention to proper use of PPE and thorough decontamination of equipment that comes in contact with groundwater and/or the ground surface is also essential to preventing personal exposures and sample cross-contamination. Site-specific requirements may also necessitate the use of plastic sheeting and/or other work-area precautions to prevent releases, exposures, and cross-contamination during sampling.

When working in roadways, parking lots, and other high-traffic areas, wear high visibility clothing and use safety cones, signage, flashing signals, flaggers, or other safety precautions. Properly establish traffic control according to detailed instructions contained in Department of Transportation (DOT) traffic control handbooks/manuals. Obtain permits for work in right-of-ways, including permission to dispose of investigation derived waste (purge water) to public sanitary sewer or wastewater treatment facilities if called for in the site-specific sampling plan.

2.1.3 Laboratory Coordination

Provide the analytical laboratory with enough lead time to manage the project. Order sample containers, communicate billing, reporting information (e.g., level IV QC reporting), and field sampling dates prior to field work. Requests for quick turnaround require advanced notice.

Be sure to complete the following checklist when ordering and receiving sample containers:

- Confirm list of analytes
- Confirm methods of analysis and minimum required sample volume
- Determine whether samples are to be field-filtered and/or field-preserved
- Order extra containers as a contingency
- Count the number and type of containers received
- Discuss hold times and shipping and receiving procedures
- Determine whether special instructions are needed in writing on the chain of custody (COC)

Once the groundwater samples have been collected and shipped, make practice of calling the laboratory as a courtesy to provide anticipated arrival dates and numbers of samples. Identify samples with short hold times or that may contain exceptionally high concentrations of compounds of concern. Keep a copy of the signed COC that was shipped with the samples, and also keep any documentation of the laboratory's receipt of COCs. Include a specific list of the analytes requested on the COC as this is used by the lab to confirm the appropriate analyses have been completed and/or reported.

2.1.4 Field Equipment

Select sampling equipment necessary to achieve the data quality objectives for the project. Inspect, calibrate, and decontaminate all equipment prior to use in the field according to SOP 07-11-01 (Equipment Calibration, Operation, and Maintenance), and SOP 07-04-09 (Equipment Decontamination).

The following list provides an overview of some of the items typically needed in the field:

- Health and Safety Plan (HASP)
- First Aid Kit
- PPE (minimum Level D)
- Scope of Work
- Site Maps
- Well Keys/Site Access Keys
- Mobile Phone
- Camera
- Calculator
- Field Log Book/Field Forms
- Tools
- Chain of Custody Forms
- Custody Seals
- Sample Containers
- Cooler and Ice
- Strapping Tape
- Permanent Markers/Pens
- Ziploc® Baggies
- Paper Towels
- Plastic Sheeting
- Garbage Bags
- Water Level Meter
- Weighted Steel Tape
- Oil-Water Meter
- Calibrated Buckets
- Alconox® Soap
- Brushes
- De-ionized (DI)/Potable Water
- Water Quality Meters
- Calibration Solutions
- Calibration Standards
- Meter Operation Manuals

- Flow-Through Cell
- Calibrated Beakers/Cups
- Tubing (HDPE, Tygon®, silicon)
- Disposable Filters (barrel filters)
- Bladder Pump
- Bladder Pump Control Box
- Safety Line for Bladder Pump
- Disposable Bladders
- Check Valves, Catch Plates
- Air Compressor
- Peristaltic Pump
- Submersible Pump (Whaler®, other)
- Extension Cords
- Hose Clamps
- Portable Battery (automotive/marine)
- Alligator Clips
- Electric Tape
- Generator and Gasoline

2.1.5 Field Forms

Field-records of all purging and sampling procedures are kept either in field notebooks or on site-specific field forms. Field notes for groundwater sampling may include observations and documentation of well inspection, water level, equipment calibration, purging and sampling information, sample control logs, and chain of custody. Record-keeping requirements are described Section 4.1.

2.1.6 Waste Disposal

Contaminated purge water will be discharged as directed in the site-specific sample plan. If disposal is required, it should be arranged prior to the sampling event. A waste profile and permission from regulatory authority and wastewater operator may be needed to dispose purge water to a sanitary sewer, wastewater treatment facility, landfill, or on-site disposal facility.

3.1 Groundwater Sampling Procedure

This SOP describes steps to follow when performing the well volume method using bailers or submersible pumps, and the low-flow method using bladder or peristaltic pumps.

Sampling generally proceeds in the following fashion:

- Establish a safe working zone
- Assess well condition
- Measure depth to groundwater
- Measure depth to well bottom (except in some cases)
- Measure thickness of any non-aqueous phase liquids (NAPLs or DNAPLs), if present
- Calculate well volumes
- Purge the well, using either the well volume or low flow (low-stress/ micro-purge) method
- Collect samples
- Label and pack samples on ice for shipping
- Decontaminate equipment
- Complete all record-keeping requirements, including COC
- Ship samples

3.1.1 Well Integrity

Assess the condition of monitoring wells and protective casings prior to sampling activities. Measure depth to well bottom and compare measurement to previous measurements. The presence of obstructions and bent or broken casing (risers) must be considered before lowering pumps or other equipment into the well. Make note of, photograph, and repair, if possible, any damage to the monitoring well. Replace any missing locks or pressure caps prior to leaving the site. Include a well condition report as a part of the groundwater sampling field notes. Refer to SOP 07-07-01 (Well Integrity) for additional instructions.

3.1.2 Depth to Groundwater

Record the depth to groundwater to the nearest 0.01 ft, relative to the reference point at the top of well casing. A notch or permanent marking at the top of well casings (typically PVC) commonly marks the reference point. Measure depth to groundwater beginning at the least contaminated well and proceed to the most contaminated well. Decontaminate the water level meter (probe) with laboratory-grade soap and potable or deionized water between each well location. Refer to SOP 07-07-05 (Groundwater and Non-Aqueous Phase Liquid Elevation Measurement) and SOP 07-04-09 (Equipment Decontamination) for additional instructions.

Take time to monitor whether the measured depth to groundwater represents static groundwater elevation. Pressure caps may prevent some water columns from equilibrating with atmospheric pressure; be alert for this condition when pressure caps are very tight or produce an audible popping or hissing noise when removed. Record these observations in field notes and return to the well several times to make additional measurements to determine whether the water level has equilibrated.

Groundwater with elevated specific conductance (conductivity) may also interfere with the accuracy of water level measurement due to meter sensitivity. Adjust the sensitivity of the water level meter to make an accurate measurement, however, try to use a consistent sensitivity setting from well to well.

When groundwater elevation contour maps are to be prepared, collect synoptic depth to groundwater measurements (e.g. collect measurements consecutively at every site well in the shortest period of time possible and prior to any sampling activities).

3.1.3 Depth to Bottom

Measurement of depth to well bottom is also made with a water level meter or with a measuring tape with a weighted bottom. Measure the depth to well bottom to nearest 0.01 ft relative to the reference point. Adjust measurements to account for the length of the water meter probe housing which extends below the water level sensor or for the length of weight below the bottom of the tape, if any. Decontaminate measuring tapes and water level probes and the full length of measuring tape that entered the well casing with laboratory grade soap and potable or de-ionized (DI) water according to SOP 07-04-09 (Equipment Decontamination), prior to use at other wells.

Depth to bottom measurements should be avoided in situations when performing the measurement stirs up sediment settled in the well sump. If possible, wait to take depth to well bottom measurement until after sampling is completed, and/or rely on past measurement of depth to well bottom to calculate well volumes. Note on field forms when historical depth to bottom measurements are used.

3.1.4 Thickness of NAPLs

Where immiscible liquids, such as petroleum non-aqueous phase liquid (NAPL), is present on the surface of the water column, an oil-interface probe (oil-water meter) is used to measure NAPL thickness. Differing patterns of audible alarms indicate “oil” as opposed to water. Record the depth to NAPL and depth to water relative to the reference point at the top of well casing. Decontaminate the probe and length of measuring tape that entered the well casing with laboratory grade soap and potable or DI water before use at another well. Refer to SOP 07-04-09 (Equipment Decontamination) for more instructions.

NAPL thickness can also be estimated using a bailer (glass or plastic). Slowly lower the bailer into the top of the water column. Do not allow the bailer to fill completely. Retrieve the bailer, place on a bailer stand, and measure the thickness of product in the bailer. Record the measurement as an estimate.

3.1.5 Purging and Pumping Equipment

Purging for the well volume method can be accomplished with bailers and a variety of submersible pumps (e.g., Grundfos®, Whaler®, Proactive®), inertia (e.g., WaTerra®). Bladder pumps (e.g., Well Wizard®), and suction (peristaltic) pumps are preferred when performing the low-flow method. In some cases, use of a combination of equipment is appropriate, because the type of bailer or pump selected for purging may not be appropriate for sampling.

The material construction of bailers and pumps should also be considered with respect to potential interferences. For example, the use of polyvinyl chloride (PVC) and polyethylene is discouraged when the detected concentrations of organic compounds is anticipated to be at or near laboratory detection limits, because organics may leach in and out of these materials. Teflon® and Teflon®-lined sampling devices are preferred in these cases.

3.2 Purging and Sampling Using the Well Volume Method

Using the well volume method, a pre-determined volume of water is evacuated from the well using a pump or bailer. Typically a minimum of 3 to 5 well volumes of water is removed to evacuate stagnant water from the monitoring well casing (riser pipe) and filter pack. Minimum purge volume requirements vary based on project-specific and regulatory requirements. Modification (reduction) of the minimum number of purge volumes is acceptable when groundwater quality parameters (field parameters) are monitored at regular intervals during purging. Samples can be collected when parameters stabilize within acceptable limits or when minimum purge volumes have been achieved.

3.2.1 Well Volume Estimation

Purge volumes are calculated in the field and depend on the measured depth to groundwater, measured or historical depth to well bottom, and well casing diameter.

The following calculation is used to estimate one well volume:

$$\text{Volume} = \pi(r^2)(h)$$

Where: r = inside radius of well casing (ft.)
h = height of standing water column in well casing (ft.)
$\pi \approx 3.14$; and 1 $ft^3 \approx 7.48$ gal)

Estimating Common Well Volumes

Groundwater monitoring wells are commonly constructed of 2-inch diameter, Schedule 40 or Schedule 80 polyvinyl chloride (PVC) risers and screens. The conversion chart below can be also be used to estimate well volumes for PVC monitoring wells. The volume of water (gallons) per foot of water column is shown in the far right column of the chart. Commonly used conversions for 2-inch diameter Schedule 40 and Schedule 80 PVC are highlighted.

Wells other than monitoring wells, such as injection and extraction wells, wells with multiple casings, production wells, and drinking water wells are constructed with larger diameter PVC, stainless steel, or iron casing. Measure and use the inside diameter of casing material to estimate the well volume according to the calculations above.

Conversion Table for Common PVC Well Diameters

Nominal Casing Diameter (inch)	Casing Inside Diameter (inches)	Casing Inside Radius (inches)	Casing Inside Radius (feet)	Volume per Foot of Water Column (gal)
Schedule 40				
1	1.05	0.53	0.04	0.04
1.25	1.38	0.69	0.06	0.08
1.5	1.61	0.81	0.07	0.11
2	**2.07**	1.04	0.09	**0.163**
3	3.07	1.54	0.13	0.38
4	4.03	2.02	0.17	0.66
6	6.065	3.03	0.25	1.50
8	7.981	3.99	0.33	2.60
12	11.938	5.97	0.50	5.81
Schedule 80				
1	0.96	0.48	0.04	0.04
1.25	1.28	0.64	0.05	0.07
1.5	1.5	0.75	0.06	0.09
2	**1.94**	0.97	0.08	**0.153**
3	2.9	1.45	0.12	0.34
4	3.83	1.92	0.16	0.60

Borehole Volume Calculations

Borehole volume accounts for the volume of standing water in the well casing and the volume of water contained in the well's filter pack material. Calculations of borehole volume require knowledge of well construction – borehole diameter, height of filter pack and filter pack seal, inside and outside diameter of well casing, and assumed effective porosity of the filter pack material. Borehole volumes are most often used when drilling and developing wells, but in some instances it is useful to compare the number of well volumes removed during purging to an equivalent number of borehole volumes.

Several methods are commonly used to estimate borehole volume. The following calculations are one example of estimation of one borehole volume:

Borehole volume = well volume + volume of water in filter pack

Well volume = $\pi(r^2)(h)$
where: r = inside radius of well casing (ft)
h = height of standing water column in well casing (ft)

Volume of water in filter pack = $n[\pi(r_1)^2 - \pi(r_2)^2]\, h_{fp}$
where: n = effective porosity of filter pack material
r_1 = radius of borehole (ft)
r_2 = outside radius of well casing (ft)
h_{fp} = height of standing water in filter pack (ft)

3.2.2 Groundwater Quality Parameters

Water quality parameters (field parameters) are monitored periodically when performing a modified well volume method. Stagnant water in the well casing is determined to be completely purged from the well when water quality parameters stabilize. Often, parameters stabilize before 3 well volumes have been removed. However, purging more than one well volume may be necessary for water quality parameters to stabilize. If parameters do not stabilize after 3 well volumes have been removed, additional well volumes should be removed. If water quality parameters do not stabilize within 5 volumes, it is at the discretion of the project leader whether to collect a sample or to continue purging.

Record all water quality parameter data, at a minimum, beginning with the first well volume, and every well volume after. In cases where a pump is used, water quality data are recorded at regular intervals along with the time, pumping rate, and total purge volume. When purging water with a pump, an in-line flow-through cell should be used to collect water quality parameter data. When using a bailer, parameters should be checked periodically by placing the water quality instruments (probes/meters) in a beaker or cup containing each sample of purged water. When measuring in a beaker, atmospheric exposure may affect readings for oxidation reduction potential [ORP] and dissolved oxygen.

Samples are collected after a minimum of one well volume of groundwater has been purged from the well and parameters have stabilized. Alternatively, samples are collected after 3 to 5 well volumes are purged.

Stability for water quality parameters is achieved when parameter readings fall within the following criteria for three consecutive time intervals.

Field-Measured Parameter Stabilization Criteria for Groundwater[1]

Parameter	Stabilization Criteria
Conductance, Specific Electrical	+/- 3% µS/cm @ 25°C
Dissolved Oxygen	+/- 10% of reading or +/- 0.2 mg/L, whichever is greater
Oxidation-Reduction Potential	+/- 20 mV
pH	+/- 0.2 standard units
Temperature	+/- 0.1°C
Turbidity*	<10 NTUs or ± 10% when turbidity is greater than 10 NTUs

Notes: µS/cm = micro Siemens per centimeter

°C = degrees Celsius
mg/L = milligrams per liter
mV = millivolts
NTUs = nephelometric turbidity units

* *Turbidity is an optional field parameter*

3.2.3 Purging Using a Bailer

Disposable or dedicated bailers are preferred when bailers are used for most purging and sampling scenarios, because they eliminate time needed to clean bailers and the possibility of cross contamination. However, if a non-dedicated, re-usable, bailer is used, the bailer must be washed with laboratory-grade soap and triple rinsed inside and out with DI water before purging or sampling according to SOP 07-04-09 (Equipment Decontamination).To minimize purge time, select the largest diameter bailer that will fit into the well and a length and weight of bailer that you can easily handle.

1 Stabilization criteria referenced here are consistent with ASTM D6771-02 *Practice for Low-Flow Purging and Sampling for Wells and Devices Used for Ground-Water Quality Investigations*

Prior to deploying the bailer in the well, fasten nylon rope, preferably braided to the top of the bailer, and fasten the other end of the rope to the protective casing or some other object at the ground surface to prevent the loss of the rope and bailer down the well. Check the rope knots periodically during the bailing process, and re-tighten or re-fasten as needed.

Disposable Nitrile®, PVC, or latex gloves must be worn during bailing. Change gloves frequently when gloves become dirty or torn. At a minimum, wear new gloves when sampling, after decontaminating equipment, and when beginning work at a new well location.

Use the following procedure to manually deploy and retrieve the bailer to and from the water column:

- Slowly lower the bailer into the well until it contacts the water column
- Allow the bailer to fill with water until it becomes submerged
- Pull the bailer out of the well and coil the rope into a clean bucket or onto clean plastic sheeting
- Do not allow the bailer to come into contact with any surface other than your gloves, the inside of the well, clean plastic sheeting, or a dedicated bucket
- Pour water from the bailer into a calibrated bucket to keep track of the volume purged, and periodically pour water into a cup or beaker to monitor water quality parameters
- Continue bailing until the required volume of water is purged from the well or until water quality parameters stabilize
- Contain purged water, as necessary, for proper disposal
- Collect samples (see Section 3.4)
- Decontaminate equipment

3.2.4 Purging Using Submersible Pumps

Non-dedicated pumps and any non-dedicated tubing must be decontaminated using laboratory-grade soap and water according to SOP 07-04-09 (Equipment Decontamination) prior to lowering the pump and tubing into a well. Place gasoline-powered electrical generating equipment downwind of the well location to minimize the possibility for cross contamination. Disposable Nitrile®, PVC, or powderless latex gloves must be worn when handling down-hole equipment. At a minimum, wear new gloves when sampling, after decontaminating equipment, and when beginning work at a new well location.

Purging of the well involves the correct placement of the pump and turning it on:

- Slowly lower the equipment (pump, electrical cords, discharge tubing, safety line) into the well; use zip ties to bundle tubing and cords together to prevent it from tangling in the well or becoming stuck in a well joint
- Lower the pump to the depth of the well screen, if possible; for deep wells, lower the pump as deep as practical, depending on pump capacity
- Do not place the pump on the well bottom, to avoid stirring up sediment settled at the well bottom, and to avoid clogging the well with sediment
- Turn on the pump and record the pumping rate using a calibrated bucket and stopwatch
- When monitoring water quality parameters, use a flow through cell and water quality probes (sensors) to periodically collect parameter data; if not using a flow-through cell, periodically collect samples of purge water in a cup or beaker; note when parameter data are collected for samples exposed to the atmosphere
- Continue pumping until the required volume of water has been purged or water quality parameters stabilize
- Contain purge water, as necessary, for proper disposal
- Collect samples (see Section 3.4)
- Decontaminate equipme

3.2.4 Sampling

When purging and sampling with bailers, fill laboratory containers directly from the bailer using a bailer stand and bottom dischargers. Samples collected for VOC analysis are collected via VOC dischargers, which restrict the flow rate to prevent aeration. Samples that require field-filtering are first contained in a disposable carboy and then pumped through a barrel filter using a peristaltic pump.

When using submersible pumps, collect samples directly from the discharge tubing using a pumping rate not greater than the purging rate. If using a flow-through cell, disconnect it prior to sampling. Samples that require field-filtering can be filtered in-line using a filter connected directly to discharge tubing, or a disposable carboy may be used, as described above.

Use tubing appropriate for the compounds of concern. Collect samples for analysis of the most sensitive parameters first, and collect samples requiring field filtration last. Sampling protocol is described in detail in Section 3.4.

3.3 Purging and Sampling Using the Low-flow Method

Using the low-flow (low-stress, micro-purge) method, groundwater is purged at rates affecting minimal to no drawdown which effectively isolates stagnant water in the well casing (riser) above the pump inlet. Depth to groundwater and water quality parameters (field parameters) should be monitored throughout the purging process. Pumping rates are adjusted to ensure that flow of groundwater to the pump is from the saturated formation and not from stagnant water in the well casing. Samples are collected once drawdown and water quality parameters stabilize.

Purging for the low-flow method is performed using either a peristaltic (suction) pump, or a bladder pump. Tubing and bladders should be Teflon® or Teflon®-lined, although non-lined high-density polyethylene (HDPE) tubing is appropriate for many compounds of concern. In some situations, low-flow methods may be performed using other submersible pumps (e.g. Grundfos®, Whaler®, Proactive®) and inertia pumps (e.g. WaTerra®); see Section 3.3.3 for potential data quality implications.

3.3.1 Using a Peristaltic Pump

A peristaltic pump is used at the ground surface to apply a suction force to lift water from the well through small diameter tubing. Maximum lift for peristaltic pumps is in the range of 15 to 29 feet; and, pumping rates range from less than 50 milliliters per minute (mL/min) to several gallons per minute (gal/min). Peristaltic pumps exert reduced pressure on the pumped water which can result in degassing and volatilization of the sample. Changes in pressure can affect pH, oxidation reduction potential (ORP), and other gas-sensitive parameters (ASTM D6634-01[2006]). As a result, <u>USEPA recommends that peristaltic pumps not be used for low-flow groundwater sampling when depth to water exceeds 15 feet</u>, especially when collecting samples for analysis of volatile organic compounds (VOCs).

3.3.2 Using a Bladder Pump

A bladder pump uses compressed air to squeeze a flexible membrane (bladder) that is contained in a rigid housing. Groundwater enters the bladder under hydrostatic pressure through a check valve, and compressed air supplied via small diameter airline compresses the bladder which forces water from the bladder to the surface through a small diameter water return line (the compressed air does not contact the water). Flow rate and airline pressure are regulated via an electronic control box. Pressure is applied in timed cycles, allowing the bladder to refill and compress at intervals appropriate for the depth, hydraulic conductivity of the saturated formation, and desired flow rate. Lift capacity of the pump is directly related to the pressure of the drive gas source.

<u>Representative groundwater samples can be obtained for all analytes in nearly all field conditions using a bladder pump</u>. Low-flow sampling with a bladder pump reduces the possibility for degassing, agitation, and volatilization of the sample, as compared to peristaltic or submersible pumps.

3.3.3 Using Other Pumps

Other submersible pumps (e.g. Grundfos®, Whaler®, ProActive®) are commonly used to purge groundwater from monitoring wells (i.e. for the well volume method) or to accomplish well development. However, they are not always appropriate for low-flow sampling. Some studies show that using submersible pumps to collect groundwater samples for analysis of VOCs generates analytical data similar to that for bladder pumps; however, the valves used to restrict the flow of submersible pumps reduce pressure potentially resulting in degassing of the sample. Submersible pump impellers also cause heat and turbulent flow which can also result in changes in water chemistry. Pump failures may also release contaminants (oiled parts, plastics, etc) into a monitoring well. Due to these limitations, bladder pumps are recommended over submersible pumps for low flow sampling, particularly for VOCs.

3.3.4 Field Procedure

The objective of the low-flow method is to perform low-stress pumping of a monitoring well to clearly document that samples represent groundwater entering the well from the screened formation at the depth of the pump inlet. To do so, the sampler must place the pump inlet at the appropriate depth, pump in a manner that minimizes stress to the formation, and monitor drawdown and groundwater quality parameters at regular intervals.

The low-flow field method is performed according to the following steps:

- Assemble equipment, (e.g. pumps, tubing, flow through cell, water quality instruments)
- Clean (decontaminate) all down-hole equipment
- Calibrate water quality instruments
- Measure initial depth to groundwater
- Place pump/pump inlet tubing at appropriate depth in the screened interval
- Begin pumping at an initial rate (typically 100 mL/min or less)
- Calculate minimum purge volume (time intervals) for parameter readings
- Monitor water level drawdown and water quality parameters
- Adjust pumping rate to minimize/stabilize drawdown
- Continue pumping until drawdown and water quality parameters stabilize
- Collect samples

Preparation

Clean all non-dedicated down-hole equipment according to SOP 07-04-09 (Equipment Decontamination) prior to measuring initial depth to water or lowering a pump or inlet tubing into the well. Non-dedicated bladder pumps should be disassembled, cleaned, and re-assembled; also remove and clean pump gaskets, check valves, and inlet screens. Clean, calibrate, and test water quality instruments (probes) according to the manufacturer's instruction manuals. Document calibration results at the beginning of the day and periodically throughout the day, according to the site-specific work plan. Flow through cells and containers for purge water should be assembled prior to the start of pumping. Lengths of tubing should be measured to match the depth at which the pump or pump inlet will be deployed in the well. If dedicated tubing is used (i.e. tubing that is left hanging inside a well casing), inspect and replace tubing, if compromised.

Depth of Pump Inlet

The appropriate depth of pump or pump inlet tubing depends on the hydrogeology of the screened formation and well construction details:

- In cases where the screen intersects a single soil/rock material, the pump inlet should be placed at the midpoint of the well screen.
- In cases where the screen intersects multiple layers of soil/rock material or fractured rock, the pump inlet should be placed at a depth intersecting the layer expected to have the highest hydraulic conductivity.
- Where zones of contamination are known or assumed to occur at specific depths, the depth of pump inlet should match the depth of contamination. For example, petroleum compounds often accumulate in smear zones near the water table interface – pump inlets placed at the midpoint or near the bottom of well screen may not provide a representative sample in this instance.
- Do not place the pump inlet at or near the well bottom, because pumping near the well bottom can mobilize solids settled in the well sump.
- Do not place the pump inlet at or above the top of the well screen, because low-stress pumping would capture stagnant water in the well casing rather than formation water.

Pumping Rate

The initial pumping rate should be 100 mL/min or less. Lower hydraulic conductivity units (i.e. clay) should be pumped at lower initial flow rates; higher hydraulic conductivity units (i.e. sand) can be pumped at higher initial flow rates. Adjust the pumping rate to be as low as practicable, to achieve stabilization of water quality parameters without inducing significant drawdown (e.g. without pumping stagnant water from the well casing). Do not induce continuous drawdown. Pumping rates at which water level stabilization can be achieved range generally from 100 to 500 mL/min. <u>Samples must not be collected using a pumping rate that exceeds the pumping rate at which stabilization was achieved.</u> Conceptually, once flow rate and water quality parameters have stabilized, a direct connection to the aquifer has been established, and any changes or disruptions to flow rate could break that connection and result in stagnant water being included in the samples.

The optimal pumping rate that will achieve stabilization for drawdown and water quality parameters will be specific to each well. Do not attempt to pump every well at a site at the same pumping rate. Use historical sampling information to replicate pumping rates for specific wells, as appropriate.

Monitoring Drawdown

Depth to water in the monitoring well should be monitored at 1 to 2 minute intervals until water level stabilization occurs and periodically afterwards. Drawdown during the course of pumping and sampling should not exceed 25% of the distance between the top of screen and pump inlet. Also, the volume of water pumped that is attributable to drawdown (stagnant water pumped from the well casing) should not exceed 10% of the total volume of water pumped. Some wells, especially those screened in clay, may not achieve water level stabilization (i.e., the water level continues to drop even at flow rates less than 50 ml/min). If this occurs, contact the field leader and Project Manager to discuss alternative methods for sample collection such as completely purging the well and returning to collect the sample once the well has recovered, or using a passive sampling method.

Monitoring Water Quality Parameters

Water quality parameters that provide evidence that formation-quality water is being pumped include pH, temperature, conductivity (specific conductance), dissolved oxygen, and oxidation-reduction potential (redox, or ORP, also measured as Eh). Turbidity, discussed below, may also be a useful field parameter. Record these parameters continuously (if possible) or at regular time intervals using a closed flow through cell or similar instrumentation. Use a small volume flow through cell and monitor the cell for air bubbles (leakage).

The frequency of water quality parameter measurements should be not less than the time needed to evacuate the volume of the in-line flow through cell. Also determine the volume of water contained in the pump (i.e. bladder volume) and discharge tubing. Consider increasing time intervals to account for these volumes, especially when pumping rates are slow and/or the depth to pump inlet is significant. In instances where water quality parameter stabilization occurs quickly, be sure to also allow enough time for individual water quality instruments to stabilize (check manufacturer’s recommendations). Dissolved oxygen sensors, for example, typically take longer to stabilize than pH, temperature, conductivity, and ORP sensors.

Stabilization of water quality parameters is achieved when three consecutive readings, several minutes apart, fall within the criteria listed below. These criteria are consistent with ASTM D6771-02: however, they may not apply to all sites. Site-specific parameters and criteria may be established to account for variations in aquifer properties, groundwater chemistry, well hydraulics, and contaminant distribution.

Field-Measured Parameter Stabilization Criteria for Groundwater

Parameter	Stabilization Criteria
Conductance, Specific Electrical	+/- 3% µS/cm @ 25°C
Dissolved Oxygen	+/- 10% of reading or +/- 0.2 mg/L, whichever is greater
Oxidation-Reduction Potential	+/- 20 mV
pH	+/- 0.2 standard units
Temperature	+/- 0.1°C
Turbidity	<10 NTUs or ± 10% when turbidity is greater than 10 NTUs

Notes: µS/cm = micro Siemens per centimeter
°C = degrees Celsius
mg/L = milligrams per liter
mV = millivolts
NTUs = nephelometric turbidity units

Turbidity

Turbidity is indicative of the stress pumping places on the screened formation. Measure turbidity with the same frequency (time intervals) as other water quality parameters or, at a minimum, at the beginning of pumping and again prior to collecting a sample. Ideally, low-flow purging should proceed until turbidity is less than 10 NTU, however, turbidity greater than 10 NTU can be natural and unavoidable. Analytical bias can occur for samples collected with turbidity greater than natural conditions.

When turbidity increases during pumping, too much stress is being placed on the well – lower the pumping rate. If the turbidity remains high, stop pumping and allow the well to rest without removing the pump. Resume pumping at a low rate and monitor turbidity for stabilization. As noted above, natural turbidity may remain higher than targeted stabilization criteria.

To minimize initial turbidity, carefully lower pumps and tubing into the monitoring well to avoid stirring sediment that has settled at the well bottom. Turbidity and other water quality parameters will typically stabilize more quickly when using dedicated pumps.

3.3.5 Sampling

When using the low-flow method, disconnect the flow cell without shutting off the pump and collect samples directly from the discharge tubing using the same pumping rate as was used to achieve stabilization. Use tubing appropriate for the compounds of concern. Collect samples for analysis of the most sensitive parameters first, and collect samples requiring field filtration last. Sampling protocol is described in detail in Section 3.4.

Be aware of potential quality control issues when collecting samples using the low-flow method:

- Samples should not be collected using a pumping rate greater than the purging/stabilization rate
- Once stabilization has been achieved do not disrupt the connection to the groundwater in the formation by shutting off the pump or changing the flow rate
- When collecting samples for analysis of VOCs, pump at a rate less than 250 mL/min, and avoid aerating groundwater in pump tubing or flow through cell
- Some chemical constituents may leach to tubing
    - Teflon® or Teflon®-lined tubing is preferred for samples that will be analyzed for VOCs, SVOCs, pesticides, and PCBs
    - HDPE or polypropylene tubing may be used for metals and other organics
    - Siliclastic (silicon) tubing should be less than 1 foot in length (when used with peristaltic pumps and when used with barrel filters)
- Shade equipment and tubing to avoid direct sunlight and warm ambient air temperatures

Field Forms

Field forms or field notes should record the following information, in addition to site and well information, to document water level and water quality parameter stabilization during low-flow pumping and sampling:

- Type, make, and model of pumping and water quality instruments
- Equipment calibration (include copies of calibration certificates as appropriate)
- Decontamination procedures
- Depth of pump or pump inlet
- Volumes of flow through cell, discharge tubing, and pump (bladder)
- Initial pumping rate and time intervals
- Drawdown, stabilized water level, and pumping rate at stabilization
- Field-measured water quality data at regular time intervals during purging
- Time and pumping rates for all measurements
- Rate of pumping at time of sample collection

Section 4.1 describes in detail the record keeping requirements to follow when groundwater sampling.

Instrument Error

Instruments suspected of producing erroneous readings should be recalibrated. If the values obtained continue to be outside normal ranges, troubleshoot or replace the instrument. If the instrument cannot be replaced and provides data critical to performing and documenting the purging procedure, notify the Project Manager. Do not discard the samples, if collected. Flag any out of range data recorded in field notes using an asterisk and a written description of the occurrence. Deviation from standard field procedure, use of alternate equipment, or re-sampling may be required to determine whether anomalous readings were the result of mechanical or human error and to ensure documentation of the collection of a representative sample.

3.4 Collecting Samples

This section describes sampling protocol to follow when using either the well volume method or low-flow method. Representative samples are collected when the monitoring well is purged according to the requirements of the standard procedure and when the sample is appropriately collected, preserved, handled, shipped, and analyzed. Groundwater samples must be collected in the appropriate order, field-filtered and field-preserved according to analytical methods, accompanied with quality assurance/quality control (QA/QC) samples, immediately preserved on ice, and shipped with the appropriate chain-of-custody documentation.

3.4.1 Sampling Order

Collect samples according to analyte stability, as summarized below, unless otherwise specified in a site-specific work plan or field sampling plan:

- Volatile organic compounds (VOCs)
- Semi-volatile organic compounds (SVOCs)
- Non-filtered, non-preserved samples (e.g. PCBs, pesticides, sulfate)
- Non-filtered, preserved samples (e.g. phenols, nitrogen, total metals, organic carbon)
- Available cyanide (follow lab provide cyanide kit direction for collection of sample)
- Filtered, non-preserved samples (e.g. chromium IV)
- Filtered, preserved samples (e.g. dissolved metals)
- Miscellaneous parameters

In addition, collect samples for sulfate analysis before collecting sulfuric-acid preserved samples (e.g. nitrogen), and collect samples for nitrogen compound analysis before nitric-preserve samples (e.g. dissolved metals).

3.4.2 Filling Sample Containers

Observe the procedures and cautions below when filling sample containers:

- Take precautions when handling acid preservatives or opening containers pre-filled with acid preservatives, according to the site-specific Health & Safety Plan (HASP).
- Remove sample container lids carefully. Do not touch the inside of the lid or the Teflon® lid septum, and do not place the lid on the ground.
- If containers, lids, or Teflon® septum come in contact with the ground or any other contaminated surface, carefully rinse the object with sample water; replace septum facing the sample.
- Fill sample containers with the appropriate preservative, volume, and headspace.
- Do not allow discharge tubing to come in contact with the inside of the sample container.
- Minimize sample contact with the atmosphere and collect samples away from possible sources of cross-contamination such as vehicle or equipment exhaust.
- Overfill containers used for VOC analysis (40 ml HCL-preserved glass vials) to eliminate air bubbles. Slowly fill the vial until surface tension (convex water surface) is maintained at the top of the vial. Replace the cap gently and invert the vial to check for air bubbles. Open the vial and add more water to the existing sample, if necessary, to eliminate air bubbles. Do not empty the bottle and refill.

3.4.3 Field Filtering

Use an in-line disposable 0.45 micron (µm) filter, or equivalent, to filter groundwater samples for which the analytical method requires field-filtering. When using a pump, connect the filter directly to the pump discharge tubing, and pump a small volume of sample volume through the filter before beginning to fill the sample container. When using a bailer, water is often transferred from the bailer to a disposable carboy, and then pumped through a barrel filter using a pump, as described above. Collect a field/equipment blank whenever collecting field-filtered samples.

Follow these procedures when field-filtering groundwater samples:

- Filter samples immediately in the field; if field conditions prevent field-filtering, filter samples as soon as possible or instruct the analytical laboratory to filter samples upon receipt
- Use disposable filters (i.e. Geotech® barrel filters) to eliminate cross-contamination
- Do not re-use disposable filters
- Do not re-use temporary containers/pre-filtration containers
- Note the size and material (i.e. 500 mL polyethylene carboy) of pre-filtration containers

3.4.4 Sample Preservatives and Hold Times

Samples are to be field-preserved, if necessary, immediately after filtering or immediately after sample collection if not filtered. Pre-measured volumes of preservatives should be added to the sample bottle prior to sampling. In most cases, laboratory-supplied containers are provided with pre-measured preservatives already placed in the containers. Arrange for timely shipment of samples with short hold times.

3.4.5 QA/QC Samples

SOP 07-04-07 (Quality Control Samples) describes the intended use and collection methods for quality control samples that should be used to evaluate field and laboratory quality control procedures and the precision, accuracy, representativeness, and comparability of data obtained from groundwater samples. Deviation from the Quality Control SOP should be clearly identified in site-specific Workplan, Field Sampling Plan (FSP), or Quality Assurance Project Plan (QAPP).

The following QA/QC samples should be considered and collected, as necessary:

QA/QC Sample Type	Application
Field Duplicate	Compares differences in analytical results for identical (duplicate) samples
Matrix Spike/Matrix Spike Duplicate (MS/MSD)	Evaluates effect of sample matrix on analytical results
Trip Blank	Identifies contribution/introduction of contaminants

	during shipment/transport
Temperature Blank	Verifies proper sample transport temperature
Equipment Blank	Determines effectiveness of in-field decontamination procedures (also known as Rinseate Blank)
Field Blank	Identifies possible environmental cross-contamination

4.1 Record Keeping/Field Forms

Field-records of all purging and sampling procedures are kept either in NRT notebooks or on site-specific field forms. Electronic copies of field notes and should be made and saved to the project directory on NRT's electronic server (typically these notes are stored in the same folder as the laboratory analytical results). Sample control logs and sample identification numbers are to be completed and assigned according to SOP 07-03-01 (Sample Labeling and Storage) and SOP 07-03-05 (Sample Location, Identification, and Control).

4.1.1 Field Notebook

At a minimum, the following information should be recorded in a field notebook, on groundwater sampling forms, or on a site/project-specific groundwater sampling forms:

- Weather conditions
- Well condition
- Size, diameter, and well casing material
- Water level, relative to top of well casing
- Depth to bottom, or historical depth to bottom, relative to top of well casing
- Thickness and/or presence of any NAPLs
- Calculation of well volumes
- Time when purging begins
- Purge method (e.g. bailed, pumped)
- Initial color, odor, and clarity of purge water
- Initial water quality parameter data (e.g. pH, temperature, conductivity, ORP, turbidity)
- Time intervals, water levels, water quality parameters, pumping rate, and cumulative purge volumes (if low-flow sampling)

- Sample collection time
- Water quality parameters at the time of sample collection
- Number and type of sample containers
- Method and type of field-filtration and/or field-preservation
- Sample identification number and lab identification/chain of custody number
- Name and manufacturer of any equipment used
- Calibration results
- Description of decontamination procedures
- Total purge volume
- Location where purge water is disposed (e.g. discharge to ground or contained in drum)
- If drums are used, note the location and number of drums stored on site

4.1.2 Chain of Custody

The parameters to be analyzed are to be listed for each sample on the Chain-of-Custody (COC) as is described in SOP 07-03-03 (Chain of Custody). The COC should also clearly identify the specific USEPA-approved method of analysis to be performed on each sample, provide the specific list of analytes to be reported (e.g., list specific metals or aroclors to be reported), and provide any special instructions. For example, samples that require laboratory filtering, samples that contain known interferences with the analytical method, samples expected to contain unusually elevated concentrations of compounds, and samples with short hold times, should be clearly identified.

4.1.3 Packing and Shipping

Samples are to be placed on ice immediately after sample collection, and packed and shipped according to SOP 07-03-09 (Shipping). Samples are always shipped to the laboratory or any other facility under COC-procedure and using custody seals. When using a courier, obtain driver signatures on the COC. Ship groundwater samples in compliance with all applicable requirements for shipping hazardous and/or dangerous materials.

References

ASTM International, D4448-01 Standard Guide for Sampling Groundwater Monitoring Wells

ASTM International, D5903-96(2001) Standard Guide for Planning and Preparing for a Groundwater Sampling Event

ASTM International, D6089-97(2003)e1 Standard Guide for Documenting a Ground-Water Sampling Event

ASTM International, D6301-03 Practice for the Collection of Samples of Filterable and Nonfilterable Matter in Water

ASTM International, D6452-99(2005) Standard Guide for Purging Methods for Wells Used for Ground-Water Quality Investigations

ASTM International, D6564-00(2005) Standard Guide for Field Filtration of Ground-Water Samples

ASTM International, D6634-01 Guide for the Selection of Purging and Sampling Devices for Ground-Water Monitoring Wells

ASTM International, D6771-02 Practice for Low-Flow Purging and Sampling for Wells and Devices Used for Ground-Water Quality Investigations

USEPA, 2001, Environmental Investigations Standard Operating Procedures and Quality Assurance Manual (EISOPQAM), Region 4, Enforcement and Investigations Branch, SESD, Athens, Georgia, www.epa.gov/region4/sesd/eisopqam/eisopqam.html.

USEPA, 2002, Ground-Water Sampling Guidelines for Superfund and RCRA Project Manager, Region 5 and Region 10, EPA 542-S-02-001.

USEPA, April 2007, Guidance for Preparing Standard Operating Procedures (SOPs), EPA/60/B-07/001.

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FIELD INSTRUMENT CALIBRATION, OPERATION, AND MAINTENANCE

1.1 Scope and Application

This procedure describes guidelines for the calibration, operation, and maintenance of field instruments.

1.2 Health and Safety Warnings

Follow Natural Resource Technology, Inc. (NRT) Health and Safety standard operating procedures when working with potentially hazardous material or with material of unknown origin. Project Health and Safety Plans will contain additional practices, if necessary, to mitigate site-specific hazards.

1.3 Equipment

- Measurement and testing equipment
- Instrument operation manual
- Instrument case and necessary appurtenances (e.g., battery charger and attachments)
- Calibration standards (e.g., standard gases and pH fluids)

1.4. Background

Instrument operators must be familiar with the operation of the field instrument being used. Operators will obtain appropriate training before using the instrument in the field. If user certification is required for an instrument, it must be obtained prior to using the instrument in the field.

Instruments must be uniquely identified, such as with a serial number, and that identifier will be recorded in the field notes. Manufacturer's guides and/or operation manuals will be kept with the instruments for reference at all times.

1.5. Calibration

Field instruments must be calibrated according to the manufacturer's specifications prior to initial use. The instrument shall be recalibrated according to the following:

- The manufacturer's recommended calibration frequency
- After long periods of inactivity between uses
- When readings are observed above/below the instrument range
- If signs or evidence of equipment malfunction are observed

Daily calibration and recalibration activities will be recorded in the field logbook or on appropriate field forms. At a minimum, the following information will be recorded:

- Date and time of calibration
- Instrument make, model, and manufacturer
- Instrument identifier (e.g., serial number or unique inventory number)
- Calibration method
- Calibration standards used
- Any deviation from the manufacturer's recommended procedures or calibration frequency

1.6. Operation

Instruments will be operated in accordance with the manufacturer's instructions. Readings, malfunctions, and deviations from standard operating methods will be documented in the field logbook or on appropriate field forms.

1.7. Maintenance

Instruments will be maintained in accordance with the manufacturer's recommendations. Malfunctioning instruments, or those scheduled for routine maintenance, will be clearly labeled to prevent further use until maintenance is completed. Rentals instruments are not to be maintained by NRT and it will be returned to the supplier if repair or maintenance is required. A replacement instrument will be requested if needed. Supporting calibration and maintenance documentation from the supplier will be scanned and saved in the project folder with associated field notes from the sampling event.

Maintenance for instruments owned by NRT will be tracked and recorded on a dedicated log that will contain the following information:

- Instrument make, model, and manufacturer
- Instrument identification (e.g., serial number or unique inventory number)
- Recommended maintenance and frequency
- Status (e.g., operational, out of service for repair/maintenance, not operational)
- Dates of status change
- Dates of inspection, maintenance, or repairs

Documentation of maintenance for NRT-owned equipment will be stored in a file in the warehouse which is maintained by the warehouse manager.