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**Halliburton NUS**
**CORPORATION**

**Gannett Fleming, Inc.**
ENGINEERS AND PLANNERS

# FINAL

# PROJECT OPERATIONS PLAN

## VOLUME 3
## STANDARD OPERATING PROCEDURES

## AVTEX FIBERS SITE
## WARREN COUNTY, VIRGINIA

**REMEDIAL INVESTIGATION/FEASIBILITY STUDY**

**EPA WORK ASSIGNMENT NUMBER 37-19-3LD1**
**CONTRACT NUMBER 68-W8-0037**

**HALLIBURTON NUS PROJECT NUMBER 2766**

**JUNE 1993**

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Appendix

Note: SOPS and forms contained in the Draft POP are not repeated here. However, an update to Appendix A SF-1.2 is attached to the Appendix A Table of Contents.

# APPENDIX A

# STANDARD OPERATING PROCEDURES FOR RI ACTIVITIES

# AVTEX FIBERS SITE

# APPENDIX A

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## APPENDIX A (cont'd.)

## TABLE OF CONTENTS

Note: (1) SF-1.2 field filtration procedures (page 5 of 10) are replaced by EPA Region III Quality Assurance Directive No. 009 which is attached to this Final POP, Volume 3. Sample holding times are superseded for those shown in Volume 2.

| NUS CORPORATION<br>ENVIRONMENTAL MANAGEMENT GROUP | STANDARD OPERATING PROCEDURES | Number<br>GH-1.3 | Page<br>1 of 13 |
|---|---|---|---|
| | | Effective Date<br>05/04/90 | Revision<br>2 |
| | | Applicability<br>EMG | |
| | | Prepared<br>Earth Sciences | |
| Subject<br>SOIL AND ROCK SAMPLING | | Approved<br>D. Senovich | |

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SECTION

## 1.0 PURPOSE

The purpose of this procedure is to identify the equipment, sequence of events, and appropriate methods necessary to obtain soil, both surface and subsurface, and rock samples during field sampling activities.

## 2.0 SCOPE

The methods described within this procedure are applicable while collecting surface and subsurface soil samples; obtaining rock core samples for lithologic and hydrogeologic evaluation; excavation/foundation design and related civil engineering purposes.

## 3.0 GLOSSARY

Hand Auger- A sampling device used to extract soil from the ground in a relatively undisturbed form.

Thin-Walled Tube Sampler - A thin-walled metal tube (also called Shelby tube) used to recover relatively undisturbed soil samples. These tubes are available in various sizes, ranging from 2 to 5 inches O.D. and 18 to 54 inches long. A stationary piston device may be included in the sampler to reduce sampling disturbance and increase sample recovery.

Split-Barrel Sampler - A steel tube, split in half lengthwise, with the halves held together by threaded collars at either end of the tube. Also called a split-spoon sampler, this device can be driven into resistant materials using a drive weight mounted in the drilling string. A standard split spoon sampler (used for performing Standard Penetration Tests) is 2 inches outside diameter (OD) and 1-3/8 inches inside diameter (ID). This standard spoon typically is available in two common lengths, providing either 20-inch or 26-inch longitudinal clearance for obtaining 18-inch or 24-inch long samples, respectively. These split-spoon samplers range in size from 2-inch O.D. to 3-1/2-inch O.D., depending upon manufacturer. The larger sizes are commonly used when a larger volume of material is required.

Rock Coring - A method in which a continuous solid cylindrical sample of rock or compact rock-like soil is obtained by the use of a double tube core barrel that is equipped with an appropriate diamond-studded drill bit which is advanced with a hydraulic rotary drilling machine.

Wire-Line Coring - As an alternate for conventional coring, this is valuable in deep hole drilling, since this method eliminates trips in and out of the hole with the coring equipment. With this technique the core barrel becomes an integral part of the drill rod string. The drill rod serves as both a coring device and casing.

## 4.0 RESPONSIBILITIES

Field Operations Leader - Responsible for overall management of field activities and ensuring that the appropriate sampling procedures are being implemented.

Site Geologist - The site geologist directly oversees the sampling procedures, classifies soil and rock samples, and directs the packaging and shipping of soil samples. Such duties may also be performed by geotechnical engineers, field technicians, or other qualified field personnel.

## 5.0 PROCEDURES

### 5.1 SUBSURFACE SOIL SAMPLES

Subsurface soil samples are used to characterize subsurface stratigraphy. This characterization can indicate the potential for migration of chemical contaminants in the subsurface. In addition, definition of the actual migration of contaminants can be obtained through chemical analysis of the soil samples. Where the remedial activities may include in-situ treatment or the excavation and removal of the contaminated soil, the depth and areal extent of contamination must be known as accurately as possible.

Engineering and physical properties of soil may also be of interest should site construction activities be planned. Soil types, grain size distribution, shear strength, compressibility, permeability, plasticity, unit weight, and moisture content are some of the physical characteristics that may be determined for soil samples.

Penetration tests are also described in this procedure. The tests can be used to estimate various physical and engineering parameters such as relative density, unconfined compressive strength, and consolidation characteristics of soils.

The procedures described here are representative of a larger number of possible drilling and sampling techniques. The choice of techniques is based on a large number of variables such as cost, DQOs, local geology, etc. The final choice of methods must be made with the assistance of drilling subcontractors familiar with the local geologic conditions. Alternative techniques must be based upon the underlying principles of quality assurance implicit in the following procedures.

#### 5.1.1 Equipment

The following equipment is used for subsurface soil sampling and test boring:

- Drilling equipment, provided by subcontractor.
- Split barrel (split spoon) samplers, OD 2 inches, ID 1-3/8 inches, either 20-inch or 26 inches long. Larger O.D. samplers are available if a larger volume of sample is needed. A common size is 3-inch O.D. (2-1/2-inch I.D.).
- Thin walled tubes (Shelby), O.D. 2 to 5 inches, 18 to 54 inches long.
- Drive weight assembly, 140-lb. (± 2 lb.) weight, driving head and guide permitting free fall of 30 inches (± 1 inch).
- Drive weight assembly, 300-lb. (± 2 lb.) weight, driving head and guide permitting free fall of 18 inches (± 1 inch).
- Accessory equipment, including labels, logbook, paraffin, and sample jars.

### 5.1.2 Split Barrel (Split Spoon) Sampling (ASTM D1586-84)

The following method will be used for split barrel sampling:

- Clean out the borehole to the desired sampling depth using equipment that will ensure that the material to be sampled is not disturbed by the operation. In saturated sands and silts, withdraw the drill bit slowly to prevent loosening of the soil around the hole and maintain the water level in the hole at or above groundwater level.

- Side-discharge bits are permissible. A bottom-discharge bit shall not be used. The process of jetting through an open tube sampler and then sampling when the desired depth is reached shall not be permitted. Where casing is used, it may not be driven below the sampling elevation.

- Install the split barrel sampler and sampling rods into the boring to the desired sampling depth. After seating the sampler by means of a single hammer blow, three 6-inch increments shall be marked on the sampling rod so that the progress of the sampler can be monitored.

- The 2-inch OD split barrel sampler shall be driven with blows from a 140-lb. (± 2 lb.) hammer falling 30 inches (± 1 inch) until either a total of 50 blows have been applied during any one of the three 6-inch increments, a total of 100 blows have been applied, there is no observed advance of the sampler for 10 successive hammer blows, or until the sampler has advanced 18 inches without reaching any of the blow count limitation constraints described herein. This process is referred to as the Standard Penetration Test.

- A 300-lb. weight falling 18 inches is sometimes used to drive a 2-1/2-inch or 3-inch O.D. spoon sampler. This procedure is used where dense materials are encountered or when a large volume of sample is required. However, this method does not conform the ASTM specifications.

- Repeat this operation at intervals not greater than 5 feet in homogeneous strata, or as specified in the sampling plan.

- Record the number of blows required to effect each 6 inches of penetration or fraction thereof. The first 6 inches is considered to be seating drive. The sum of the number of blows required for the second and third 6 inches of penetration is termed the penetration resistance, N. If the sampler is driven less than 18 inches, the penetration resistance is that for the last 1 foot penetrated.

- Bring the sampler to the surface and remove both ends and one half of the split barrel so that the soil recovered rests in the remaining half of the barrel. Describe carefully the sample interval, recovery (length), composition, structure, consistency, color, condition, etc., of the recovered soil then put a representative portion of each sample into a jar, without ramming. Jars with samples not taken for chemical analysis shall be sealed with wax, or hermetically sealed (using a teflon cap liner) to prevent evaporation of the soil moisture, if the sample is to be later evaluated for moisture content. Affix labels to the jar and complete Chain-of-Custody and other required sample data forms. Protect samples against extreme temperature changes and breakage by placing them in appropriate cartons stored in a protected area. Pertinent data which shall be noted on the label or written on the jar lid for each sample includes the project number, boring number, sample number, depth interval, blow counts, and date of sampling.

- An addition to the sampler mentioned above is an internal liner, which is split longitudinally and has a thin-wall brass, steel, or paper liner inserted inside, which will preserve the sample. However, since the development of the thin-walled samplers (mentioned below) the split barrel sampler with liner has declined in use.

### 5.1.3 Thin Walled Tube (Shelby Tube) Sampling (ASTM D1587-83)

When it is desired to take undisturbed samples of soil, thin-walled seamless tube samplers (Shelby tubes) will be used. The following method will be used:

- Clean out the borehole to the sampling depth, being careful to minimize the chance for disturbance of the material to be sampled. In saturated materials, withdraw the drill bit slowly to prevent loosening of the soil around the borehole and maintain the water level in the hole at or above groundwater level.

- The use of bottom discharge bits or jetting through an open-tube sampler to clean out the hole shall not be allowed. Any side discharge bits are permitted.

- A stationary piston-type sampler may be required to limit sample disturbance and aid in retaining the sample. Either the hydraulically operated or control rod activated-type of stationary piston sampler may be used. Prior to inserting the tube sampler in the hole, check to ensure that the sampler head contains a check valve. The check valve is necessary to keep water in the sampling rods from pushing the sample out of the tube sampler during sample withdrawal and to maintain a suction within the tube to help retain the sample.

- To minimize chemical reaction between the sample and the sampling tube, brass tubes may be required, especially if the tube is stored for an extended time prior to testing. While steel tubes coated with shellac are less expensive than brass, they are more reactive, and shall only be used when the sample will be tested within a few days after sampling or if chemical reaction is not anticipated. With the sampling tube resting on the bottom of the hole and the water level in the boring at the groundwater level or above, push the tube into the soil by a continuous and rapid motion, without impacting or twisting. In no case shall the tube be pushed farther than the length provided for the soil sample. Allow about 3 inches in the tube for cuttings and sludge.

- Upon removal of the sampler tube from the hole, measure the length of sample in the tube and also the length penetrated. Remove disturbed material in the upper end of the tube and measure the length of sample again. After removing at least an inch of soil from the lower end and after inserting an impervious disk, seal both ends of the tube with at least a 1/2-inch thickness of wax applied in a way that will prevent the wax from entering the sample. Newspaper or other types of filler must be placed in voids at either end of the sampler prior to sealing with wax. Place plastic caps on the ends of the sampler, tape in the caps place, and dip the ends in wax.

- Affix labels to the tubes as required and record sample number, depth, penetration, and recovery length on the label. Mark the same information and "up" direction on the tube with indelible ink, and mark the end of the sample. Complete Chain-of-Custody and other required forms. Do not allow tubes to freeze and store the samples vertically (with the same orientation they had in the ground, i.e., top of sample is up) in a cool place out of the sun at all times. Ship samples protected with suitable resilient packing material to reduce shock, vibration, and disturbance.

Thin-walled undisturbed tube samplers are restricted in their usage by the consistency of the soil to be sampled. Often, very loose and/or wet samples cannot be retrieved by the samplers, and soils with a consistency in excess of very stiff cannot be penetrated by the sampler. Devices such as Denison or Pitcher core samplers can be used to obtain undisturbed samples of stiff soils. Using these devices normally increases sampling costs and therefore their use shall be weighed against the increased cost and the need for an undisturbed sample. In any case, if a sample cannot be obtained with a tube sampler, an attempt shall be made with a split barrel sampler at the same depth so that at least a sample can be obtained for classification purposes.

### 5.1.4 Continuous Core Soil Samples

The CME continuous sample tube system provides a method of sampling soil continuously during hollow stem augering. The 5-foot sample barrel fits within the lead auger of a hollow auger column. The samplng system can be used with a wide range of I.D. hollow stem augers (from 3-1/4-inch to 8-1/4-inch I.D.). This method has been used to sample many different materials such as glacial drift, hard clays and shales, mine tailigs, etc. This method is particularly used when SPT samples are not required and a large volume of material is needed. Also, this method is useful when a visual description of the subsurface lithology is required.

## 5.2 SURFACE SOIL SAMPLES

For loosely packed earth or waste pile samples, stainless steel scoops or trowels can be used to collect representative samples. For densely packed soils or deeper soil samples, a hand or power soil auger may be used.

The following methods are to be used:

- Use a soil auger for deep samples (6 to 24 inches) or a scoop or trowel for surface samples. Remove debris, rocks, twigs, and vegetation before collection of soil. Mark the location with a numbered stake if possible and locate sample points on a sketch of the site.

- Use a new or freshly-decontaminated sampler for each sample taken. Attach a label and identification tag. Record all required information in the field logbook and on the sample log sheet, Chain-of-Custody record, and other required forms.

- Pack and ship accordingly.

- When a representative composited sample is to be prepared (e.g., samples taken from a gridded area or from several different depths), it is best to composite individual samples in the laboratory where they can be more precisely composited on a weight or volume basis. If this is not possible, the individual samples (all of equal volume, i.e., the sample bottles shall be full) shall be placed in a decontaminated stainless steel bucket, mixed thoroughly using a stainless steel spatula or trowel, and a composite sample collected.

## 5.3 WASTE PILE SAMPLES

The use of stainless steel scoops or trowels to obtain small discrete samples of homogeneous waste piles is usually sufficient for most conditions. Layered (nonhomogeneous) piles require the use of tube samplers to obtain cross-sectional samples.

- Collect small, equal portions of the waste from several points around the pile, penetrating it as far as practical. Use numbered stakes, if possible, to mark the sampling locations and locate sampling points on the site sketch.
- Place the waste sample in a glass container. Attach a label and identification tag. Record all the required information in the field logbook and on the sample log sheet and other required forms.

For layered, nonhomogeneous piles, grain samplers, sampling triers, or waste pile samplers must be used at several representative locations to acquire a cross-section of the pile. The basic steps to obtain each sample are

- Insert a sampler into the pile at a 0- to 45-degree angle from the horizontal to minimize spillage.
- Rotate the sampler once or twice to cut a core of waste material. Rotate the grain sampler inner tube to the open position and then shake the sampler a few times to allow the material to enter the open slits. Move the sampler into position with slots upward (grain sampler closed) and slowly withdraw from the pile.

## 5.4 ROCK SAMPLING (CORING) (ASTM D2113-83)

Rock coring enables a detailed assessment of borehole conditions to be made, showing precisely all lithologic changes and characteristics. Because coring is an expensive drilling method, it is commonly used for shallow studies of 500 feet or less, or for specific intervals in the drill hole that require detailed logging and/or analyzing. It can, however, proceed for thousands of feet continuously, depending on the size of the drill rig. It yields better quality data than air rotary drilling, although at a substantially reduced drilling rate. Rate of drilling varies widely, depending on the characteristics of lithologies encountered, drilling methods, depth of drilling, and condition of drilling equipment. Average output in a 10-hour day ranges from 40 to over 200 feet. Downhole geophysical logging or television camera monitoring is sometimes used to complement the data generated by coring.

Borehole diameter can be drilled to various sizes, depending on the information needed. Standard sizes of core barrels (showing core diameter) and casing are shown in Attachment No. 1.

Core drilling is used when formations are too hard to be sampled by soil sampling methods and a continuous solid sample is desired. Usually, soil samples are used for overburden, and coring begins in sound bedrock. Casing is set into bedrock before coring begins to prevent loose material from entering the borehole, to prevent loss of drilling fluid, and to prevent cross contamination of aquifers.

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## ATTACHMENT 1

## STANDARD SIZES OF CORE BARRELS AND CASING

| Coring bit size | Nominal * | | Set size * | |
|---|---|---|---|---|
| | O.D. | I.D. | O.D. | I.D. |
| RWT | $1\frac{5}{32}$ | $\frac{3}{4}$ | 1.160 | .735 |
| EWT | $1\frac{1}{2}$ | $\frac{29}{32}$ | 1.470 | 905 |
| EX, EXL, EWG, EWM | $1\frac{1}{2}$ | $\frac{13}{16}$ | 1.470 | .845 |
| AWT | $1\frac{7}{8}$ | $1\frac{9}{32}$ | 1.875 | 1 281 |
| AX, AXL, AWG, AWM | $1\frac{7}{8}$ | $1\frac{3}{16}$ | 1.875 | 1 185 |
| BWT | $2\frac{3}{8}$ | $1\frac{3}{4}$ | 2.345 | 1 750 |
| BX, BXL, BWG, BWM | $2\frac{3}{8}$ | $1\frac{5}{8}$ | 2.345 | 1.655 |
| NWT | 3 | $2\frac{5}{16}$ | 2.965 | 2.313 |
| NX, NXL, NWG, NWM | 3 | $2\frac{1}{8}$ | 2.965 | 2.155 |
| HWT | $3\frac{29}{32}$ | $3\frac{3}{16}$ | 3.889 | 3.187 |
| HWG | $3\frac{29}{32}$ | 3 | 3.889 | 3.000 |
| $2\frac{3}{4} \times 3\frac{7}{8}$ | $3\frac{7}{8}$ | $2\frac{3}{4}$ | 3.840 | 2.890 |
| $4 \times 5\frac{1}{2}$ | $5\frac{1}{2}$ | 4 | 5.435 | 3.970 |
| $6 \times 7\frac{3}{4}$ | $7\frac{3}{4}$ | 6 | 7.655 | 5.970 |
| AX Wire line 1/ | $1\frac{7}{8}$ | 1 | 1.875 | 1.000 |
| BX Wire line 1/ | $2\frac{3}{8}$ | $1\frac{7}{16}$ | 2.345 | 1.437 |
| NX Wire line 1/ | 3 | $1\frac{15}{16}$ | 2.965 | 1.937 |

* All dimensions are in inches; to convert to millimeters, multiply by 254.
1/ Wire line dimensions and designations may vary according to manufacturer.

ATTACHMENT 1
PAGE TWO

| Size Designations | | | Casing coupling | | | | | Approximate core diameter | |
|---|---|---|---|---|---|---|---|---|---|
| Casing; Casing coupling; Casing bits; Core barrel bits | Rod; Rod couplings | Casing O.D., inches | O.D., inches | I.D., inches | Casing bit, O.D., inches | Core barrel bit O.D., inches* | Drill rod O.D., inches | Normal, inches | Thinwall, inches |
| RX | RW | 1.437 | 1.437 | 1.188 | 1.485 | 1.160 | 1.094 | — | .735 |
| EX | E | 1.812 | 1.812 | 1.500 | 1.875 | 1.470 | 1.313 | .845 | .905 |
| AX | A | 2.250 | 2.250 | 1.906 | 2.345 | 1.875 | 1.625 | 1.185 | 1.281 |
| BX | B | 2.875 | 2.875 | 2.375 | 2.965 | 2.345 | 1.906 | 1.655 | 1.750 |
| NX | N | 3.500 | 3.500 | 3.000 | 3.615 | 2.965 | 2.375 | 2.155 | 2.313 |
| HX | HW | 4.500 | 4.500 | 3.938 | 4.625 | 3.890 | 3.500 | 3.000 | 3.187 |
| RW | RW | 1.437 | Flush joint | No coupling | 1.485 | 1.160 | 1.094 | — | .735 |
| EW | EW | 1.812 | | | 1.875 | 1.470 | 1.375 | .845 | .905 |
| AW | AW | 2.250 | | | 2.345 | 1.875 | 1.750 | 1.185 | 1.281 |
| BW | BW | 2.875 | | | 2.965 | 2.345 | 2.125 | 1.655 | 1.750 |
| NW | NW | 3.500 | | | 3.615 | 2.965 | 2.625 | 2.155 | 2.313 |
| HW | HW | 4.500 | | | 4.625 | 3.890 | 3.500 | 3.000 | 3.187 |
| PW | — | 5.500 | | | 5.650 | — | — | — | — |
| SW | — | 6.625 | | | 6.790 | — | — | — | — |
| UW | — | 7.625 | | | 7.800 | — | — | — | — |
| ZW | — | 8.625 | | | 8.810 | — | — | — | — |
| — | AX 1/ | — | — | — | — | 1.875 | 1.750 | 1.000 | — |
| — | BX 1/ | — | — | — | — | 2.345 | 2.250 | 1.437 | — |
| — | NX 1/ | — | — | — | — | 2.965 | 2.813 | 1.937 | — |

* For hole diameter approximation, assume $\frac{1}{32}$ inch larger than core barrel bit.

1/ Wire line size designation, drill rod only, serves as both casing and drill rod. Wire line core bit, and core diameters vary slightly according to manufacturer.

NOMINAL DIMENSIONS FOR DRILL CASINGS AND ACCESSORIES. (DIAMOND CORE DRILL MANUFACTURERS ASSOCIATION). 288-D-2889.

Drilling through bedrock is initiated by using a diamond-tipped core bit threaded to a drill rod (outer core barrel) with a rate of drilling determined by the downward pressure, rotation speed of drill rods, drilling fluid pressure in the borehole, and the characteristics of the rock (mineralogy, cementation, weathering).

### 5.4.1 Diamond Core Drilling

A penetration of typically less than 6 inches per 50 blows using a 140-lb. hammer dropping 30 inches with a 2-inch split spoon sampler shall be considered an indication that soil sampling methods may not be applicable and that coring may be necessary to obtain samples.

When formations are encountered that are too hard to be sampled by soil sampling methods, the following diamond core drilling procedure may be used.

- Firmly seat a casing into the bedrock or the hard material to prevent loose materials from entering the hole and to prevent the loss of drilling fluid return. Level the surface of the rock or hard material when necessary by the use of a fishtail or other bits. If the drill hole can be retained open without the casing and if cross contamination of aquifers in the unconsolidated materials is unlikely, it may be omitted.

- Begin the core drilling using a double-tube swivel-core barrel of the desired size. After drilling no more than 10 feet (3 m), remove the core barrel from the hole, and take out the core. If the core blocks the flow of the drilling fluid during drilling, remove the core barrel immediately. In soft materials, a large starting size may be specified for the coring tools; where local experience indicates satisfactory core recovery or where hard, sound materials are anticipated, a smaller size or the single-tube type may be specified and longer runs may be drilled. NX/NW size coring equipment is the most commonly used size.

- When soft materials are encountered that produce less than 50 percent recovery, stop the core drilling. If soil samples are desired, secure such samples in accordance with the procedures described in ASTM Method D 1586 (Split Barrel Sampling) or in Method D 1587 (Thin-Walled Tube Sampling) for Sampling of Soils (see Section 5.1.1 and 5.1.2). Resume diamond core drilling when refusal materials are again encountered.

- Since rock structures and the occurrence of seams, fissures, cavities, and broken areas are among the most important items to be detected and described, take special care to obtain and record these features. If such broken zones or cavities prevent further advance of the boring, one of the following three steps shall be taken: (1) cement the hole; (2) ream and case; or (3) case and advance with the next smaller size core barrel, as the conditions warrant.

- In soft, seamy, or otherwise unsound rock, where core recovery may be difficult, M-design core barrels may be used. In hard, sound rock where a high percentage of core recovery is anticipated, the single-tube core barrel may be employed.

### 5.4.2 Rock Sample Preparation and Documentation

Once the rock coring has been completed and the core recovered, the rock core shall be carefully removed from the barrel, placed in a core tray (previously labeled "top" and "bottom" to avoid confusion), classified, and measured for percentage of recovery as well as the rock quality designation (RQD). Each core shall be described, classified, and logged using a uniform system as presented in Procedure GH-1.5. If moisture content will be determined or if it is desirable to prevent drying (e.g., to prevent shrinkage of clay formations) or oxidation of the core, the core shall be wrapped in plastic sleeves immediately after logging. Each plastic sleeve shall be labeled with indelible ink. The boring number, run number, and the footage represented in each sleeve shall be included, as well as the top and bottom of the core run.

After sampling, rock cores shall be placed in the sequence of recovery in well-constructed wooden boxes provided by the drilling contractor. Rock cores from two different borings shall not be placed in the same core box unless accepted by the Site Geologist. The core boxes shall be constructed to accommodate at least 20 linear feet of core in rows of approximately 5 feet each and shall be constructed with hinged tops secured with screws, and a latch (usually a hook and eye) to keep the top securely fastened down. Wood partitions shall be placed at the end of each core run and between rows. The depth from the surface of the boring to the top and bottom of the drill run and run number shall be marked on the wooden partitions with indelible ink. A wooden partition (wooden block) shall be placed at the end of each run with the depth of the bottom of the run written on the block. These blocks will serve to separate successive core runs and indicate depth intervals for each run. The order of placing cores shall be the same in all core boxes. Rock core shall be placed in the box so that, when the box is open, with the inside of the lid facing the observer, the top of the cored interval contained within the box is in the upper left corner of the box, and the bottom of the cored interval is in the lower right corner of the box (see Attachment 2). The top and bottom of each core obtained and its true depth shall be clearly and permanently marked on each box. The width of each row must be compatible with the core diameter to prevent lateral movement of the core in the box. Similarly, an empty space in a row shall be filled with an appropriate filler material or spacers to prevent longitudinal movement of the core in the box.

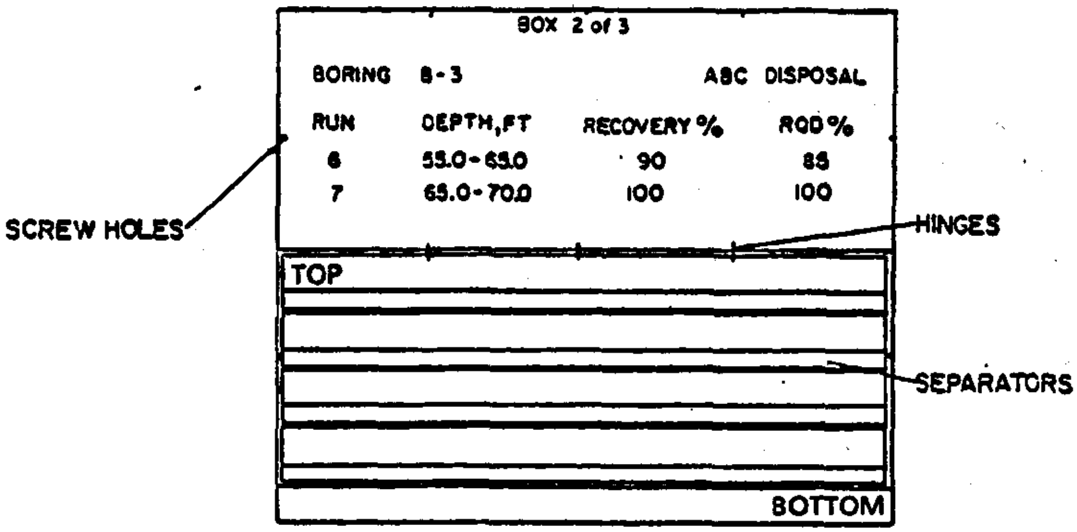
The inside and outside of the core-box lid shall be marked by indelible ink to show all pertinent data on the box's contents. At a minimum, the following information shall be included:

- Project name
- Project number
- Boring number
- Run numbers
- Footage (depths)
- Recovery
- RQD (%)
- Box number and total number of boxes for that boring (Example: Box 5 of 7).

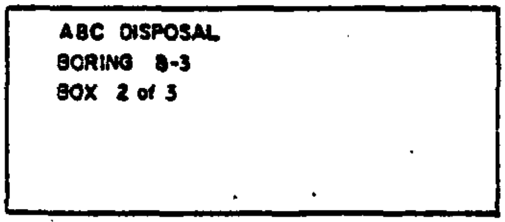
For easy retrieval when core boxes are stacked, the sides and ends of the box shall also be labeled and include project number, boring number, top and bottom depths of core and box number. Attachment No. 2 illustrates a typical rock core box.

Prior to final closing of the core box, a photograph of the recovered core and the labeling on the inside cover shall be taken. If moisture content is not critical, the core shall be wetted and wiped clean for the photograph. (This will help to show true colors and bedding features in the cores).

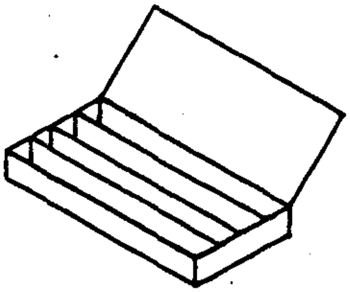
## ATTACHMENT 2

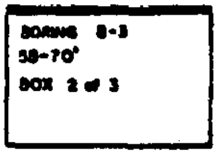


CORE BOX (OBLIQUE VIEW)



CORE BOX (TOP VIEW)





CORE BOX (END VIEW)

## TYPICAL ROCK CORE BOX

NOT TO SCALE

NUS CORPORATION
A Halliburton Company

## 6.0 REFERENCES

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Central Mine Equipment Company, Drilling Equipment, St. Louis, Missouri.

## 7.0 RECORDS

None.

**NUS CORPORATION**

**ENVIRONMENTAL MANAGEMENT GROUP**

# STANDARD OPERATING PROCEDURES

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| **Number** GH-1.4 | **Page** 1 of 20 |
| **Effective Date** 05/04/90 | **Revision** 1 |
| **Applicability** EMG | |
| **Prepared** Earth Sciences | |
| **Approved** D. Senovich | |

**Subject**
SOIL AND ROCK DRILLING METHODS

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SECTION

## 1.0 PURPOSE

The purpose of this procedure is to describe the methods, the sequence of operations and the equipment necessary to perform soil and rock borings.

## 2.0 SCOPE

This guideline addresses most of the accepted and standard drilling techniques, their benefits and drawbacks. It should be used generally to determine what type of drilling techniques would be most successful depending on site-specific geologic conditions and the type of sampling required.

## 3.0 GLOSSARY

Boulders - Rounded, semi-rounded or naturally angular particles of rock larger than 12 inches in diameter.

Clay - Fine grained soil or portions of soil having certain physical properties, composition and texture. Clay exhibits plastic properties within a range of water contents and exhibits considerable strength when air dried. Clay consists usually of fragments of hydrous aluminum or magnesium silicate minerals, and it consists predominantly of grains with diameters of less than 0.005 mm.

Cobbles - Rounded, semi-rounded or naturally angular particles of rock between 3 inches and 12 inches in diameter.

Gravel - Rounded or semirounded particles of rock that will pass a 3 inch sieve (7.62 cm) and be retained on a No. 4 U.S. standard sieve (4.76 mm). Coarse gravel is larger than 3/4-inches, while fine gravel is finer than 3/4-inches.

Stone - Crushed or naturally angular particles of rock that will pass a 3 inch sieve (7.62 cm) and be retained on a No. 4 U.S. standard sieve (4.76 mm).

Rock - Any consolidated or coherent and relatively hard, naturally formed mass of mineral matter.

Sand - Particles of rock that will pass a No. 4 U.S. standard sieve (4.76 mm) and be retained on a No. 200 U.S. standard sieve (0.074 mm). Coarse sand is larger than a No. 10 sieve, and fine sand is finer than a No. 40 sieve (0.42 mm).

Silt - Material passing the No. 200 U.S. standard sieve (0.074 mm) that is nonplastic or very slightly plastic and that exhibits little or no strength when air dried.

Soil - Sediments or other unconsolidated accumulations of solid particles that are produced by the physical and chemical disintegration of rock and that may contain organic matter.

Undisturbed Sample - A soil sample that has been obtained by methods in which every precaution has been taken to minimize disturbance to the sample.

Water Table - A surface in an aquifer where groundwater pressure is equal to atmospheric pressure.

## 4.0 RESPONSIBILITIES

Site Manager - In consultation with the project geologist, responsible for evaluating the drilling requirements for the site and specifying drilling techniques that will be successful given the study objectives and geologic conditions at the site. He should also determine the disposal methods for products generated by drilling, such as drill cuttings and well development water, as well as any specialized supplies or logistical support required for the drilling operations.

Site Geologist/Rig Geologist - Responsible for insuring that standard and approved drilling procedures are followed. The geologist will generate a detailed boring log for each test hole. This log shall include a description of materials, samples, method of sampling, blow counts, and other pertinent drilling and testing information that may be obtained during drilling (see Attachment A of Procedure GH-1.7). Often this position for inspecting the drilling operations may be filled by other geotechnical personnel, such as soils and foundation engineers, civil engineers, etc.

Determination of the exact location for borings is the responsibility of the site geologist. The final location for drilling must be properly documented on the boring log. The general area in which the borings are to be located will be shown on a site map included in the Work Plan.

Field Operations Leader - Responsible for overall supervision and scheduling of drilling activities.

Drilling Subcontractor - Responsible for obtaining all drilling permits and clearances, and supplying all services (including labor), equipment and material required to perform the drilling, testing, and well installation program, as well as maintenance and quality control of such required equipment except as stated in signed and approved subcontracts.

The driller must report any major technical or analytical problems encountered in the field to the Field Operations Leader within 24 hours, and must provide advance written notification for any changes in field procedures describing and justifying such changes. No such changes shall be made unless requested and authorized in writing by the Field Operations Leader.

The drilling subcontractor will be responsible for following decontamination procedures specified in the Work Plan. Upon completion of the work, the Drilling Subcontractor will be responsible for demobilizing all equipment, cleaning up any materials deposited on site during drilling operations, and properly backfilling any open borings.

## 5.0 PROCEDURES

### 5.1 GENERAL

The purpose of drilling boreholes is:

- To determine the type, thickness, and certain physical and chemical properties of the soil, water and rock strata which underlie the site, and
- To install monitoring wells or piezometers.

All drilling and sampling equipment will be cleaned using appropriate decontamination procedures (see Procedure GH-1.6 and SF-2.3) between samples and borings. Unless otherwise specified, it is generally advisable to drill borings at "clean" locations first, and at the most contaminated locations last, to reduce the risk of spreading contamination between locations. All borings must be logged by the rig geologist as they proceed (see Procedure GH-1.5) unless the FSAP specifically states that logging is not required. Situations where logging would not be required would include installation of multiple well points within a small area, or a "second attempt" boring adjacent to a boring that could not be continued through resistant material. In the latter case, the boring log can be resumed 5 feet above the depth at which the initial boring was abandoned, although the rig geologist should still confirm that the stratigraphy at the redrilled location conforms essentially with that encountered at the original location. If significant differences are seen, each hole should be logged separately.

## 5.2 DRILLING METHODS

The selected drilling methods described below apply to drilling in subsurface materials, including, but not limited to, sand, gravel, clay, silt, cobbles, boulders, rock and man-made fill. Drilling methods should be selected after studying the site geology and terrain, purpose of drilling, waste conditions at the site, and the overall subsurface investigation program proposed for the site. The full range of different drilling methods applicable to the proposed program should be identified with final selection based on relative cost, availability, time constraints, and how well each method meets the sampling and testing requirements of the individual drilling program.

### 5.2.1 Continuous-Flight Hollow-Stem Auger Drilling

This method of drilling consists of screwing augers with a hollow stem into the ground. Cuttings are brought to the surface by the rotating action of the auger. This method is relatively quick and inexpensive. Advantages of this type of drilling include:

- Samples can be obtained without pulling the augers out of the hole. However, this is a poor method for obtaining grab samples from thin, discrete formations because of mixing of soils which occurs as the material is brought to the surface. Sampling of such formations will require the use of split-barrel or thin-wall tube samplers advanced through the hollow core of the auger.

- No drilling fluids are required.

- A well can be installed inside the auger stem and backfilled as the augers are withdrawn.

Disadvantages and limitations of this method of drilling include:

- Augering can only be done in unconsolidated materials.

- The inside diameter of hollow stem augers used for well installation should be at least four inches greater than the well casing. Use of such large diameter hollow stem augers is more expensive than the use of small diameter augers in boreholes not used for well installation. Furthermore, the density of unconsolidated materials and depths become more of a limiting factor. More friction is produced with the larger diameter auger and subsequently greater torque is needed to advance the boring.

- The maximum effective depth for drilling is 150 feet or less, depending on site conditions and the size of augers used.

- In augering through clean sand formations below the water table, the sand will tend to flow into the hollow stem when the plug is removed for soil sampling or well installation. If the condition of "running" or "flowing" sands is persistent at a site, an alternative method of drilling is recommended, in particular for wells or boreholes deeper than 25 feet. Hollow stem auger drilling is the preferred method of drilling. Most alternative methods require the introduction of water or mud downhole (air rotary is the exception) to maintain the open borehole. With these other methods great care must be taken to ensure that the method does not interfere with the collection of a representative sample which is the object of the construction. With this in mind, the preferred order of choice of drilling method after hollow stem augering (HSA) is:

- Cable tool
- Casing drive (air)
- Air rotary
- Mud rotary
- Drive and wash
- Jetting

However, the use of any method will also depend on efficiency and cost-effectiveness. In many cases, mud rotary is the only feasible alternative to hollow stem augering. Thus, mud rotary drilling is generally acceptable as a first substitute for HSA.

The procedures for sampling soils through holes drilled by hollow-stem auger shall conform with the applicable ASTM Standards: D1587-83 and D1586-84. The hollow stem auger may be advanced by any power-operated drilling machine having sufficient torque and ram range to rotate and force the auger to the desired depth. The machine must, however, be equipped with the accessory equipment needed to perform required sampling, or rock coring.

When taking soil samples for chemical analysis, the hollow-stem auger shall be plugged until the desired sampling depth is reached. Samples can be taken using split-spoon or thin wall tube samplers driven into the formation in advance of the auger (see Procedure GH-1.3). If the sample is to be taken at a relatively deep point, the auger may be advanced without a plug to within five feet of the sample depth. Then clean out the auger stem, insert a plug and continue to the sampling depth. The plug is then removed and samples taken as specified by the rig geologist. Samples should be taken according to the specifications of the sampling plan. Any required sampling shall be performed by rotation, pressing, or driving in accordance with the standard or approved method governing use of the particular sampling tool. The sequence shall be repeated for each sample desired.

The hollow-stem auger may be used without the plug when boring for geotechnical examination or for well installation.

When drilling below the water table, specially-designed plugs which allow passage of formation water but not solid material shall be used (see Reference 1 of this guideline). This method also prevents blow back and plugging of the auger when the plug is removed for sampling.

Alternately, it may be necessary to keep the hollow stem full of water, at least to the level of the water table, to prevent blowback and plugging of the auger. If water is added to the hole, it must be sampled and analyzed to determine if it is free from contaminants prior to use. In addition, the amount of water introduced, the amount recovered upon attainment of depth, and the amount of water extracted during well development must be carefully logged in order to ensure that a representative sample of the formation water can be obtained. Well development should occur as soon after well completion as practicable (see GH-1.7 for Well Development Procedures). If gravelly or hard material is encountered which prevents advancing the auger to the desired depth, augering should be halted and either driven casing or hydraulic rotary methods should be attempted. If the depth to the bedrock/soil interface and bedrock lithology must be determined, then a 5-foot confirmatory core run should be conducted (see Section 5.2.9).

At the option of the Field Operations Leader, when resistant materials prevent the advancement of the auger, a new boring can be attempted. The original boring must be properly backfilled and the new boring started a short distance away at a location determined by the site geologist. If multiple water bearing strata were encountered, the original boring must be grouted. In some formations it may be prudent to also grout borings which only penetrate the water table aquifer, since loose soil backfill in the boring would still provide a preferred pathway for surface liquids to reach the water table.

### 5.2.2 Continuous-Flight Solid-Stem Auger Drilling

This method is similar to hollow-stem augering. Practical application of this method is severely restricted as compared with hollow stem augers. Split barrel (split-spoon) sampling cannot be done without pulling the augers which may allow the hole to collapse. The method is therefore very time consuming and is not cost effective. Also, augers would have to be withdrawn before installing a monitoring well, which again, may allow the hole to collapse. Furthermore, geologic logging by examining the soils brought to the surface is unreliable as in the case of the hollow stem auger, and depth to water may be difficult to determine while drilling.

There would be very few situations where use of a solid stem auger would be preferable to other drilling methods. The only practical applications of this method would be to drill boreholes for well installation where no lithologic information is desired and the soils are such that the borehole can be expected to remain open after the augers are withdrawn. Alternatively, the technique can be used to find depth to bedrock in an area when no other information is required from drilling.

### 5.2.3 Rotary Drilling

Direct rotary drilling includes air-rotary and fluid-rotary drilling. Air-rotary drilling is a method of drilling where the drill rig simultaneously turns and exerts a downward pressure on the drilling rods and bit while circulating compressed air down the inside of the drill rods, around the bit, and out the annulus of the borehole. Air circulation serves to both cool the bit and remove the cuttings from the borehole. Advantages of this method include:

- The drilling rate is high (even in rock).
- The cost per foot of drilling is relatively low.
- Air rotary rigs are common in most areas.
- No drilling fluid is required (except when water is injected to keep down dust).
- The borehole diameter is large, to allow room for proper well installation procedures.

Disadvantages to using this method include:

- Formations must be logged from the cuttings that are blown to the surface and thus the depths of materials logged are approximate.

- Air blown into the formation during drilling may "bind" the formation and impede well development and natural groundwater flow.

- In-situ samples cannot be taken, unless the hole is cased.

- Casing must generally be used in unconsolidated materials.

- Air rotary drill rigs are large and heavy.

A variation of the typical air-rotary drill bit is a down hole hammer which hammers the drill bit down as it drills. This makes drilling in hard rock faster. Air-rotary drills can also be adapted to use for rock coring although they are generally slower than other types of core drills. A major application of the air-rotary drilling method would be to drill holes in rock for well installation.

Fluid-Rotary drilling operates in a similar manner to air rotary drilling except that a drilling fluid ("mud") or clean water is used in place of air to cool the drill bit and remove cuttings. There are a variety of fluids that can be used with this drilling method, including bentonite slurry and synthetic slurries. If a drilling fluid other than water/cuttings is used, it must be a natural clay (i.e., bentonite) and a "background" sample of the fluid should be taken for analysis of possible organic or inorganic contaminants.

Advantages to the fluid-rotary drilling method include:

- The ability to drill in many types of formations.
- Relatively quick and inexpensive.
- Split barrel (split-spoon) or thin-wall tube samples can be obtained without removing drill rods if the appropriate size drill rods and bits (i.e., fish-tail or drag bit) are used.
- In some borings temporary casing may not be needed as the drilling fluids may keep the borehole open.
- Drill rigs are readily available in most areas.

Disadvantages to this method include:

- Formation logging is not as accurate as with hollow stem auger method if split barrel (split-spoon) samples are not taken (i.e., the depths of materials logged from cuttings delivered to the surface are approximate).
- Drilling fluids reduce permeability of the formation adjacent to the boring to some degree, and require more extensive well development than "dry" techniques (augering, air-rotary).
- No information on depth to water is obtainable while drilling.
- Fluids are needed for drilling, and there is some question about the effects of the drilling fluids on water samples obtained. For this reason as well, extensive well development may be required.
- In very porous materials (i.e., rubble fill, boulders, coarse gravel) drilling fluids may be continuously lost into the formation. This will require either constant replenishment of the drilling fluid, or the use of casing through this formation.
- Drill rigs are large and heavy, and must be supported with supplied water.
- Ground water samples can be potentially diluted with drilling fluid.

The procedures for performing direct rotary soil investigations and sampling shall conform with the applicable ASTM standards: D2113-83, D1587-83, and D1586-84.

For air or fluid-rotary drilling, the rotary drill may be advanced to the desired depth by any power-operated drilling machine having sufficient torque and ram range to rotate and force the bit to the desired depth. The drilling machine must, however, be equipped with any accessory equipment needed to perform required sampling, or coring. Prior to sampling, any settled drill cuttings in the borehole must be removed.

Soil samples shall be taken as specified by the Work Plan or more frequently if requested by the field geologist. Any required sampling shall be performed by rotation, pressing, or driving in accordance with the standard or approved method governing use of the particular sampling tool.

When field conditions prevent the advancement of the hole to the desired depth, a new boring may be drilled at the request of the Field Operations Leader. The original boring shall be backfilled using methods and materials appropriate for the given site and a new boring started a short distance away at a location determined by the site geologist.

### 5.2.4 Reverse Circulation Rotary Drilling

The common reverse-circulation rig is a water or mud rotary rig with a large diameter drill pipe which circulates the drilling water down the annulus and up the inside of the drill pipe (reverse flow direction from direct mud rotary). This type of rig is used for the construction of large-capacity production water wells and is not suited for small, water-quality sampling wells because of the use of drilling muds and the large diameter hole which is created. A few special reverse-circulation rotary rigs are made with double-wall drill pipe. The drilling water or air is circulated down the annulus between the drill pipes and up inside the inner pipe.

Advantages of the latter method include:

- The formation water is not contaminated by the drilling water.
- Formation samples can be obtained, from known depths.
- When drilling with air, immediate information is available regarding the water-bearing properties of formations penetrated.
- Collapsing of the hole in unconsolidated formations is not as great a problem as when drilling with the normal air rotary rig.

Disadvantages include:

- Double-wall, reverse-circulation drill rigs are very rare and expensive to operate.
- Placing cement grout around the outside of the well casing above a well screen often is difficult, especially when the screen and casing are placed down through the inner drill pipe before the drill pipe is pulled out.

### 5.2.5 Drill-through Casing Driver

The driven-casing method consists of alternately driving casing (fitted with a sharp, hardened casing shoe) into the ground using a hammer lifted and dropped by the drill rig or an air hammer and cleaning out the casing using a rotary chopping bit and air or water to flush out the materials. The casing is driven down in stages (usually 5 feet per stage). A continuous record is kept of the blows per foot in driving the casing (see Procedure GH-1.5). The casing is normally advanced by a 300-pound hammer falling freely through a height of 30-inches. Simultaneous washing and driving of the casing is not recommended. If this procedure is used, the elevations between which water is used in driving the casing should be recorded.

The driven casing method is used in unconsolidated formations only. When the boring is to be used for later well installation, the driven casing used should be at least four inches larger in diameter than the well casing to be installed. Advantages to this method of drilling include:

- Split barrel (split-spoon) sampling can be conducted while drilling.
- Well installation is easily accomplished.
- Drill rigs used are relatively small and mobile.
- The use of casing minimizes flow into the hole from upper water-bearing layers; therefore multiple aquifers can be penetrated and sampled for rough field determinations of some water quality parameters.

Some of the disadvantages include:

- This method can only be used in unconsolidated formations.
- The method is slower than other methods (average drilling progress is 30 to 50 feet per day).
- Maximum depth of the borehole varies with the size of the drill rig and casing diameter used, and the nature of the formations drilled.
- The cost per hour or per foot of drilling may be substantially higher than other drilling methods.
- It is difficult and time consuming to pull back the casing if it has been driven very deep (deeper than 50 feet in many formations).

### 5.2.6 Cable Tool Drilling

A cable tool rig uses a heavy, solid-steel, chisel-type drill bit ("tool") suspended on a steel cable, which when raised and dropped chisels or pounds a hole through the soils and rock. Drilling progress may be expedited by the use of "slip-jars" which serve as a cable-activated down hole percussion device to hammer the bit ahead.

When drilling through the unsaturated zone, some water must be added to the hole. The cuttings are suspended in the water and then bailed out periodically. Below the water table, after sufficient ground water enters the borehole to replace the water removed by bailing, no further water need be added.

When soft caving formations are encountered, it is usually necessary to drive casing as the hole is advanced to prevent collapse of the hole. Often the drilling can be only a few feet below the bottom of the casing. Because the drill bit is lowered through the casing, the hole created by the bit is smaller than the casing. Therefore, the casing (with a sharp, hardened casing shoe on the bottom) must be driven into the hole (see Section 5.2.5 of this guideline).

Advantages of the cable-tool method include the following:

- Information regarding water-bearing zones is readily available during the drilling. Even relative permeabilities and rough water quality data from different zones penetrated can be obtained by skille perators.

- The cable-tool rig ca erate satisfactorily in all formations, but is best suited for caving, boulder, ca or coa avel type formations (e.g., glacial till) or formations with large cavities abo ne wat le (such as limestones).

- When casing is used, casing seals formation water out of the hole, preventing down-hole contamination and allowing sampling of deeper aquifers for field-measurable water quality parameters.

- Split barrel (split spoon) or thin-wall tube samples can be collected through the casing.

*Disadvantages include:*

- Drilling is slow compared with rotary rigs.

- The necessity of driving the casing in unconsolidated formations requires that the casing be pulled back if exposure of selected water-bearing zones is desired. This process complicates the well completion process and often increases costs. There is also a chance that the casing may become stuck in the hole.

- The relatively large diameters required (minimum of 4-inch casing) plus the cost of steel casing result in higher costs compared to rotary drilling methods where casing is not required, such as use of a hollow stem auger.

- Cable-tool rigs have largely been replaced by rotary rigs. In some parts of the U.S., availability may be difficult.

### 5.2.7 Jet Drilling (Washing)

Jet drilling, which should be used only for piezometer or vadose zone sampler installation, consists of pumping water or drilling mud down through a small diameter (1/2 to 2-inch) standard pipe (steel or PVC). The pipe may be fitted with a chisel bit or a special jetting screen. Formation materials dislodged by the bit and jetting action of the water are brought to the surface through the annulus around the pipe. As the pipe is jetted deeper, additional lengths of pipe may be added at the surface.

Jet percussion is a variation of the jetting method, in which the casing is driven with a drive weight. Normally, this method is used to place 2-inch diameter casing in shallow, unconsolidated sand formations but has been used to install 3- to 4-inch diameter casings to 200 feet.

Jetting is acceptable in very soft formations, usually for shallow sampling, and when introduction of drilling water to the formation is acceptable. Such conditions would occur during rough stratigraphic investigation or installation of piezometers for water level measurement. Advantages of this method include:

- Jetting is fast and inexpensive.
- Because of the small amount of equipment required, jetting can be accomplished in locations where access by a normal drilling rig would be very difficult. For example, it would be possible to jet down a well point in the center of a lagoon at a fraction of the cost of using a drill rig.
- Jetting numerous well points just into a shallow water table is an inexpensive method for determining the water table contours, hence flow direction.

Disadvantages include the following:

- A large amount of foreign water or drilling mud is introduced above and into the formation to be sampled.
- Jetting is usually done in very soft formations which are subject to caving. Because of this caving, it is often not possible to place a grout seal above the screen to assure that water in the well is only from the screened interval.
- The diameter of the casing is usually limited to 2 inches; therefore, samples must be obtained by methods applicable to small diameter casings.
- Jetting is only possible in very soft formations that do not contain boulders or coarse gravel, and the depth limitation is shallow (about 30 feet without jet percussion equipment).
- Large quantities of water are often needed.

### 5.2.8 Drilling with a Hand Auger

This method is applicable wherever the formation, total depth of sampling, and the site and groundwater conditions are such as to allow hand auger drilling. Hand augering can also be considered at locations where drill rig access is not possible. All hand auger borings will be performed according to ASTM D1452-80.

Samples should be taken continuously unless otherwise specified by the Work Plan. Any required sampling is performed by rotation, pressing, or driving in accordance with the standard or approved method governing use of the particular sampling tool. Typical equipment used for sampling and advancing shallow "hand auger" holes are Iwan samplers (which are rotated) or post hole diggers (which are operated like tongs). This technique is slow but effective where larger pieces of equipment do not have access and where very shallow holes are desired (less than 5 feet). Surficial soils must be composed of relatively soft and non-cemented formations to allow penetration by the auger.

### 5.2.9 Rock Drilling and Coring

When soil borings cannot be continued using augers or rotary methods due to the hardness of the soil or when rock or large boulders are encountered, drilling and sampling can be performed using a diamond bit corer in accordance with ASTM D2113.

Drilling is done by rotating and applying downward pressure to the drill rods and drill bit. The drill bit is a circular, hollow, diamond studded bit attached to the outer core barrel in a double tube core barrel. The use of single tube core barrels is not recommended, as the rotation of the barrel erodes the sample and limits its use for detailed geological evaluation. Water or air is circulated down through the drill rods and annular space between the core barrel tubes to cool the bit and remove the cuttings. The bit cuts a core out of the rock which rises into an inner barrel mounted inside the outer barrel. The inner core barrel and rock core are removed by lowering a wire line with a coupling into the drill rods, latching onto the inner barrel and withdrawing the inner barrel. A less efficient variation to this method utilizes a core barrel that cannot be removed without pulling all of the drill rods. This variation is practical only if less than 50 feet of core is required.

Core borings are made through the casing used for the soil borings. The casing must be driven and sealed into the rock formation to prevent seepage from the overburden into the hole to be cored (see Section 5.3 of this guideline). A double-tube core barrel with a diamond bit and reaming shell or equivalent should be used to recover rock cores of a size specified in the Work Plan. The most common core barrel diameters are listed in Attachment A. Soft or decomposed rock should be sampled with a driven split-barrel whenever possible or cored with a Denison or Pitcher sampler.

When coring rock, including shale and claystone, the speed of the drill and the drilling pressure, amount and pressure of water, and length of run can be varied to give the maximum recovery from the rock being drilled. Should any rock formation be so soft or broken that the pieces continually fall into the hole, causing unsatisfactory coring, the hole should be reamed and a flush joint casing installed to a point below the broken formation. The size of the flush joint casing must permit securing the core size specified. When soft or broken rock is anticipated, the length of core runs should be reduced to less than 5 feet to avoid core loss and minimize core disturbance.

Advantages of core drilling include:

- Undisturbed rock cores can be recovered for examination and/or testing.
- In formations in which the cored hole will remain open without casing, water from the rock fractures may be recovered from the well without the installation of a well screen and gravel pack.
- Formation logging is extremely accurate.
- Drill rigs are relatively small and mobile.

Disadvantages include:

- Water or air is needed for drilling.
- Coring is slower than rotary drilling (and more expensive).

- Depth to water cannot accurately be determined if water is used for drilling.

- The size of the borehole is limited.

This drilling method is useful if accurate determinations of rock lithology are desired or if open wells are to be installed into bedrock. To install larger diameter wells in coreholes, the hole must be reamed out to the proper size after boring, using air or mud rotary drilling methods.

### 5.2.10 Drilling & Support Vehicles.

In addition to the drilling method required to accomplish the objectives of the field program, the type of vehicle carrying the drill rig and/or support equipment, and its suitability for the site terrain, will often be an additional deciding factor in planning the drilling program. The types of vehicles available are extensive, and depend upon the particular drilling subcontractor's fleet. Most large drilling subcontractors will have a wide variety of vehicle and drill types suited for most drilling assignments in their particular region, while smaller drilling subcontractors will usually have a fleet of much more limited diversity. The weight size, and means of locomotion (tires, tracks, etc.) of the drill rig must be selected to be compatible with the site terrain, to assure adequate mobility between borehole locations. Such considerations also apply to necessary support vehicles used to transport water and/or drilling materials to the drill rigs at the borehole locations. When the drill rigs or support vehicles do not have adequate mobility to easily traverse the site, provisions must be made for assisting equipment, such as bulldozers, winches, timber planking, etc., to maintain adequate progress during the drilling program.

Some of the typical vehicles which are usually available for drill rigs and support equipment are:

- Totally portable drilling/sampling equipment, where all necessary components (tripods, samplers, hammers, catheads, etc.) may be hand-carried to the borehole site. Drilling/sampling methods used with such equipment include:

  - Hand augers and lightweight motorized augers
  - Retractable plug samplers-driven by hand (hammer)
  - Motorized cathead - a lightweight aluminum tripod with a small gas-engine cathead mounted on one leg, used to install small diameter cased borings. This rig is sometimes called a "monkey on a stick."

- Skid-mounted drilling equipment containing a rotary drill or engine-driven cathead (to lift hammers and drill string), a pump, and a dismounted tripod. The skid is pushed, dragged, or winched (using the cathead drum) between boring locations.

- Small truck-mounted drilling equipment uses a jeep, stake body or other light truck (4 to 6 wheels), upon which are mounted the drill and/or a cathead, a pump, and a tripod or small drilling derrick. On some rigs the drill and/or a cathead are driven by a power take-off from the truck, instead of by a separate engine.

- Track-mounted drilling equipment is similar to truck-mounted rigs, except that the vehicle used has wide bulldozer tracks for traversing soft ground. Sometimes a continuous-track "all terrain vehicle" is also modified for this purpose. Some types of tracked drill rigs are called "bombardier" or "weasel" rigs.

- Heavy truck-mounted drilling equipment is mounted on tandem or dual tandem trucks to transport the drill, derrick, winches, and pumps or compressors. The drill may be provided with a separate engine or may use a power take-off from the truck engine. Large augers, hydraulic rotary and reverse circulation rotary drilling equipment are usually mounted on such heavy duty trucks. For soft-ground sites, the drilling equipment is sometimes mounted on and off the road vehicle having low pressure, very wide diameter tires and capable of floating; these vehicles are called "swamp buggy" rigs.

- Marine drilling equipment is mounted on various floating equipment for drilling borings in lakes, estuaries and other bodies of water. The floating equipment varies, and is often manufactured or customized by the drilling subcontractor to suit specific drilling requirements. Typically, the range of flotation vehicles includes:

    - Barrel float rigs - a drill rig mounted on a timber platform buoyed by empty 55-gallo drums or similar flotation units.

    - Barge-mounted drill rigs.

    - Jack-up platforms - drilling equipment mounted on a floating platform having retractable legs to support the unit on the sea or lake bed when the platform is jacked up out of the water.

    - Drill ships - for deep ocean drilling.

In addition to the mobility for the drilling equipment, similar consideration must be given for *equipment to support the drilling operations. Such vehicles or floating equipment are needed to* transport drill water, drilling supplies and equipment, samples, drilling personnel, etc. to and/or from various boring locations.

### 5.2.11 Equipment Sizes

In planning subsurface exploration programs, care must be taken in specifying the various drilling components, so that they will fit properly in the boring or well.

For drilling open boreholes using rotary drilling equipment, tri-cone drill bits are employed with air, water or drilling mud to remove cuttings and cool the bit. Tri-cone bits are slightly smaller than the holes they drill (i.e., 5-7/8" or 7-7/8" bits will nominally drill 6" and 8" holes, respectively).

For obtaining split-barrel samples of a formation, samplers are manufactured in sizes ranging from 2-inches to 4-1/2 inches in outside diameter. However, the most commonly used size is the 2-inch *O.D., 1-3/8-inch I.D. split-barrel sampler. When this sampler is used, and driven by a 140-pound* (± 2 pound) hammer dropping 30-inches (± 1 inch), the procedure is called a Standard Penetration Test, and the blows per foot required to advance the sampler into the formation can be correlated to the formation's density or strength.

In planning the drilling of boreholes using hollow stem augers or casing, in which thin-wall tube samples or diamond core drilling will be performed, refer to the various sizes and clearances provided in Attachment A of this guideline. Sizes selected must be stated in the Work Plan.

### 5.2.12 Estimated Drilling Progress

To estimate the anticipated rates of drilling progress for a site the following must be considered:

- The speed of the drilling method employed.
- Applicable site conditions (e.g., terrain, mobility between borings, difficult drilling conditions in bouldery soils, rubble fill or broken rock, etc.).
- Project-imposed restrictions (e.g., drilling while wearing personal protective equipment, decontamination of drilling equipment, etc.).

Based on recent experience in drilling average soil conditions (no boulders) and taking samples at 5-foot intervals, for moderate depth (30' to 50') boreholes (not including installation or development of wells), the following daily rates of total drilling progress may be anticipated for the following drilling methods:

| Drilling Method | Average Daily Progress (linear feet) |
|---|---|
| Hollow-stem augers | 75' |
| Solid-stem augers | 50' |
| Mud Rotary Drilling | 100' (cuttings samples) |
| Reverse Circulation Rotary | 100' (cuttings samples) |
| Skid Rig with driven casing | 30' |
| Rotary with driven casing | 50' |
| Cable Tool | 30' |
| Hand Auger | Varies |
| Continuous Rock Coring | 50' |

## 5.3 PREVENTION OF CROSS-CONTAMINATION

A telescoping or multiple casing technique minimizes the potential for the migration of contaminated groundwater to lower strata below a confining layer. The telescoping technique consists of drilling to a confining layer utilizing a spun casing method with a diamond cutting or augering shoe, (a method similar to the rock coring method described in Section 5.2.9, except that larger casing is used) or a driven-casing method (see Section 5.2.5 of this guideline), and installing a specified diameter steel well casing. The operation consists of three separate steps. Initially, a drilling casing usually of 8-inch diameter is installed followed by installation of the well casing (6-inch diameter is common for 2-inch wells). This well casing is driven into the confining layer to insure a tight seal at the bottom of the hole. The well casing is sealed at the bottom with a bentonite-cement slurry. The remaining depth of the boring is drilled utilizing a narrower diameter spun or driven casing technique within the outer well casing. A smaller diameter well casing with an appropriate length of slotted screen on the lower end is installed to the surface.

Clean sand is placed in the annulus around and to a point about 2 feet above the screen prior to withdrawal of the drilling casing. The annular space above the screen and to a point 2 feet above the bottom of the outer well casing is sealed with a tremied cement-bentonite slurry which is pressure-grouted or displacement-grouted into the hole. The remaining casing annulus is backfilled with clean material and grouted at the surface, or it is grouted all the way to the surface.

## 5.4 CLEANOUT OF CASING PRIOR TO SAMPLING

The boring hole must be completely cleaned of disturbed soil, segregated coarse material and clay adhering to the inside walls of the casing. The cleaning must extend to the bottom edge of the casing and, if possible, a short distance further (1 or 2 inches) to bypass disturbed soil resulting from the advancement of the casing. Loss of wash water during cleaning should be recorded.

For disturbed samples both above and below the water table and where introduction of relatively large volumes of wash water is permissible, the cleaning operation is usually performed by washing the material out of the casing with water; however, the cleaning should never be accomplished with a strong, downward directed jet which will disturb the underlying soil. When clean-out has reached the bottom of the casing or slightly below (as specified above), the string of tools should be lifted one foot off the bottom with the water still flowing, until the wash water coming out of the casing is clear of granular soil particles. In formations where the cuttings contain gravel and other larger particles, it is often useful to repeatedly raise and lower the drill rods and wash bit while washing out the hole, to surge these large particles upward out of the hole. As a time saver, the drilling contractor may be permitted to use a split barrel (split-spoon) sampler with the ball check valve removed as the clean out tool, provided the material below the spoon is not disturbed and the shoe of the spoon is not damaged. However, because the ball check valve has been removed, in some formations it may be necessary to install a flap valve or spring sample retainer in the split spoon bit, to prevent the sample from falling out as the sampler is withdrawn from the hole. The use of jet-type chopping bits is discouraged except where large boulders and cobbles or hard-cemented soils are encountered. If water markedly softens the soils above the water table, clean out should be performed dry with an auger.

For undisturbed samples below the water table, or where wash water must be minimized, clean out is usually accomplished with an appropriate diameter clean out auger. This auger has cutting blades at the bottom to carry loose material up into the auger, and up-turned water jets just above the cutting blades to carry the removed soil to the surface. In this manner there is a minimum of disturbance at the top of the material to be sampled. If any gravel material washes down into the casing and cannot be removed by the cleanout auger, a split-barrel sample can be taken to remove it. Bailers and sandpumps should not be used. For undisturbed samples above the groundwater table, all operations must be performed in a dry manner.

If all of the cuttings created by drilling through the overlying formations are not cleaned from the borehole prior to sampling, some of the problems which may be encountered during sampling include:

- When sampling is attempted through the cuttings remaining in the borehole, all or part of the sampler may become filled with the cuttings. This limits the amount of sample from the underlying formation which can enter and be retained in the sampler, and also raises questions on the validity of the sample.
- If the cuttings remaining in the borehole contain coarse gravel and/or other large particles, these may block the bit of the sampler and prevent any materials from the underlying formation from entering the sampler when the sampler is advanced.

- In cased borings, should sampling be attempted through cuttings which remain in the lower portion of the casing, these cuttings could cause the sampler to become bound into the casing, such that it becomes very difficult to either advance or retract the sampler.

- When sampler blow counts are used to estimate the density or strength of the formation being sampled, the presence of cuttings in the borehole will usually give erroneously high sample blow counts.

To confirm that all cuttings have been removed from the borehole prior to attempting sampling, it is important that the rig geologist measure the "stickup" of the drill string. This is accomplished by measuring the assembled length of all drill rods and bits or samplers (the drill string) as they are lowered to the bottom of the hole, below some convenient reference point of the drill string; then to measure the height of this reference point above the ground surface. The difference of these measurements is the depth of the drill string (lower end of the bit or sampler) below the ground surface, which must then be compared with the depth of sampling required (installed depth of casing or depth of borehole drilled). If the length of drill string below grade is more than the drilled or casing depth, the borehole has been cleaned too deeply, and this deeper depth of sampling must be recorded on the log. If the length of drill string below grade is less than the drilled or casing depth, the difference represents the thickness of cuttings which remain in the borehole. In most cases, an inch or two of cuttings may be left in the borehole with little or no problem. However, if more than a few inches for cuttings are encountered, the borehole must be recleaned prior to attempting sampling.

## 5.5 MATERIALS OF CONSTRUCTION

The effects of monitoring well construction materials on specific chemical analytical parameters are described and/or referenced in FT-7.01. However, there are several materials used during drilling, particularly drilling fluids and lubricants, which must be used with care to avoid compromising the representativeness of soil and ground water samples.

The use of synthetic or organic polymer slurries is not permitted at any location where soil samples for chemical analysis are to be collected. These slurry materials could be used for installation of long term monitoring wells, but the early time data in time series collection of ground water data may then be suspect. If synthetic or organic polymer muds are proposed for use at a given site, a complete written justification including methods are procedures for their use must be provided by the site geologist and approved by the site manager. The specific slurry composition and the concentration of selected chemicals for each site must be known.

For many drilling operations, potable water is an adequate lubricant for drill stem and drilling tool connections. However, there are instances, such as drilling in tight clayey formations or in loose gravels, when threaded couplings must be lubricated to avoid binding. In these instances, to be determined in the field at the judgment of the site geologist and noted in the Site Logbook, and only after approval by the site manager, a vegetable oil or silicone based lubricant should be used. Petroleum based greases, etc. will not be permitted. Samples of lubricants used must be provided and analyzed for chemical parameters appropriate to the given site.

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## 7.0 ATTACHMENTS

Attachment A - Drilling Equipment Sizes

## ATTACHMENT A

## DRILLING EQUIPMENT SIZES

| Drilling Component | Designation or Hole Size (in) | O.D. (in) | I.D. (in) | Coupling I.D. (in) |
|---|---|---|---|---|
| Hollow-Stem Augers (Ref 7) | 6 1/4 | 5 | 2 1/4 | |
| | 6 3/4 | 5 3/4 | 2 3/4 | - |
| | 7 1/4 | 6 1/4 | 3 1/4 | - |
| | 13 1/4 | 12 | 6 | - |
| Thin Wall Tube Samplers (Ref 7) | - | 2 | 1 7/8 | - |
| | - | 2 1/2 | 2 3/8 | - |
| | - | 3 | 2 7/8 | - |
| | - | 3 1/2 | 3 3/8 | - |
| | - | 4 1/2 | 4 3/8 | - |
| | - | 5 | 4 3/4 | - |
| Drill Rods (Ref 7) | RW | 1 3/32 | 23/32 | 13/32 |
| | EW | 1 3/8 | 15/16 | 7/16 |
| | AW | 1 3/4 | 1 1/4 | 5/8 |
| | BW | 2 1/8 | 1 3/4 | 3/4 |
| | NW | 2 5/8 | 2 1/4 | 1 3/8 |
| | HW | 3 1/2 | 3 1/16 | 2 3/8 |
| | E | 1 5/16 | 7/8 | 7/16 |
| | A | 1 5/8 | 1 1/8 | 9/16 |
| | B | 1 7/8 | 1 1/4 | 5/8 |
| | N | 2 3/8 | 2 | 1 |
| | | | | Wall Thickness (in) |
| Driven External Coupled Extra Strong Steel* Casing (Ref 8) | 2 1/2 | 2.875 | 2.323 | 0.276 |
| | 3 | 3.5 | 2.9 | 0.300 |
| | 3 1/2 | 4.0 | 3.364 | 0.318 |
| | 4 | 4.5 | 3.826 | 0.337 |
| | 5 | 5.63 | 4.813 | 0.375 |
| | 6 | 6.625 | 5.761 | 0.432 |
| | 8 | 8.625 | 7.625 | 0.500 |
| | 10 | 10.750 | 9.750 | 0.500 |
| | 12 | 12.750 | 11.750 | 0.500 |

* Add twice the casing wall thickness to casing O.D. to obtain the approximate O.D. of the external pipe couplings.

## ATTACHMENT A

## DRILLING EQUIPMENT SIZES

| Drilling Component | Designation or Hole Size (in) | O.D. (in) | I.D (in) | Coupling I.D. (in) |
|---|---|---|---|---|
| Flush Coupled Casing (Ref 7) | RX | 1 7/16 | 1 3/16 | 1 3/16 |
| | EX | 1 13/16 | 1 5/8 | 1 1/2 |
| | AX | 2 1/4 | 2 | 1 29/32 |
| | BX | 2 7/8 | 2 9/16 | 2 3/8 |
| | NX | 3 1/2 | 3 3/16 | 3 |
| | HX | 4 1/2 | 4 1/8 | 3 15/16 |
| Flush Joint Casing (Ref 7) | RW | 1 7/16 | 1 3/16 | |
| | EW | 1 13/16 | 1 1/2 | |
| | AW | 2 1/4 | 1 29/32 | |
| | BW | 2 7/8 | 2 3/8 | |
| | NW | 3 1/2 | 3 | |
| | HW | 4 1/2 | 4 | |
| | PW | 5 1/2 | 5 | |
| | SW | 6 5/8 | 6 | |
| | UW | 7 5/8 | 7 | |
| | ZW | 8 5/8 | 8 | |
| Diamond Core Barrels (Ref 7) | EWM | 1 1/2 | 7/8 ** | |
| | AWM | 1 7/8 | 1 1/8 ** | |
| | BWM | 2 3/8 | 1 5/8 ** | |
| | NWM | 3 | 2 1/8 | |
| | HWG | 3 7/8 | 3 | |
| | 2 3/4 X 3 7/8 | 3 7/8 | 2 11/16 | |
| | 4 X 5 1/2 | 5 1/2 | 3 15/16 | |
| | 6 X 7 3/4 | 7 3/4 | 5 15/16 | |
| | AQ (wireline) | 1 57/64 | 1 1/16 ** | |
| | BQ (wireline) | 2 23/64 | 1 7/16 ** | |
| | NQ (wireline) | 2 63/64 | 1 7/8 | |
| | HQ (wireline) | 3 25/32 | 2 1/2 | |

** Because of the fragile nature of the core and the difficulty to identify rock details, use of small diameter core (1 3/8") is not recommended.

**NUS CORPORATION**

**ENVIRONMENTAL MANAGEMENT GROUP**

# STANDARD OPERATING PROCEDURES

| | | | |
|---|---|---|---|
| Number | GH-1.5 | Page | 1 of 26 |
| Effective Date | 05/04/90 | Revision | 2 |
| Applicability | EMG | | |
| Prepared | Earth Sciences | | |
| Approved | D. Senovich | | |

Subject: BOREHOLE AND SAMPLE LOGGING

## TABLE OF CONTENTS

SECTION

## 1.0 PURPOSE

The purpose of this document is to establish standard procedures and technical guidance on borehole and sample logging.

## 2.0 SCOPE

These procedures provide descriptions of the standard techniques for borehole and sample logging. These techniques shall be used for each boring logged to provide consistent descriptions of subsurface lithology. While experience is the only method to develop confidence and accuracy in the description of soil and rock, the field geologist/engineer can do a good job of classification by careful, thoughtful observation and by being consistent throughout the classification procedure.

## 3.0 GLOSSARY

None.

## 4.0 RESPONSIBILITIES

Site Geologist - Responsible for supervising all boring activities and assuring that each borehole is completely logged. If more than one rig is being used onsite the Site Geologist must make sure that each field geologist is properly trained in logging procedures. A brief review or training session may be necessary prior to the start up of the field program and/or upon completion of the first boring.

## 5.0 PROCEDURES

The classification of soil and rocks is one of the most important jobs of the field geologist/engineer. To maintain a consistent flow of information, it is imperative that the field geologist/engineer understand and accurately use the field classification system described in this SOP. This identification is based on visual examination and manual tests.

## 5.1 MATERIALS NEEDED

When logging soil and rock samples, the geologist or engineer may be equipped with the following:

- Rock hammer
- Knife
- Camera
- Dilute HCl
- Ruler (marked in tenths and hundreths of feet)
- Hand Lens

## 5.2 CLASSIFICATION OF SOILS

All data shall be written directly on the boring log (Exhibit 4-1) or in a field notebook if more space is needed. Details on filling out the boring log are discussed in Section 5.5.

### 5.2.1 USCS Classification

Soils are to be classified according to the Unified Soil Classification System (USCS). This method of classification is detailed in Exhibit 4-2. This method of classification identifies soil types on the basis of grain size and cohesiveness.

Fine-grained soils, or fines, are smaller than the No. 200 sieve and are of two types: silt (M) and clay (C). Some classification systems define size ranges for these soil particles, but for field classification purposes, they are identified by their respective behaviors. Organic material (O) is a common component of soil but has no size range; it is recognized by its composition. The careful study of the USCS will aid in developing the competence and consistency necessary for the classification of soils.

Coarse grained soils shall be divided into rock fragments, sand, or gravel. The terms and sand and gravel not only refer to the size of the soil particles but also to their depositional history. To insure accuracy in description, the term rock fragments shall be used to indicate angular granular materials resulting from the breakup of rock. The sharp edges typically observed indicate little or no transport from their source area, and therefore the term provides additional information in reconstructing the depositional environment of the soils encountered. When the term "rock fragments" is used it shall be followed by a size designation such as (1/4 inche-1/2 inche)" or "coarse-sand size" either immediately after the entry or in the remarks column. The USCS classification would not be affected by this variation in terms.

### 5.2.2 Color

Soil colors shall be described utilizing a single color descriptor preceded, when necessary, by a modifier to denote variations in shade or color mixtures. A soil could therefore be referred to as "gray" or "light gray" or "blue-gray." Since color can be utilized in correlating units between sampling locations, it is important for color descriptions to be consistent from one boring to another.

Colors must be described while the sample is still moist. Soil samples shall be broken or split vertically to describe colors. Samplers tend to smear the sample surface creating color variations between the sample interior and exterior.

The term "mottled" shall be used to indicate soils irregularly marked with spots of different colors. Mottling in soils usually indicates poor aeration and lack of good drainage.

Soil Color Charts shall not be used unless specified by the project manager.

### 5.2.3 Relative Density and Consistency

To classify the relative density and/or consistency of a soil, the geologist is to first identify the soil type. Granular soils contain predominantly sands and gravels. They are noncohesive (particles do not adhere well when compressed). Finer grained soils (silts and clays) are cohesive (particles will adhere together when compressed).

The density of noncohesive, granular soils is classified according to standard penetration resistances obtained from split barrel sampling performed according to the methods detailed in Standard Operating Procedures GH-1.3 and SA-1.2. Those designations are:

| Designation | Standard Penetration Resistance (Blows per Foot) |
|---|---|
| Very loose | 0 to 4 |
| Loose | 5 to 10 |
| Medium dense | 11 to 30 |
| Dense | 31 to 50 |
| Very dense | Over 50 |

Standard penetration resistance is the number of blows required to drive a split-barrel sampler with a 2-inch outside diameter 12 inches into the material using a 140 pound hammer falling freely through 30 inches. The sampler is driven through an 18-inch sample interval, and the number of blows is recorded for each 6-inch increment. The density designation of granular soils is obtained by adding the number of blows required to penetrate the last 12 inches of each sample interval. It is important to note that if gravel or rock fragments are broken by the sampler or if rock fragments are lodged in the tip, the resulting blow count will be erroneously high, reflecting a higher density than actually exists. This shall be noted on the log and referenced to the sample number. Granular soils are given the USCS classifications GW, GP, GM, SW, SP, SM, GC, and SC (see Exhibit 4-2).

The consistency of cohesive soils is determined by performing field tests and identifying the consistency as shown in Exhibit 4-3. Cohesive soils are given the USCS classifications ML, MH, CL, CH, OL, or OH (see Exhibit 4-2).

The consistency of cohesive soils is determined either by blow counts, a pocket penetrometer (values listed in the table as Unconfined Compressive Strength) or by hand by determining the resistance to penetration by the thumb. The pocket penetrometer and thumb determination methods are conducted on a selected sample of the soil, preferably the lowest 0.5 foot of the sample in the split-barrel sampler. The sample shall be broken in half and the thumb or penetrometer pushed into the end of the sample to determine the consistency. Do not determine consistency by attempting to penetrate a rock fragment. If the sample is decomposed rock, it is classified as a soft decomposed rock rather than a hard soil. Consistency shall not be determined solely by blow counts. One of the other methods shall be used in conjunction with it. The designations used to describe the consistency of cohesive soils are as follows:

| Consistency | Unc. Compressive Str. Tons/Square Foot | Standard Penetration Resistance (Blows per Foot) | Field Identification Methods |
|---|---|---|---|
| Very soft | Less than 0.25 | 0 to 2 | Easily penetrated several inches by fist |
| Soft | 0.25 to 0.50 | 2 to 4 | Easily penetrated several inches by thumb |
| Medium stiff | 0.50 to 1.0 | 4 to 8 | Can be penetrated several inches by thumb |
| Very stiff | 1.0 to 2.0 | 8 to 15 | Readily indented by thumb |
| Hard | 2.0 to 4.0 | 15 to 30 | Readily indented by thumbnail |
| Hard | More than 4.0 | Over 30 | Indented with difficulty by thumbnail |

### 5.2.4 Weight Percentages

In nature, soils are comprised of particles of varying size and shape, and are combinations of the various grain types. The following terms are useful in the description of soil:

| Terms of Identifying Proportion of the Component | Defining Range of Percentages by Weight |
|---|---|
| trace | 0 - 10 percent |
| some | 11 - 30 percent |
| and or adjective form of the soil type (e.g., "sandy") | 31 - 50 percent |

Examples:

- Silty fine sand: 50 to 69 percent fine sand, 31 to 50 percent silt.
- Medium to coarse sand, some silt: 70 to 80 percent medium to coarse sand, 11 to 30 percent silt.
- Fine sandy silt, trace clay: 50 to 68 percent silt, 31 to 49 percent fine sand, 1 to 10 percent clay.
- Clayey silt, some coarse sand: 70 to 89 percent clayey silt, 11 to 30 percent coarse sand.

### 5.2.5 Moisture

Moisture content is estimated in the field according to four categories: dry, moist, wet, and saturated. In dry soil, there appears to be little or no water. Saturated samples obviously have all the water they can hold. Moist and wet classifications are somewhat subjective and often are determined by the individual's judgment. A suggested parameter for this would be calling a soil wet if rolling it in the hand or on a porous surface liberates water, i.e., dirties or muddies the surface. Whatever method is adopted for describing moisture, it is important that the method used by an individual remains consistent throughout an entire drilling job.

Laboratory tests for water content shall be performed if the natural water content is important.

### 5.2.6 Stratification

Stratification can only be determined after the sample barrel is opened. The stratification or bedding thickness for soil and rock is depending on grain size and composition. The classification to be used for stratification description is shown in Exhibit 4-4.

### 5.2.7 Texture/Fabric/Bedding

The texture/fabric/bedding of the soil shall be described. Texture is described as the relative angularity of the particles: rounded, subrounded, subangular, and angular. Fabric shall be noted as to whether the particles are flat or bulky and whether there is a particular relation between particles (i.e., all the flat particles are parallel or there is some cementation). The bedding or structure shall also be noted (e.g., stratified, lensed, nonstratified, heterogeneous varved).

### 5.2.8 Summary of Soil Classification

In summary, soils shall be classified in a similar manner by each geologist/engineer at a project site. The hierarchy of classification is as follows:

- Density and/or consistency
- Color
- Plasticity (Optional)
- Soil types
- Moisture content
- Stratification
- Texture, fabric, bedding
- Other distinguishing features

## 5.3 CLASSIFICATION OF ROCKS

Rocks are grouped into three main divisions, including sedimentary, igneous and metamorphic rocks. Sedimentary rocks are by far the predominant type exposed at the earth's surface. The following basic names are applied to the types of rocks found in sedimentary sequences:

- Sandstone - Made up predominantly of granular materials ranging between 1/16 to 2 mm in diameter.

- Siltstone - Made up of granular materials less than 1/16 to 1/256 mm in diameter. ractures irregularly. Medium thick to thick bedded.

- Claystone - Vary fine grained rock made up of clay and silt-size materials. Fractures irregularly. Very smooth to touch. Generally has irregularly spaced pitting on surface of drilled cores.

- Shale - A fissile very fine grained rock. Fractures along bedding planes.

- Limestone - Rock made up predominantly of calcite ($CaCO_3$). Effervesces strongly upon the application of dilute hydrochloric acid.

- Coal - Rock consisting mainly of organic remains.

- Others - Numerous other sedimentary rock types are present in lesser amounts in the stratigraphic record. The local abundance of any of these rock types is dependent upon the depositional history of the area. These include conglomerate, halite, gypsum, dolomite, anhydrite, lignite, etc. are some of the rock types found in lesser amounts.

In classifying a sedimentary rock the following hierarchy shall be noted:

- Rock type
- Color
- Bedding thickness
- Hardness
- Fracturing
- Weathering
- Other characteristics

### 5.3.1 Rock Type

As described above, there are numerous names of sedimentary rocks. In most cases a rock will be a combination of several grain types, therefore, a modifier such as a sandy siltstone, or a silty sandstone can be used. The modifier indicates that a significant portion of the rock type is composed of the modifier. Other modifiers can include carbonaceous, calcareous, siliceous, etc.

Grain size is the basis for the classification of clastic sedimentary rocks. Exhibit 4-5 is the Udden-Wentworth classification that will be assigned to sedimentary rocks. The individual boundaries are slightly different than the USCS subdivision for soil classification. For field determination of grain sizes, a scale can be used for the coarse grained rocks. For example, the division between siltstone and claystone may not be measurable in the field. The boundary shall be determined by use of a hand lens. If the grains cannot be seen with the naked eye but are distinguishable with a handlens, the rock is a siltstone. If the grains are not distinguishable with a handlens, the rock is a claystone.

### 5.3.2 Color

The color of a rock can be determined in a similar manner as for soil samples. Rock core samples shall be classified while wet, when possible, and air cored samples shall be scraped clean of cuttings prior to color classifications.

Rock Color Charts shall not be used unless specified by the project manager.

### 5.3.3 Bedding Thickness

The bedding thickness designations applied to soil classification will also be used for rock classification.

### 5.3.4 Hardness

The hardness of a rock is a function of the compaction, cementation, and mineralogical composition of the rock. A relative scale for sedimentary rock hardness is as follows:

- Soft - Weathered, considerable erosion of core, easily gouged by screwdriver, scratched by fingernail. Soft rock crushes or deforms under pressure of a pressed hammer. This term is always used for the hardness of the saprolite (decomposed rock which occupies the zone between the lowest soil horizon and firm bedrock).
- Medium soft - Slight erosion of core, slightly gouged by screwdriver, or breaks with crumbly edges from single hammer blow.
- Medium hard - No core erosion, easily scratched by screwdriver, or breaks with sharp edges from single hammer blow.
- Hard - Requires several hammer blows to break and has sharp conchoidal breaks. Cannot be scratched with screwdriver.

Note the difference in usage here of the works "scratch" and "gouge." A scratch shall be considered a slight depression in the rock (do not mistake the scraping off of rock flour from drilling with a scratch in the rock itself), while a gouge is much deeper.

### 5.3.5 Fracturing

The degree of fracturing or brokeness of a rock is described by measuring the fractures or joint spacing. After eliminating drilling breaks, the average spacing is calculated and the fracturing is described by the following terms:

- Very broken (V. BR.) - Less than 2 in. spacing between fractures
- Broken (BR.) - 2 in. to 1 ft. spacing between fractures
- Blocky (BL.) - 1 to 3 ft. spacing between fractures
- Massive (M.) - 3 to 10 ft. spacing between fractures

The structural integrity of the rock can be approximated by calculating the Rock Quality Designation (RQD) of cores recovered. The RQD is determined by adding the total lengths of all pieces exceeding 4 inches and dividing by the total length of the coring run, to obtain a percentage.

Method of Calculating RQD
(After Deere, 1964)

$$\text{RQD}\ \% = r/l \times 100$$

r = Total length of all pieces of the lithologic unit being measured, which are greater than 4 inches length, and have resulted from natural breaks. Natural breaks include slickensides, joints, compaction slicks, bedding plane partings (not caused by drilling), friable zones, etc.

l = Total length of the coring run.

### 5.3.6 Weathering

The degree of weathering is a significant parameter that is important in determining weathering profiles and is also useful in engineering designs. The following terms can be applied to distinguish the degree of weathering:

- Fresh - Rock shows little or no weathering effect. Fractures or joints have little or no staining and rock has a bright appearance.
- Slight - Rock has some staining which may penetrate several centimeters into the rock. Clay filling of joints may occur. Feldspar grains may show some alteration.
- Moderate - Most of the rock, with exception of quartz grains, is stained. Rock is weakened due to weathering and can be easily broken with hammer.
- Severe - All rock including quartz grains is stained. Some of the rock is weathered to the extent of becoming a soil. Rock is very weak.

### 5.3.7 Other Characteristics

The following items shall be included in the rock description:

- *Description of contact between two rock units. These can be sharp or gradational.*
- Stratification (parallel, cross stratified)
- Description of any filled cavities or vugs.
- Cementation (calcoreous, siliceous, hematitic)

- Description of any joints or open fractures.
- Observation of the presence of fossils.
- Notation of joints with depth, approximate angle to horizontal, any mineral filling or coating, and degree of weathering.

All information shown on the boring logs shall be neat to the point where it can be reproduced on a copy machine for report presentation. The data shall be kept current to provide control of the drilling program and to indicate various areas requiring special consideration and sampling.

### 5.3.8. Additional Terms Used in the Description of Rock

The following terms are used to further identify rocks:

- Seam - Thin (12 inch or less), probably continuous layer.

- Some - Indicates significant (15 to 40 percent) amounts of the accessory material. For example, rock composed of seams of sandstone (70 percent) and shale (30 percent) would be "sandstone -- some shale seams."

- Few - Indicates insignificant (0 to 15 percent) amounts of the accessory material. For example, rock composed of seam of sandstone (90 percent) and shale (10 percent) would be "sandstone -- few shale seams."

- Interbedded - Used to indicate thin or very thin alternating seams of material occurring in approximately equal amounts. For example, rock composed of thin alternating seams of sandstone (50 percent) and shale (50 percent) would be "interbedded sandstone and shale."

- Interlayered - Used to indicate thick alternating seams of material occurring in approximately equal amounts.

The preceding sections describe the classification of sedimentary rocks. The following are some basic names that are applied to igneous rocks:

- Basalt - A fine-grained extrusive rock composed primarily of calcic plagioclase and pyroxene.

- Rhyolite - A fine-grained volcanic rock containing abundant quartz and orthoclase. The fine-grained equivalent of a granite.

- Granite - A coarse-grained plutonic rock consisting essentially of alkali feldspar and quartz.

- Diorite - A coarse-grained plutonic rock consisting essentially of sodic plagioclase and hornblende.

- Gabbro - A coarse-grained plutonic rock consisting of calcic plagioclase and clinopyroxene. Loosely used for any coarse grained dark igneous rock.

The following are some basic names that are applied to metamorphic rocks:

- Slate - A very fine-grained foliated rock possessing a well developed slaty cleavage. Contains predominantly chlorite, mica, quartz, and sericite.
- Phyllite - A fine-grained foliated rock that splits into thin flaky sheets with a silky sheen on cleavage surface.
- Schist - A medium to coarse-grained foliated rock with subparallel arrangement of the micaceous minerals which dominate its composition.
- Gneiss - A coarse-grained foliated rock with bands rich in granular and platy minerals.
- Quartzite - A fine to coarse-grained nonfoliated rock breaking across grains, consisting essentially of quartz sand with silica cement.

### 5.4 ABBREVIATIONS

Abbreviations may be used in the description of a rock or soil. However, they shall be kept at a minimum. Following are some of the abbreviations that may be used:

| | | | | | |
|---|---|---|---|---|---|
| C | - Coarse | Lt | - Light | Yl | - Yellow |
| Med | - Medium | BR | - Broken | Or | - Orange |
| F | - Fine | BL | - Blocky | SS | - Sandstone |
| V | - Very | M | - Massive | Sh | - Shale |
| Sl | - Slight | Br | - Brown | LS | - Limestone |
| Occ | - Occasional | Bl | - Black | Fgr | - Fine grained |
| Tr | - Trace | | | | |

### 5.5 BORING LOGS AND DOCUMENTATION

This section describes in more detail the procedures to be used in completing boring logs in the field. Information obtained from the preceeding sections shall be used to complete the logs. A sample boring log has been provided as Exhibit 4-6. The field geologist/engineer shall use this example as a guide in completing each borings log. Each boring log shall be fully described by the geologist/engineer as the boring is being drilled. Every sheet contains space for 25 feet of log. Information regarding classification details is provided on the back of the boring log, for field use.

#### 5.5.1 Soil Classification

- Identify site name, boring number, job number, etc. Elevations and water level data to be entered when surveyed data is available.
- Enter sample number (from SPT) under appropriate column. Enter depth sample was taken from (1 block = 1 foot). Fractional footages, i.e., change of lithology a 13.7 feet, shall be lined off at the proportional location between the 13 and 14 foot marks. Enter blow counts (Standard Penetration Resistance) diagonally (as shown). Standard penetration resistance is covered in Section 5.2.3.

- Determine sample recovery/sample length as shown. Measure the total length of sample recovered from the split spoon sampler, including material in the drive shoe. Do not include cuttings or wash material that may be in the upper portion of the sample tube.

- Indicate any change in lithology by drawing a line at the appropriate depth. For example, if clayey silt was encountered from 0 to 5.5 feet and shale from 5.5 to 6.0 feet, a line shall be drawn at this increment. This information is helpful in the construction of cross-sections. As an alternative, symbols may be used to identify each change in lithology.

- The density of granular soils is obtained by adding the number of blows for the last two increments. Refer to Density of Granular Soils Chart of back of log sheet. For consistency of cohesive soils refer also to the back of log sheet - Consistency of Cohesive Soils. Enter this information under the appropriate column. Refer to Section 5.2.3.

- Enter color of the material in the appropriate column.

- Describe material using the USCS. Limit this column for sample description only. The predominate material is described last. If the primary soil is silt but has fines (clay) - use clayey silt. Limit soil descriptors to the following:

    - Trace 0 - 10 percent
    - Some 11 - 30 percent
    - And 31 - 50 percent

- Also indicate under Material Classification if the material is fill or natural soils. Indicate roots, organic material, etc.

- Enter USCS symbol - use chart on back of boring log as a guide. If the soils fall into one of two basic groups, a borderline symbol may be used with the two symbols separated by a slash. For example ML/CL or SM/SP.

- The following information shall be entered under the Remarks Column and shall include, but is not limited by the following:

    - Moisture - estimate moisture content using the following terms - dry, moist, wet and saturated. These terms are determined by the individual. Whatever method is used to determine moisture, be consistent throughout the log.

    - Angularity - describe angularity of coarse grained particles using Angular, Subangular, Subrounded, Rounded. Refer to ASTM D 2488 or Earth Manual for criteria for these terms.

    - Particle shape - flat, elongated, or flat and elongated.

    - Maximum particle size or dimension.

    - Water level observations.

    - Reaction with HCl - none, weak or strong.

- Additional comments:
  - Indicate presence of mica, caving of hole, when water was encountered, difficulty in drilling, loss or gain of water.
  - Indicate odor and HNu or OVA reading if applicable.
  - *Indicate any change in lithology by drawing in line through the lithology change* column and indicate the depth. This will help later on when cross-sections are constructed.
  - At the bottom of the page indicate type of rig, drilling method, hammer size and drop and any other useful information (i.e., borehole size, casing set, changes in drilling method).
  - Vertical lines shall be drawn (as shown in Exhibit 4.6) in columns 5 to 8 from the bottom of each sample to the top of the next sample to indicate consistency of material from sample to sample, if the material is consistent. Horizontal lines shall be drawn if there is a change in lithology, then vertical lines drawn to that point.
  - Indicate screened interval of well, as needed, in the lithology column. Show top and bottom of screen. Other details of well construction are provided on the well construction forms.

### 5.5.2 Rock Classification

- Indicate depth at which coring began by drawing a line at the appropriate depth. Indicate core run depths by drawing coring run lines (as shown) under the first and fourth columns on the log sheet. Indicate RQD, core run number, RQD percent and core recovery under the appropriate columns.
- Indicate lithology change by drawing a line at the appropriate depth as explained in Section 5.5.1.
- Rock hardness is entered under designated column using terms as described on the back of the log or as explained earlier in this section.
- Enter color as determined while the core sample is wet; if the sample is cored by air, the core shall be scraped clean prior to describing color.
- Enter rock type based on sedimentary, igneous or metamorphic. For sedimentary rocks use terms as described in Section 5.3. Again, be consistent in classification. Use modifiers and additional terms as needed. For igneous and metamorphic rock types use terms as described in Sections 5.3.8.
- Enter brokeness of rock or degree of fractûring under the appropriate column using symbols VBR, BR, BL, or M as explained in Section 5.3.5 and as noted on the back of the Boring Log.

- The following information shall be entered under the remarks column. Items shall include but are not limited to the following:
  - Indicate depths of joints, fractures and breaks and also approximate to horizontal angle (such as high, low), i.e., 70° angle from horizontal, high angle.
  - Indicate calcareous zones, description of any cavities or vugs.
  - Indicate any loss or gain of drill water.
  - Indicate drop of drill tools or change in color of drill water.

- Remarks at the bottom of Boring Log shall include:
  - Type and size of core obtained.
  - Depth casing was set.
  - Type of Rig used.

- As a final check the boring log shall include the following:
  - Vertical lines shall be drawn as explained for soil classification to indicate consistency of bedrock material.
  - If applicable, indicate screened interval in the lithology column. Show top and bottom of screen. Other details of well construction are provided on the well construction forms.

### 5.5.3 Classification of Soil and Rock from Drill Cuttings

The previous sections describe procedures for classifying soil and rock samples when cores are obtained. However, some drilling methods (air/mud rotary) may require classification and borehole logging based on identifying drill cuttings removed from the borehole. Such cuttings provide only general information on subsurface lithology. Some procedures that shall be followed when logging cuttings are:

- Obtain cutting samples at approximately 5 foot intervals, sieve the cuttings (if mud rotary drilling) to obtain a cleaner sample, place the sample into a small sample bottle or "zip lock" bag for future reference, and label the jar or bag (i.e. hole number, depth, date etc.). Cuttings shall be closely examined to determine general lithology.

- Note any change in color of drilling fluid or cuttings, to estimate changes in lithology.

- Note drop or chattering of drilling tools or a change in the rate of drilling, to determine fracture locations or lithologic changes.

- Observe loss or gain of drilling fluids or air (if air rotary methods are used), to identify potential fracture zones.

- Record this and any other useful information onto the boring log as provided in Exhibit 4-1.

This logging provides a general description of subsurface lithology and adequate information can be obtained through careful observation of the drilling process. It is recommended that split barrel and rock core sampling methods be used at selected boring locations during the field investigation to provide detailed information to supplement the less detailed data generated through borings drilled using air/mud rotary methods.

## 5.6 REVIEW

Upon completion of the borings logs, copies shall be made and reviewed. Items to be reviewed include:

- Checking for consistency of all logs
- Checking for conformance to the guideline
- Checking to see that all information is entered in their respective columns and spaces

## 6.0 REFERENCES

Unified Soil Classification System (USCS)

ASTM D2488, 1985

Earth Manual, U.S. Department of the Interior, 1974

## 7.0 RECORDS

Originals of the boring logs shall be retained in the project files.

## EXHIBIT 4-1

***BORING LOG*** ***NUS CORPORATION***

**PROJECT:** .................................................. **BORING NO.:** ..............................
**PROJECT NO.:** .............................. **DATE:** .............................. **DRILLER:** ..............................
**ELEVATION:** .............................. **FIELD GEOLOGIST:** ..............................
**WATER LEVEL DATA :** ..................................................
**(Date, Time & Conditions)** ..................................................

| SAMPLE NO. & TYPE OR RQD | DEPTH (Ft.) OR RUN NO. | BLOWS/6" OR RQD (%) | SAMPLE RECOVERY /SAMPLE LENGTH | LITHOLOGY CHANGE (Depth/Ft.) OR SCREENED INTERVAL | MATERIAL DESCRIPTION | | | USCS OR BROKENNESS | REMARKS |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | SOIL DENSITY/ CONSISTENCY OR ROCK HARDNESS | COLOR | MATERIAL CLASSIFICATION | | |
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REMARKS ____________________________________________
____________________________________________
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BORING ________

PAGE____OF____

## EXHIBIT 4-2

## SOIL TERMS

### UNIFIED SOIL CLASSIFICATION (USCS)

**COARSE GRAINED SOILS**
More than half of material is LARGER than No. 200 sieve size

| | | FIELD IDENTIFICATION PROCEDURES (Excluding particles larger than 3" & basing fractions on estimated weights) | GROUP SYMBOL | TYPICAL NAMES |
|---|---|---|---|---|
| GRAVELS 50%(+) > 1/4" Ø | CLEAN GRAVELS (Low % fines) | Wide range in grain size and substantial amounts of all intermediate particle sizes. | GW | Well graded gravels, gravel-sand mixtures, little or no fines. |
| | | Predominantly one size or a range of sizes with some intermediate sizes missing. | GP | Poorly graded gravels, gravel-sand mixtures, little or no fines. |
| | GRAVELS W/FINES (High % fines) | Non plastic fines (for identification procedures see ML) | GM | Silty gravels, poorly graded gravel-sand-silt mixtures. |
| | | Plastic fines (for identification procedures see CL) | GC | Clayey gravels, poorly graded gravel-sand-clay mixtures. |
| SANDS 50%(+) < 1/4" Ø | CLEAN SANDS (Low % fines) | Wide range in grain size and substantial amounts of all intermediate particle sizes. | SW | Well graded sands, gravelly sands, little or no fines. |
| | | Predominantly one size or a range of sizes with some intermediate sizes missing. | SP | Poorly graded sands, gravelly sands, little or no fines. |
| | SANDS W/FINES (High % fines) | Non plastic fines (for identification procedures see ML) | SM | Silty sands, poorly graded sand-silt mixtures. |
| | | Plastic fines (for identification procedures see CL) | SC | Clayey sands, poorly graded sand-clay mixtures. |

**FINE GRAINED SOILS**
More than half of material is SMALLER than No. 200 sieve size

FIELD IDENTIFICATION PROCEDURES (Excluding particles larger than 3" & basing fractions on estimated weights)
Identification procedure on fraction smaller than No. 40 sieve size

| | DRY STRENGTH (Crushing Characteristics) | DILATANCY (Reaction to Shaking) | TOUGHNESS (Consistency Near Plastic Limit) | GROUP SYMBOL | TYPICAL NAMES |
|---|---|---|---|---|---|
| SILTS & CLAYS Liquid limit < 50 | None to slight | Quick to slow | None | ML | Inorganic silts and very fine sands, rock flour, silty or clayey fine sands with slight plasticity |
| | Medium to high | None to very slow | Medium | CL | Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays |
| | Slight to medium | Slow | Slight | OL | Organic silts and organic silt-clays of low plasticity |
| SILTS & CLAYS Liquid limit > 50 | Slight to medium | Slow to none | Slight to medium | MH | Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts |
| | High to very high | None | High | CH | Inorganic clays of high plasticity, fat clays |
| | Medium to high | None to very slow | Slight to medium | OH | Organic clays of medium to high plasticity |
| HIGHLY ORGANIC SOILS | Readily identified by color, odor, spongy feel and frequently by fibrous texture. | | | Pt | Peat and other organic soils |

Boundary classifications: Soils possessing characteristics of two groups are designated by combining group symbols. For example GW-GC, well graded gravel-sand mixture with clay binder.
All sieve sizes on this chart are U.S. standard.

**DENSITY OF GRANULAR SOILS**

| DESIGNATION | STANDARD PENETRATION RESISTANCE - BLOWS/FOOT |
|---|---|
| Very loose | 0-4 |
| Loose | 5-10 |
| Medium dense | 11-30 |
| Dense | 31-50 |
| Very dense | Over 50 |

**CONSISTENCY OF COHESIVE SOILS**

| CONSISTENCY | UNC. COMPRESSIVE STR. TONS/SQ. FT. | STANDARD PENETRATION RESISTANCE - BLOWS/FOOT | FIELD IDENTIFICATION METHODS |
|---|---|---|---|
| Very soft | Less than 0.25 | 0 to 2 | Easily penetrated several inches by fist |
| Soft | 0.25 to 0.50 | 2 to 4 | Easily penetrated several inches by thumb |
| Medium stiff | 0.50 to 1.0 | 4 to 8 | Can be penetrated several inches by thumb |
| Stiff | 1.0 to 2.0 | 8 to 15 | Readily indented by thumb |
| Very stiff | 2.0 to 4.0 | 15 to 30 | Readily indented by thumbnail |
| Hard | More than 4.0 | Over 30 | Indented with difficulty by thumbnail |

## ROCK TERMS

**ROCK HARDNESS (FROM CORE SAMPLES)**

| DESCRIPTIVE TERMS | SCREWDRIVER OR KNIFE EFFECTS | HAMMER EFFECTS |
|---|---|---|
| Soft | Easily gouged | Crushes when pressed with hammer |
| Medium soft | Can be gouged | Breaks (one blow) Crumbly edges |
| Medium hard | Can be scratched | Breaks (one blow) Sharp edges |
| Hard | Cannot be scratched | Breaks conchoidally (several blows) Sharp edges |

**ROCK BROKENNESS**

| DESCRIPTIVE TERMS | ABBREVIATION | SPACING |
|---|---|---|
| Very broken | (V. Br.) | 0 - 2" |
| Broken | (Br.) | 2" - 1' |
| Blocky | (Bl.) | 1' - 3' |
| Massive | (M.) | 3' - 10' |

**LEGEND**

SOIL SAMPLES - TYPES

S - 2" O.D. Split Barrel Sample
ST - 3" O.D. Undisturbed Sample
O - Other Samples, Specify in Remarks

ROCK SAMPLES - TYPES

X - NX (Conventional) Core (~2-1/8" O.D.)
Q - NQ (Wireline) Core (~1-7/8" O.D.)
Z - Other Core Sizes, Specify in Remarks

WATER LEVELS

12/18
▽ 12.6' Initial Level w/Date & Depth

12/18
▼ 12.6' Stabilized Level w/Date & Depth

## EXHIBIT 4-3

## CONSISTENCY FOR COHESIVE SOILS

| Consistency | (Blows per Foot) | Unconfined Compressive Strength (tons/square foot by pocket penetration | Field Identification |
|---|---|---|---|
| Very soft | 0 to 2 | Less than 0.25 | Easily penetrated several inches by fist |
| Soft | 2 to 4 | 0.25 to 0.50 | Easily penetrated several inches by thumb |
| Medium stiff | 4 to 8 | 0.50 to 1.0 | Can be penetrated several inches by thumb with moderate effort |
| Stiff | 8 to 15 | 1.0 to 2.0 | Readily indented by thumb but penetrated only with great effort |
| Very stiff | 15 to 30 | 2.0 to 4.0 | Readily indented by thumbnail |
| Hard | Over 30 | More than 4.0 | Indented by thumbnail |

## EXHIBIT 4-4

## BEDDING THICKNESS CLASSIFICATION

| Thickness (Metric) | Thickness (Approximate English Equivalent) | Classification |
|---|---|---|
| > 1.0 meter | > 3.3' | Massive |
| 30 cm - 1 meter | 1.0' - 3.3' | Thick Bedded |
| 10 cm - 30 cm | 4" - 1.0' | Medium Bedded |
| 3 cm - 10 cm | 1" - 4" | Thin Bedded |
| 1 cm - 3 cm | 2/5" - 1" | Very Thin Bedded |
| 3 mm - 1 cm | 1/8" - 2/5" | Laminated |
| 1 mm - 3 mm | 1/32" - 1/8" | Thinly Laminated |
| <1 mm | < 1/32" | Micro Laminated |

(Weir, 1973 and Ingram, 1954)

## EXHIBIT 4-5

## GRAIN SIZE CLASSIFICATION FOR ROCKS

| Particle Name | Grain Size Diameter |
|---|---|
| Cobbles | > 64 mm |
| Pebbles | 4-64 mm |
| Granules | 2-4 mm |
| Very Coarse Sand | 1-2 mm |
| Coarse Sand | 0.5-1 mm |
| Medium Sand | 0.25-0.5 mm |
| Fine Sand | 0.125-0.25 mm |
| Very Fine Sand | 0.0625-0.125 mm |
| Silt | 0.0039-0.0625 mm |

After Wentworth, 1922

**BORING LOG** **NUS CORPORATION**

PROJECT: HEBELKA SITE BORING NO.: MW 3A
PROJECT NO.: 619 Y DATE: 9-21-87 DRILLER: B. GOLLIHUE
ELEVATION: 510.07 FIELD GEOLOGIST: SJ CONTI
WATER LEVEL DATA WL 26.35 - TPVC 10-16-87
(Date, Time & Conditions)

| SAMPLE NO. & TYPE / RQD | DEPTH (FT) / RUN NO. | BLOWS 6" OR RQD (%) | SAMPLE RECOVERY / SAMPLE LENGTH | LITHOLOGY CHANGE (DEPTH/FT) OR SCREEN INT | SOIL DENSITY / CONSISTENCY OR ROCK HARDNESS | COLOR | MATERIAL CLASSIFICATION | USCS / ROCK | REMARKS |
|---|---|---|---|---|---|---|---|---|---|
| S-1 | 0.0 | 3<br>6 | 1.5/1.5 | | STIFF | BRN | CLAYEY SILT - TR SHALE | ML | 0-6" TOPSOIL<br>MOIST 0PPM |
| | 1.5 | 6 | | | | | FRAG - TR ORG. | | RESIDUAL SOIL. |
| | 5.0 | | | | | | | | |
| S-2 | 6.0 | 11<br>100/.5 | 0.5/1.0 | 5.5<br>6.0 | M.SOFT | GRAY BRN | DEC SHALE AND SILT | VBR | DAMP 0PPM |
| | | | | | TO | | | | REFUSAL @ 6'<br>5.5 TOP OF DEC |
| | | | | | M.HARD | | | | ROCK |
| | | | | | | | | | AUGERED TO 15'.<br>W/SOLID STEM AUG. |
| | | | | | | | | | CUTTING MOIST @ 8'<br>WATER @ 11' ± |
| | | | | | | | | | WL @ 12:10 PM WAS<br>≈ 9' FROM G.S. |
| | | | | | | | | | SET 4" PVC CAS. @<br>15.0' |
| 9-21 | 15.0 | | | | | | | | |
| 9-22 | | | | | M.HARD | BRN GRAY | SILTY SHALE - FEW | VBR | SEVERAL 0 PPM |
| | | | | | | | QUARTZ PCS | | Fe STAINED JOINTS \ ON CORE |
| | | | | | | | | | THRUOUT RUN.<br>JOINTS AND BREAKS |
| | | | | | | | | | ARE HORIZ TO LO ∠.<br>W/VUGS ON LOWER |
| 0.2/10.0 | ① | 0%/10 | 7.9/10.0 | | | | | | PORTION 23 TO 25 OF CORE |
| | 25.0 | | | | | | | | |

REMARKS ACKER AD II RIG - SOLID STEM AUGERS USED TO ADVANCE BORINGS - 140 LB WT & 30" DROP - TO TAKE 2" Φ SP. SPOON SAMPLES - SET UP OVER HOLE @ 11:10 AM. WILL SAMPLE THIS HOLE - SET 4" CASING THEN DO SHALLOW WELL. STARTED TO CORE 9-22-87 USING THE WIRE-LINE CORING METHOD.

BORING MW 3A

PAGE 1 OF 3

* See Legend on Back

| Subject | Number | Page |
|---|---|---|
| BOREHOLE AND SAMPLE LOGGING | GH-1.5 | 21 of 26 |
| | Revision 2 | Effective Date 05/04/90 |

**BORING LOG** **NUS CORPORATION**

PROJECT: HEBELKA SITE BORING NO.: MW 3A
PROJECT NO.: 619Y DATE: 9-22-87 DRILLER: B. GOLLHUE
ELEVATION: FIELD GEOLOGIST: SJ. CONTI
WATER LEVEL DATA:
(Date, Time & Conditions)

| | SAMPLE NO. & TYPE OR RQD | DEPTH (FT.) OR RUN | BLOWS 6" OR RQD (%) | SAMPLE RECOVERY / SAMPLE LENGTH | LITHOLOGY CHANGE (DEPTH/FT.) | SOIL DENSITY/CONSISTENCY OR ROCK HARDNESS | COLOR | MATERIAL CLASSIFICATION | USCS | REMARKS |
|---|---|---|---|---|---|---|---|---|---|---|
| 9-22 | | 25.0 | | | | M.HARD | GRAY | SILTY SHALE | VBR | SHALE IS VBR W/ HORIZ TO LO ∠ JNTS |
| | | | | | | | | (SILTSTONE) | | ≈26 TO 27 2- VERT |
| | | | | | | | | -FEW QUARTZ | | JOINTS. IRON STAINS ON JNTS |
| | | | | | | | | SEAMS | | ROCK BECOMES AND BREAKS MORE LIKE |
| | | | | | | | | | | A SILTSTONE WITH DEPTH. |
| | 0/10.0 | ② | 0%/0 | 8.7/10.0 | | | | | | |
| | | | | | | | | | BR | ≈32 TO 33 FEW QUARTZ PIECES W/ |
| | | | | | | | | | VBR | VUGS. SL. MICACEOUS |
| | | | | | | | | | | VF QUARTZ GRAINS IN MATRIX - 30X MAG. |
| | | 35.0 | | | | | | | | ≈34 TO 35 - 2 VERT JOINTS |
| | | | | | | M.HARD | GRAY | SILTY SHALE (SILTSTONE) | VBR | 35.0-35.5 QUARTZ PIECES |
| | | | | | | | | -FEW QUARTZ | BR | |
| | | | | | | | | SEAMS | VBR | BECOMES SL. CALCAR. @ 37± THIN CALCITE |
| | | | | | | | | | | LAMINATIONS. WATER STAINED JNTS |
| | | | | | | | | | BR | THRUOUT RUN MORE SO 35-37± |
| | 1.9/10.0 | ③ | 19%/0 | 9.3/10.0 | | | | | VBR | 39.5 → 42.0 |
| | | | | | | | | | | 42.7→43.0 HI ∠ JNT |
| | | | | | | | | | BR | 42.4→42.7 VERT JNT |
| | | | | | | | | | | |
| | | 45.0 | | | | | | | VBR | |
| | | | | | | | | | | 45.3→45.8 VERT JNT. & VBR |
| | | | | | | | | | | 47.5 VERT JOINT |
| | | | | | | | | | BR | 48. HI ∠ JOINT |
| | | | | | | | | | | SLIGHTLY CALCAREOUS MORE CALCITE |
| | | | | | | | | | | PRESENT |

REMARKS

BORING MW 3A

PAGE 2 OF 3

* See Legend on Back

**BORING LOG** **NUS CORPORATION**

PROJECT: HEBELKA SITE
BORING NO.: MW 3A
PROJECT NO.: 619 Y
DATE: 9-22-87
DRILLER: B. GOLLIHUE
ELEVATION:
FIELD GEOLOGIST: SJ CONTI
WATER LEVEL DATA
(Date, Time & Conditions)

| SAMPLE NO. & TYPE | DEPTH (FT.) | BLOWS 6" OR RQD (%) | SAMPLE RECOVERY SAMPLE LENGTH | LITHOLOGY CHANGE (Depth Ft.) | MATERIAL DESCRIPTION* SOIL DENSITY CONSISTENCY OR ROCK HARDNESS | COLOR | MATERIAL CLASSIFICATION | USCS | REMARKS |
|---|---|---|---|---|---|---|---|---|---|
| 1.9/10.0 | ④ | 19% | 10.0/10.0 | | M.HARD | GRAY | SILTY SHALE (SILTSTONE) | VBR | 50.5 → 51.0 VBR |
| | | | | | | | SL. CALCAREOUS | BR | 51.5 → 54.0 BR w/ SEV LO & JOINTS |
| | | | | | | | | | |
| | | | | | | | | | |
| | 55.0 | | | | | | | | |
| | | | | | | | | VBR | POOR RECOVERY |
| | | | | | | | | | w/ SOFT ZONES. |
| | | | | | | | | | |
| | | | | | | | | | |
| 0/10 | ⑤ | 0% | 1.8/10.0 | | | | | | |
| | | | | | | | | | |
| | | | | | | | | | |
| | | | | | | | | | |
| | | | | | | | | | |
| | 65.0 | | | | | | | | |
| | | | | 66 | | | | | |
| | | | | | | | | | |
| | | | | | | | | | 68.0- DRILLER NOTED SOFT AREA - LOSS OF |
| | | | | | | | | | 1/3 OF WATER - CHANGE IN COLOR OF DRILL |
| 0/0 | ⑥ | 0% | 1.3/10.0 | | | | | | WATER TO YELLOW BROWN) |
| | | | | | | | | | POOR RECOVERY |
| | | | | | | | | | FEW CALCAREOUS |
| | | | | | | | | | ZONES. |
| | | | | | | | | | |
| | 75.0 | | | 76 | | | | | |

REMARKS AT 75' @ 1:45 PM - PULLING TOOLS - TO REAM HOLE. AT 1:50 PM. CORED HOLE TO 75' REAMED TWICE DUE TO RUNNING SAND (FRACTURE) AT ≈ 68. REAMED 2ND TIME TO 81'. SET WELL 66'-76'.

BORING MW 3A
PAGE 3 OF 3

* See Legend on Back

## EXHIBIT 4-6

***BORING LOG*** ***NUS CORPORATION***

PROJECT: WESTLINE SITE BORING NO.: MW 013
PROJECT NO.: 473Y DATE: 7-7-87 DRILLER: B ERICSON
ELEVATION: 1462.37 FIELD GEOLOGIST: SJ CONTI PENN - DRILL
WATER LEVEL DATA (Date, Time & Conditions): 5.54' @ 9:50 AM 7-23-87 T-PVC ACKER AD-II

| SAMPLE NO. & TYPE OR RQD | DEPTH (Ft.) OR RUN NO. | BLOWS 6" OR RQD (%) | SAMPLE RECOVERY / SAMPLE LENGTH | LITHOLOGY CHANGE (Depth/Ft.) OR SCREENED INT. | SOIL DENSITY/CONSISTENCY OR ROCK HARDNESS | COLOR | MATERIAL CLASSIFICATION | USCS | REMARKS (HNU) (HEAD SP) |
|---|---|---|---|---|---|---|---|---|---|
| | 0.0 | 5<br>3 | 1.4/1.5 | | LOOSE | BLK BRN | CLAYEY SILT AND CINDER | ML | MOIST (0PPM) |
| S-1 | | 2 | | | | | TR. COAL FRAG. | | 3/4" Φ FRAG - NEAR OLD RR. LINE. |
| | | | | | | | TR-SS. FRAG | | |
| | | | | | | | (FILL) | | |
| | 5.0 | | | | | RED | | | |
| S-2 | | 1<br>1 | 1.3/1.5 | 6.0 | V. LOOSE | BRN TO | SANDY SILT - TR GRG TO | SM | MOIST TO WET (3PPM) |
| | 6.5 | 3 | | | | GRAY | SILTY SAND - TR GRAVEL | | GRAY SAND @ 6' ± MICACEOUS LOTS NOTICED |
| | | | | | | | | | DRILLER NOTE H2O 8-10' |
| | 10.0 | | | | | | | | |
| S-3 | | 11<br>23 | 1.2/1.5 | | DENSE | BRN | SILTY SAND AND S.S. | GM | WET (0PPM) |
| | 11.5 | 27 | | | | | FRAGS. (GRAV.) | | 1" Φ SIZE MAX SIZE SUBANGULAR TO SUBROUNDED GRAVEL |
| | | | | | | | | | |
| | 15.0 | | | | | | | | |
| S-4 | | 7<br>47 | 1.0/1.5 | — | V. DENSE | BRN | SILTY FINE TO C. SAND | SM | WET (0PPM) |
| | 16.5 | 43 | | | | | AND GRAVEL | | 1" Φ SIZE MAX SIZE SUBANGULAR TO SUBROUNDED GRAVEL |
| | | | | | | | | | |
| | 20.0 | | | | | | | | |
| S-5 | 20.9 | 17<br>50/.4 | .4/.9 | | V. DENSE | ORANG BRN | SILTY SAND - SOME | GM | WET (0PPM) |
| | | | | | | | GRAVEL AND | | MOIST |
| | | | | | | | S.S FRAGS | | BECOMES MORE LIKE SANDY SILT AT BOTM OF SAMPLE |
| | | | | | | | | | |

REMARKS START @ 1:15 PM - 7-7-87 USING 4¼" ID HOLLOW STEMS
S-4 @ 3:30 PM TO ADVANCE THE BORING USING
S-5 @ 4:30 PM ACKER DRILL - MOUNTED ON
FORD 8000 TRUCK
SAMPLES TAKEN
USING 140 lb WT AND 30 INCH DROP.

BORING MW 013
PAGE 1 OF 4

**BORING LOG** **NUS CORPORATION**

PROJECT: WESTLINE SITE BORING NO.: MW013
PROJECT NO.: 473Y DATE: 7-7-87 DRILLER: S. ERICSON
ELEVATION: FIELD GEOLOGIST: S.A. CONTI
WATER LEVEL DATA:
(Date, Time & Conditions)

| | SAMPLE NO. & TYPE OR RQD | DEPTH (Ft.) OR RUN NO. | BLOWS 6" OR RQD (%) | SAMPLE RECOVERY / SAMPLE LENGTH | LITHOLOGY CHANGE (Depth/Ft.) OR SCREEN INT. | MATERIAL DESCRIPTION: SOIL DENSITY/CONSISTENCY OR ROCK HARDNESS | COLOR | MATERIAL CLASSIFICATION | USCS | REMARKS (HNU) |
|---|---|---|---|---|---|---|---|---|---|---|
| | S-6 | 25.0 | 6<br>17 | 1.1/1.5 | | DENSE | OLIVE BLUE | SILTY SAND - SOME | GM | WET 0PPM |
| | | 26.5 | 30 | | | | GRAY | GRAVEL - TR CLAY | | C.S. IS FRIABLE FIRST CHANGE IN |
| | | | | | | | | TR. SS. FRAG. | | COLOR. NOT ENOUGH CLAY TO BE CONFINING |
| | | | | | | | | | | NOTES MAY SET ZONE 2 |
| 7/7 | | 30.0 | | | | | MOTTLED | | | CASING @ 28' |
| 7/8 | S-7 | | 17<br>27 | 1.4/1.5 | | V.DENSE | BRN BLUE | SILTY SAND - SOME GRAVEL | GM/ | MOIST - WET (0PPM) |
| | | 31.5 | 36 | | | | GRAY | TR. SS. FRAG. | GM | CHANGE TO [illegible] BLUE |
| | | | | | | | | TR CLAY | | GRAY & FRIABLE. SATURATED, SPLIT |
| | | | | | | | | | | NOT MUCH CLAY - BUT MAY BE SEMI-CONFINING. |
| | | 35.0 | | | | | | | | |
| | S-8 | 35.9 | 30<br>50/.4 | 0.7/0.9 | | V.DENSE | BLUE GRAY | SILTY F. TO C. SAND - | SM/ | MOIST → WET (0PPM) |
| | | | | | | | | SOME GRAVEL | GM | V.SL. TR. CLAY - LESS |
| | | | | | | | | TR. SS. FRAG. | | THAN S-7 1" Ø FRAG. - MORE |
| | | | | | | | | | | GRAVEL, SAND THAN ABOVE. |
| | | 40.0 | | | | | BLUE | | | POSSIBLE 38 TO 48 SCREEN LOC. SQUEEZED |
| | S-9 | | 31<br>34 | 1.2/1.5 | | V.DENSE | BRN GRAY | SILTY SAND (FINE TO M.) | SM | HOLDS TOGETHER WHEN MOIST → WET (0PPM) |
| | | 41.5 | 24 | | | | | SOME GRAVEL - TR. | /GM | LITTLE MORE CLAY THAN |
| | | | | | | | | CLAY | | S-8 SUBANGULAR GRAVEL |
| | | | | | | | | | | VERY SLOW DRILLING 40-45 (RIG STALLS) |
| | | 45.0 | | | | | BLUE | | | LESS CLAY LAST 3" OF SAMPLE. |
| | S-10 | | 13<br>34 | 1.2/1.5 | | V.DENSE | BRN GRAY | SILTY SAND (FINE TO M.) | SM/ | MOIST → WET (0PPM) |
| | | 46.5 | 50 | | | | | SOME GRAVEL - TR | GM | 1" Ø SIZE - HOLDS TOGETHER WHEN SQUEEZED |
| | | | | | | | | CLAY | | BUT NOT COHESIVE CLASSIFICATION |
| | | | | | | | | | | [illegible] DRILLING TO 50' |
| | | | | | | | | | | |

REMARKS S-6 @ 4:40 PM
S-8 @ 8:36 AM 7-8-87
S-10 @ 10:40 AM ; S-11 @

BORING MW013
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**BORING LOG** **NUS CORPORATION**

PROJECT: WESTLINE SITE  BORING NO.: MW 013
PROJECT NO.: 473Y  DATE: 7-8-87  DRILLER: B. ERICSON
ELEVATION:  FIELD GEOLOGIST: SJ CONTI
WATER LEVEL DATA:
(Date, Time & Conditions)

| | SAMPLE NO. & TYPE OR RQD | DEPTH (Ft.) OR RUN NO. | BLOWS 6" OR RQD (%) | SAMPLE RECOVERY / SAMPLE LENGTH | LITHOLOGY CHANGE (Depth/Ft.) OR SCREEN INT. | SOIL DENSITY/CONSISTENCY OR ROCK HARDNESS | COLOR | MATERIAL CLASSIFICATION | USCS | REMARKS |
|---|---|---|---|---|---|---|---|---|---|---|
| | S-11 | 50.0 | 15<br>41 | 1.9/1.5 | | V.DENSE | MOTTD WHT | SILTY SAND- SOME GR. | GM/ | MOIST - (OPPM) |
| | | 51.5 | 50/3 | | | ↓ | GRN GRAY | TR CLAY | SM | MOTTLE W/ PCS OF BLACK COAL/LIGNITE. |
| | | | | | | ↓ | ↓ | ↓ | ↓ | MORE CLAY THAN ABOVE PORTIONS OF SAMPLE - |
| | | | | | | ↓ | ↓ | ↓ | ↓ | COHESIVE CLASSIF. |
| | | 55.0 | | | 55.0 | ↓ | ↓ | ↓ | ↓ | |
| | S-12 | | 11<br>15 | 1.4/1.5 | | V.STIFF | GRAY ORNG | SANDY CLAY / CLAYEY SAND | SC | MOIST → WET (OPPM) |
| | | 56.5 | 26 | | | TO STIFF | BRN | SOME GRAVEL | ↓ | NOTE COLOR CHANGE ALSO - MORE CLAY |
| | | | | | | ↓ | ↓ | ↓ | ↓ | THAN ANY SAMPLE-SUBROUNDED GRAINS |
| | | | | | | ↓ | ↓ | ↓ | ↓ | FIRST COHESIVE TYPE CLASSIF. |
| | | 60.0 | 40 | | | ↓ | ↓ | ↓ | ↓ | |
| | S-13 | 60.9 | 50/.4 | 0.7/0.9 | | V.DENSE | ORNG BRN | SANDY CLAY/ CLAYEY SAND - SOME | SC/ | MOIST → WET (OPPM) |
| | | | | | | ↓ | ↓ | GRAVEL | GW | NOT AS MUCH CLAY AS S-12 BUT VERY |
| | | | | | | ↓ | ↓ | ↓ | ↓ | COMPACT. SUBROUNDED GRAINS |
| | | | | | | ↓ | ↓ | ↓ | ↓ | SET CAS. @ 62'. |
| | | 65.0 | | | | ↓ | ↓ | ↓ | ↓ | |
| 7/13 | S-14 | 65.8 | 37<br>50/.3 | 0.8/0.8 | | V.DENSE | BRN ORNG | SILTY SAND- SOME GR. | SM/ | MOIST (OPPM) |
| | | | | | | ↓ | ↓ | AND ROCK FRAG- | GW | MORE CLAY TOWARDS |
| | | | | | 68.0 | ↓ | ↓ | TR. CLAY | ↓ | TOP OF SAMPLE MAX 3/4" Φ SIZE |
| | | | | | | ↓ | YELLOW BRN | ↓ | ↓ | COLOR CHANGE AT 68' MORE SAND PER |
| | | 70.0 | | | | ↓ | ↓ | ↓ | ↓ | DRILLER - BOTTOM OF SEMI CONF LAYER ? |
| 7/14 | S-15 | | 39<br>39 | 1.0/1.5 | | V.DENSE | YELLOW BRN | CLAYEY SAND (F. TO C.) SOME | SC/ | MOIST → WET (OPPM) |
| | | 71.5 | 41 | | | ↓ | ↓ | GRAVEL -TR | GC | 1" MAX GRAVEL. |
| | | | | | | ↓ | ↓ | ROCK FRAG. | ↓ | MORE GRAVEL @ 72' PER DRILLER |
| | | | | | | ↓ | ↓ | ↓ | ↓ | |
| | | | | | | ↓ | ↓ | ↓ | ↓ | |

REMARKS USING HOLLOW STEM TO ADVANCE BORING - WASHING OUT THRU AUGERS, WHEN NEEDED TO OBTAIN SAMPLE
S-12 @ 1:46 PM
S-13 → 3:32 PM - LOGGED IN BY 3:47 PM
SET 6" Φ STEEL CASING TO 62' - WILL DRILL BELOW CASING AFTER GROUT SETS UP. S-14 @ 3:00 PM 7-13-87
S-15 @ 7:57 AM 7-14-87

BORING MW 013
PAGE 3 OF 4

| | | |
|---|---|---|
| Subject<br>BOREHOLE AND SAMPLE LOGGING | Number<br>GH-1.5 | Page<br>26 of 26 |
| | Revision<br>2 | Effective Date<br>05/04/90 |

**BORING LOG** **NUS CORPORATION**

PROJECT: WESTLINE SITE BORING NO.: MW013
PROJECT NO.: 437Y DATE: 7-13-87 / 7-14-87 DRILLER: B. ERICSON
ELEVATION: FIELD GEOLOGIST: SJ. CONTI
WATER LEVEL DATA:
(Date, Time & Conditions)

| SAMPLE NO. & TYPE OR RQD | DEPTH (FT.) OR RUN NO. | BLOWS 6" OR RQD (%) | SAMPLE RECOVERY / SAMPLE LENGTH | LITHOLOGY CHANGE (Depth/Ft.) or SCR. INT. 75 | MATERIAL DESCRIPTION SOIL DENSITY/ CONSISTENCY OR ROCK HARDNESS | COLOR | MATERIAL CLASSIFICATION | USCS | REMARKS (HNU) |
|---|---|---|---|---|---|---|---|---|---|
| S-16 | 75.0 | 25<br>50/ | 0.9/1.0 | | V. DENSE | GRAY ORANG | FINE TO C. CLAYEY SAND - SOME | SC | WET (0PPM) |
| | 76.0 | .5 | | | | BRN | GRAVEL - TR | | NOT AS MUCH CLAY AS S-15 - BOTM OF |
| | | | | | | | ROCK FRAG (S.S.) | | SAMPLE BECOMES MORE SANDY |
| | | | | | | | | | MAX 1" Φ RC. |
| | 80.0 | | | | | | | | NO SAMPLE @ 80' - |
| | | | | | | | | | DECIDED TO GO TO 85'. |
| | | | | | | | | | |
| | | | | | | | | | |
| | | | | | | | | | |
| | 85.0 | 50/ | 0.4/0.4 | | V. DENSE | GRAY ORANG | SILTY F. TO C. SAND - SOME | SW | WET (0PPM) |
| S-17 | 85.4 | .4 | | 85 | | BRN | GRAVEL - TR | | SUBROUNDED GRAINS |
| | | | | | | | S.S. FRAG - TR | | V. SL. TR CLAY - WILL |
| | | | | | | | CLAY | | SET SCREEN ≈ 75' TO 85' IN THIS BORING. |
| | | | | | | | | | |
| | | | | | | | BOTM OF HOLE | | |
| | | | | | | | @ 85.0' | | |
| | | | | | | | | | |
| | | | | | | | | | |
| | | | | | | | | | |
| | | | | | | | | | |
| | | | | | | | | | |
| | | | | | | | | | |
| | | | | | | | | | |
| | | | | | | | | | |
| | | | | | | | | | |

REMARKS S-17 @ 2:20 PM 7-14-87 - METHOD BEHIND 6" CASING SPUN 4" Φ - 5⅞" OD CASING TO BOTM. USING WATER AS DRILLING FLUID

BORING MW 013
PAGE 4 OF 4

| | | |
|---|---|---|
| NUS CORPORATION<br>ENVIRONMENTAL MANAGEMENT GROUP | STANDARD OPERATING PROCEDURES | Number: GH-1.6<br>Page: 1 of 3<br>Effective Date: 05/04/90<br>Revision: 2<br>Applicability: EMG<br>Prepared: Earth Sciences |
| Subject | DECONTAMINATION OF DRILLING RIGS AND MONITORING WELL MATERIALS | Approved: D. Senovich |

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**SECTION**

| Subject | Number | Page |
|---|---|---|
| DECONTAMINATION OF DRILLING RIGS AND MONITORING WELL MATERIALS | GH-1.6 | 2 of 3 |
| | Revision 2 | Effective Date 05/04/90 |

## 1.0 PURPOSE

The purpose of this procedure is to provide reference information regarding the appropriate procedures to be followed when conducting decontamination activities of drilling equipment and monitoring well materials used during field investigations.

## 2.0 SCOPE

This procedure addresses only drilling equipment and monitoring well materials decontamination, and shall not be considered for use with chemical sampling and field analytical equipment decontamination.

## 3.0 GLOSSARY

None.

## 4.0 RESPONSIBILITIES

Field Operations Leader - Responsible for ensuring that project specific plans and the implementation of field investigations are in compliance with these procedures.

## 5.0 PROCEDURES

To insure that analytical chemical results are reflective of the actual concentrations present at sampling locations, various drilling equipment involved in field investigations must be properly decontaminated. This will minimize the potential for cross-contamination between sampling locations, and the transfer of contamination off site.

Prior to the initiation of a drilling program. all drilling equipment involved in field sampling activities shall be decontaminated by steam cleaning at a predetermined area. The steam cleaning procedure shall be performed using a high-pressure spray of heated potable water producing a pressurized stream of steam. This steam shall be sprayed directly onto all surfaces of the various equipment which might contact environmental sample. The decontamination procedure shall be performed until all equipment is free of all visible potential contamination (dirt, grease, oil, noticeable odors, etc.) In addition, this decontamination procedure shall be performed at the completion of each sampling and/or drilling location, including soil borings, installation of monitoring wells, test pits, etc. Such equipment shall include drilling rigs, backhoes, downhole tools, augers, well casings, and screens.

The steam cleaning area shall be designed to contain decontamination wastes and waste waters, and can be a lined excavated pit or a bermed concrete or asphalt pad. For the latter, a floor drain must be provided which is connected to a holding facility. A shallow above-surface tank may be used or a pumping system with discharge to a waste tank may be installed.

In certain cases, due to budget constraints, such an elaborate decontamination pad is not possible. In such cases, a plastic lined gravel bed pad with a collection system may serve as an adequate decontamination area. The location of the steam cleaning area shall be on site in order to minimize potential impacts at certain sites.

Guidance to be used when decontaminating equipment shall include:

- As a general rule, any part of the drilling rig which extends over the borehole, shall be steam cleaned.
- All drilling rods, augers, and any other equipment which will be introduced to the hole shall be steam cleaned.
- The drilling rig, all rods and augers, and any other potentially contaminated equipment shall be decontaminated between each well location to prevent cross contamination of potential hazardous substances.

Rinsate samples of well casing and screens may be necessary if specifically required for a given site. If required, at least 1 percent, and no more than 5 percent of steam cleaned lengths of casing and screens combined shall be sampled.

Prior to leaving at the end of each work day and/or at the completion of the drilling program, drilling rigs and transport vehicles used onsite for personnel or equipment transfer shall be steam cleaned. A drilling rig left at the drilling location does not need to be steam cleaned until it is finished drilling at that location.

## 6.0 RECORDS

None.

| | | | |
|---|---|---|---|
| NUS CORPORATION<br>ENVIRONMENTAL MANAGEMENT GROUP | STANDARD OPERATING PROCEDURES | Number<br>GH-1.7 | Page<br>1 of 17 |
| | | Effective Date<br>05/04/90 | Revision<br>1 |
| | | Applicability<br>EMG | |
| | | Prepared<br>Earth Sciences | |
| Subject<br>GROUNDWATER MONITORING POINT INSTALLATION | | Approved<br>D. Senovich | |

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## 1.0 PURPOSE

This procedure describes methods for proper monitoring well design, installation, and development.

## 2.0 SCOPE

This procedure is applicable to the construction of permanent monitoring wells at hazardous waste sites. The methods described herein may be modified by project-specific requirements for monitoring well construction. In addition, many regulatory agencies have specific regulations pertaining to monitoring well construction and permitting. These requirements must be ascertained during the development of the investigation and any required permits which may have to be obtained before field work begins. Innovative monitoring well installation techniques, which typically are not used, will be discussed only generally in this procedure.

## 3.0 GLOSSARY

Monitoring Well - A well which is properly screened (if screening is necessary), cased, and sealed which is capable of providing a groundwater level and groundwater sample representative of the zone being monitored.

Piezometer - A pipe or tube inserted into the water bearing zone, typically open to water flow at the bottom and to the atmosphere at the top, and used to measure water level elevations. Piezometers may range in size from 1/2-inch diameter plastic tubes to well points or monitoring wells.

Potentiometric Surface - The surface to which water in an aquifer would rise by hydrostatic pressure.

Well Point (Drive Point) - A screened or perforated tube (Typically 1-1/4 or 2 inches in diameter) with a solid, conical, hardened point at one end, which is attached to a riser pipe and driven into the ground with a sledge hammer, drop weight, or mechanical vibrator. Well points may be used for groundwater injection and recovery, as piezometers (i.e., to measure water levels) or to provide groundwater samples for water quality data.

## 4.0 RESPONSIBILITIES

Driller - The driller provides adequate and operable equipment, sufficient quantities of materials, and an experienced and efficient labor force to perform all phases of proper monitoring well installation and construction. He may also be responsible for obtaining, in advance, any required permits for monitoring well installation and construction.

Rig Geologist - The rig geologist supervises well installation and construction by the Driller, documents all phases of well installation and construction, and insures that well construction is adequate to provide representative ground water data from the monitored interval. Geotechnical engineers, field technicians, or other suitable trained personnel may also serve in this capacity.

## 5.0 PROCEDURES

### 5.1 EQUIPMENT/ITEMS NEEDED

Below is a list of items that may be needed while installing a monitoring well.

- Health and safety equipment as required by the site safety officer.
- Well drilling and installation equipment with associated materials (typically supplied by the driller).
- Hydrogeologic equipment (weighted engineers tape, water level indicator, retractable engineers rule electronic calculator, clipboard, mirror and flashlight - for observing downhole activities, paint and ink marker for marking monitoring wells, sample jars, well installation forms, and a field notebook).
- Drive point installations tools (Sledge Hammer, drop hammer, or mechanical vibrator; tripod, pipe wrenches, drive points, riser pipe, and end caps).

### 5.2 WELL DESIGN

The objectives for each monitoring well and its intended use must be clearly defined before the monitoring system is designed. Within the monitoring system, different monitoring wells may serve different purposes and, therefore, require different types of construction. During all phases of the well design, attention must be given to clearly documenting the basis for design decisions, the details of well construction, and the materials to be used. The objectives for installing the monitoring wells may include:

- Determining groundwater flow directions and velocities.
- Sampling or monitoring for trace contaminants.
- Determining aquifer characteristics (e.g., hydraulic conductivity)

Siting of monitoring wells shall be performed after a preliminary estimation of the groundwater flow direction. In most cases, these can be determined through the review of geologic data and the site terrain. In addition, production wells or other monitoring wells in the area may be used to determine the groundwater flow direction. If these methods cannot be used, piezometers, which are relatively inexpensive to install, may have to be installed in a preliminary phase to determine groundwater flow direction.

#### 5.2.1 Well Depth, Diameter, and Monitored Interval

The well depth, diameter, and monitored internal must be tailored to the specific monitoring needs of each investigation. Specification of these items generally depends on the purpose of the monitoring system and the characteristics of the hydrogeologic system being monitored. Wells of different depth, diameter, and monitored interval can be employed in the same groundwater monitoring system. For instance, varying the monitored.interval in several wells, at the same location (cluster wells) can help to determine the vertical gradient and the levels at which contaminants are present. Conversly, a fully penetrating well is usually not used to quantify or vertically locate a contamination plume, since groundwater samples collected in wells that are screened over the full thickness of the water bearing zone will be representative of average conditions across the entire monitored interval. However, fully penetrating wells can be used to establish the existence of contamination in water bearing zone. The well diameter would depend upon the hydraulic characteristics of the water bearing zone. Sampling requirements, drilling method and cost.

The decision concerning the monitored interval and well depth is based on the following information:

- The vertical location of the contaminant source in relation to the water bearing zone.
- The depth, thickness and uniformity of the water bearing zone.
- The anticipated depth, thickness, and characteristics (e.g., density relative to water) of the contaminant plume.
- Fluctuation in groundwater levels (due to pumping, tidal influences, or natural recharge/discharge events).
- The presence and location of contaminants encountered during drilling.
- Whether the purpose of the installation is for determining existence or non-existence of contamination or if a particular stratigraphic zone is being investigated.
- The analysis of borehole geophysical logs.

In most situations where groundwater flow lines are horizontal, depending on the purpose of the well and the site conditions, monitored intervals are 20 feet or less. Shorter screen lengths (1 to 2 feet) are usually required where flow lines are not horizontal, (ie., if the wells are to be used for accurate measurement of the potentiometric head at a specific point).

Many factors influence the diameter of a monitoring well. The diameter of the monitoring well depends on the application. In determining well diameter, the following needs must be considered:

- Adequate water volume for sampling.
- Drilling methodology.
- Type of sampling device to be used.
- Costs

Standard monitoring well diameters are 2, 4, 6, or 8 inches. However, drive points are typically 1-1/4 or 2 inches in diameter. For monitoring programs which require screened monitoring wells, either a 2-inch or 4-inch diameter well is preferred. Typically, well diameters greater than 4 inches are used in monitoring programs in which open hole monitoring wells are required. In the smaller diameter wells, the volume of stagnant water in the well is minimized, and well construction costs are reduced, however, the type of sampling devices that can be used are limited. In specifying well diameter, sampling requirements must be considered. Up to a total of 4 gallons of water may be required for a single sample to account for full organic and inorganic analyses, and split samples. The water in the monitoring well available for sampling is dependent on the well diameter as follows:

| Casing Inside Diameter, Inch | Standing Water Depth to Obtain 1 Gal Water (feet) | Total Depth of Standing Water for 4 Gal. (feet) |
|---|---|---|
| 2 | 6.13 | 25 |
| 4 | 1.53 | 6 |
| 6 | 0.68 | 3 |

However, if a specific well recharges quickly after purging, then well diameter may not be an important factor regarding sample volume requirements.

Pumping tests for determining aquifer characteristics may require larger diameter wells; however, in small diameter wells.in-situ permeability tests can be performed during drilling or after well installation is completed.

### 5.2.2 Riser Pipe and Screen Materials

Well materials are specified by diameter, type of material, and thickness of pipe. Well screens require an additional specification of slot size. Thickness of pipe is referred to as "schedule" for polyvinyl chloride (PVC) casing and is usually Schedule 40 (thinner wall) or 80 (thicker wall). Steel pipe thickness is often referred to as "Strength" and Standard Strength is usually adequate for monitoring well purposes. With larger diameter pipe, the wall thickness must be greater to maintain adequate strength. The required thickness is also dependent on the method of installation;-risers for drive points require greater strength than wells installed inside drilled borings.

The selection of well screen.and riser materials depends on the method of drilling, the type of subsurface materials in which the well penetrates, the type of contamination expected, and natural water quality and depth. Cost and the level of accuracy required are also important. The materials generally available are Teflon, stainless steel, PVC, galvanized steel, and carbon steel. Each has advantages and limitations (see Attachment A of this guideline for an extensive discussion on this topic). The two most commonly used materials are PVC and stainless steel for wells in which screens are installed and are compared in Attachment B. Stainless steel is preferred where trace metals or organic sampling is required; however, costs are high. Teflon materials are extremely expensive, but are relatively inert and provide the least opportunity for water contamination due to well materials. PVC has many advantages, including low cost, excellent availability, light weight, and ease of manipulation; however, there are also some questions about organic chemical sorption and leaching that are currently being researched (see Barcelona et al., 1983). Concern about the use of PVC can be minimized if PVC wells are used strictly for geohydrologic measurements and not for chemical sampling. The crushing strength of PVC may limit the depth of installation, but schedule 80 materials normally used for wells greater than 50 feet deep may overcome some of the problems associated with depth. However, the smaller inside diameter of Schedule 80 pipe may be an important factor when considering the size of bailers or pumps to be used for sampling or testing. Due to this problem, the minimum well pipe size recommended for schedule 80 wells is 4 inch I.D.

Screens and risers may have to be decontaminated before use because oil-based preservatives and oil used during thread cutting and screen manufacturing may contaminate samples. Metal pipe, may corrode and release metal ions or chemically react with organic constituents, but this is considered by some to be less of a problem than the problem associated with PVC material. Galvanized steel is not recommended for metal analyses, as zinc and cadmium levels in groundwater samples may be elevated from the zinc coating.

Threaded, flush-joint casing is most often preferred for monitoring well applications. PVC, Teflon, and steel can all be obtained with threaded joints at slightly more costs. Welded-joint steel casing is also acceptable. Glued PVC may release organic contamination into the well and therefore should not be used if the well is to be sampled for organic contaminants.

When the water bearing zone is in consolidated bedrock, such as limestone or fractured granite, a well screen is often not necessary (the well is simply an open hole in bedrock). Unconsolidated materials, such as sands, clay, and silts require a screen. A screen slot size of 0.010 or 0.020 inch is generally used when a screen is necessary and the screened interval is artificially packed with a fine sand. The slot size controls the quantity of water entering the well and prevents entry of natural materials or sand pack. The screen shall pass no more than 10 percent of the pack material, or in-situ aquifer material. The rig geologist shall specify the combination of screen slot size and sand pack which will be compatible with the water bearing zone, to maximize groundwater inflow and minimize head losses and movement of fines into the wells. (For example, as a standard procedure, a Morie No. 1 or Ottowa sand may be used with a 0.010-inch slot screen, however, with a 0.020-inch slot screen, the filter pack material must be the material retained on a No. 20 to No. 30 U.S. standard sieve.)

### 5.2.3 Annular Materials

Materials placed in the annular space between the borehole and riser pipe and screen include a sand pack when necessary, a bentonite seal, and cement-bentonite grout. The sand pack is usually a fine to medium grained well graded, silica sand. The quantity of sand placed in the annular space is dependent upon the length of the screened interval but should always extend at least 1 foot above the top of the screen. At least one to three feet of bentonite pellets or equivalent shall be placed above the sand pack. The cement-bentonite grout or equivalent extends from the top of the bentonite pellets to the ground surface.

On occasion, and with the concurrence of the involved regulatory agencies, monitoring wells may be packed naturally, i.e., no artificial sand pack will be installed, and the natural formation material will be allowed to collapse around the well screen after the well is installed. This method has been utilized where the formation material itself is a relatively uniform grain size, or when artificial sand packing is not possible due to borehole collapse.

Bentonite expands by absorbing water and provides a seal between the screened interval and the overlying portion of the annular space and formation. Cement-bentonite grout is placed on top of the bentonite pellets to the surface. The grout effectively seals the well and eliminates the possibility for surface infiltration reaching the screened interval. Grouting also replaces material removed during drilling and prevents hole collapse and subsidence around the well. A tremie pipe should be used to introduce grout from the bottom of the hole upward, to prevent bridging and to provide a better seal. However, in boreholes that don't collapse, it may be more practical to pour the grout from the surface without a tremie pipe.

Grout is a general term which has several different connotations. For all practical purposes within the monitoring well installation industry, grout refers to the solidified material which is installed and occupies the annular space above the bentonite pellet seal. Grout, most of the time, is made up of two assemblages of material, i.e., a cement-bentonite grout. A cement bentonite grout normally is a mixture of cement, bentonite and water at a ratio of one 90-pound bag of Portland Type I cement, 3-5 pounds of granular or flake-type bentonite and 6 gallons of water. A neat cement is made up of one ninety-pound bag of Portland Type I cement and 6 gallons of water.

In certain cases, the borehole may be drilled to a depth greater than the anticipated well installation depth. For these cases, the well shall be backfilled to the desired depth with bentonite pellets or equivalent. A short (1'-2') section of capped riser pipe sump is sometimes installed immediately below the screen, as a silt reservoir, when significant post-development silting is anticipated. This will ensure that the entire screen surface remains unobstructed.

### 5.2.4 Protective Casing

When the well is completed and grouted to the surface, a protective steel casing is often placed over the top for the well. This casing generally has a hinged cap and can be locked to prevent vandalism. A vent hole shall be provided in the cap to allow venting of gases and maintain atmospheric pressure as water levels rise or fall in the well. The protective casing has a larger diameter than the well and is set into the wet cement grout over the well upon completion. In addition, one hole is drilled just above the cement collar through the protective casing which acts as a weep hole for the flow of water which may enter the annulus during well development, purging, or sampling.

A Protective casing which is level with the ground surface is used in roadway or parking lot applications where the top of a monitoring well must be below the pavement. The top of the riser pipe is placed 4 to 5 inches below the pavement, and a locking protective casing is cemented in place to 3 inches below the pavement. A large diameter protective sleeve is set into the wet cement around the well with the top set level with the pavement. A manhole type lid placed over the protective sleeve. The cement should be slightly mounded to direct pooled water away from the well head.

## 5.3 MONITORING WELL INSTALLATION

### 5.3.1 Monitoring Wells in Unconsolidated Sediments

After the borehole is drilled to the desired depth, well installation can begin. The procedure for well installation will partially be dictated by the stability of the formation in which the well is being placed. If the borehole collapses immediately after the drilling tools are withdrawn, then a temporary casing must be installed and well installation will proceed through the center of the temporary casing, and continue as the temporary casing is withdrawn from the borehole. In the case of hollow stem auger drilling, the augers will act to stabilize the borehole during well installation.

Before the screen and riser pipe are lowered into the borehole, all pipe and screen sections should be measured with an engineers rule to ensure proper well placement. When measuring sections, the threads on one end of the pipe or screen must be excluded while measuring, since the pipe and screen sections are screwed flush together.

After the screen and riser pipe are lowered through the temporary casing, then the sand pack can be installed. A weighted tape measure must be used during the procedure in order to carefully monitor installation progress. The sand is poured into the annulus between the riser pipe and temporary casing, as the casing is withdrawn. Sand should always be kept within the temporary casing during withdrawal in order to ensure an adequate sand pack. However, if too much sand is within the temporary casing (greater than 1 foot above the bottom of the casing) bridging between the temporary casing and riser pipe may occur.

After the sand pack is installed to the desired depth, (at least 1 foot above the top of the screen) then the bentonite pellet seal or equivalent, can be installed, in the same manner as the sand pack. At least 1 to 3 feet of bentonite pellets should be installed above the sand pack.

The cement-bentonite grout is then mixed and either poured or tremied into the annulus as the temporary casing or augers are withdrawn. Finally, the protective casing can be installed as detailed in Section 5.2.4.

In stable formations where borehole collapse does not occur, the well can be installed as discussed above, and the use of a temporary casing is not needed. However, centralizers may have to be installed, one above, and one below the screen, to assure enough annular space for sand pack placement. *A typical overburden monitoring well sheet is shown.*

### 5.3.2 Confining Layer Monitoring Wells

When drilling and installing a well in a confined aquifer, proper well installation techniques must be applied to avoid cross contamination between. Under most conditions, this can be accomplished by installing double-cased wells. This is accomplished by drilling a large diameter boring through the upper aquifer, 1 to 3 feet into the underlying confining layer, and setting and pressure grouting or tremie grouting the outer casing into the confining layer. The grout material must fill the space between the native material and the outer casing. A smaller diameter boring is then continued through the confining layer for installation of the monitoring well as detailed for overburden monitoring wells, with the exception of not using a temporary casing during installation. Sufficient time which will be determined by the rig geologist, must be allowed for setting of the grout prior to drilling through the confined layer. A typical confining layer monitoring well sheet is shown in Attachment C.

### 5.3.3 Bedrock Monitoring Wells

When installing bedrock monitoring wells, a large diameter boring is drilled through the overburden and approximately 5 feet into the bedrock. A casing (typically steel) is installed and either pressure grouted or tremie grouted in place. After the grout is cured, a smaller diameter boring is continued through the bedrock to the desired depth. If the boring does not collapse, the well can be left open, and a screen is not necessary. If the boring collapses, then a screen is required and can be installed as detailed for overburden monitoring wells. However, if a screen is to be used, then the casing which is installed through the overburden and into the bedrock does not require grouting and can be installed temporary until final well installation is completed. Typical well construction forms for bedrock monitoring wells are shown in Attachment C.

### 5.3.4 Drive Points

Drive points can be installed with either a sledge hammer, drop hammer, or a mechanical vibrator. The screen is threaded and tightened onto the riser pipe with pipe wrenches. The drive point is simply pounded into the subsurface to the desired depth. If a heavy drop hammer is used, then a tripod and pulley setup is required to lift the hammer. Drive points typically cannot be driven to depths exceeding 10 feet.

### 5.3.5 Innovative Monitoring Well Installation Techniques

Certain innovative sampling devices have proven advantageous. These devices are essentially screened samplers installed in a borehole with only one or two small-diameter tubes extending to the surface. Manufacturers of these types of samplers claim that four samplers can be installed in a 3-inch diameter borehole. This reduces drilling costs, decreases the volume of stagnant water, and provides a sampling system that minimizes cross contamination from sampling equipment. These samplers also perform well when the water table is within 25 feet from the surface (the typical range of suction pumps). Two manufacturers of these samplers are Timco Manufacturing Company, Inc., of

Prairie du Sac, Wisconsin, and BARCAD Systems, Inc., of Concord, Massachusetts. Each offers various construction materials.

Two additional types of multilevel sampling systems have been developed. Both employ individual screened openings through a small-diameter casing. One of these systems (marketed by Westbay Instruments Ltd. of Vancouver, British Columbia, Canada) uses a screened port and a sampling probe to obtain samples and head measurements or perform permeability tests. this system allows sampling ports at intervals as close as 5 feet, if desired, in boreholes from 3 to 4.8 inches in diameter.

The other system, developed at the University of Waterloo at Waterloo, Ontario, Canada, requires field assembly of the individual sampling ports and tubes that actuate a simple piston pump and force the samples to the surface. Where the depth to ground water is less than 25 feet, the piston pumps are not required. The assembly is made of easily obtained materials; however, the cost of labor to assemble these monitoring systems may not be cost-effective.

## 5.4 WELL DEVELOPMENT METHODS

The purpose of well development is to stabilize and increase the permeability of the gravel pack around the well screen, and to restore the permeability of the formation which may have been reduced by drilling operations. Wells are typically developed until all fine material and drilling water is removed from the well. Sequential measurements of pH, conductivity and temperature taken during development may yield information (stabilized values) that sufficient development is reached. The selection of the well development method (shall) be made by the rig geologist and is based on the drilling methods, well construction and installation details, and the characteristics of the formation that the well is screened in. The primary methods of well development are summarized below. A more detailed discussion may be found in Driscoll (1986).

Overpumping and Backwashing - Wells may be developed by alternatively drawing the water level down at a high rate (by pumping or bailing) and then reversing the flow direction (backwashing) so that water is passing from the well into the formation. This back and forth movement of water through the well screen and gravel pack serves to remove fines from the formation immediately adjacent to the well, while preventing bridging (wedging) of sand grains. Backwashing can be accomplished by several methods including pouring water into the well and then bailing, starting and stopping a pump intermittently to change water levels, or forcing water into the well under pressure through a water-tight fitting ("rawhiding"). Care should be taken when backwashing not to apply too much pressure, which could damage or destroy the well screen.

Surging with a Surge Plunger - A surge plunger (also called a surge block) is approximately the same diameter as the well casing and is used to agitate the water, causing it to move in and out of the screens. This movement of water rpulls fine materials into the well, where they may be removed by any of several methods, and prevents bridging of sand particles in the gravel pack. There are two basic types of surge plungers; solid and valved surge plungers. In formations with low yields, a valved surge plunger may be preferred, as solid plungers tend to force water out of the well at a greater rate than it will flow back in. Valved plungers are designed to produce a greater inflow than outflow of water during surging.

Compressed Air - Compressed air can be used to develop a well by either of two methods: backwashing or surging. Backwashing is done by forcing water out through the screens, using increasing air pressure inside a sealed well, then releasing the pressurized air to allow the water to flow back into the well. Care should be taken when using this method so that the water level does not drop below the top of the screen, thus reducing well yield. Surging, or the "open well" method, consists of alternately releasing large volumes of air suddenly into an open well below the water level to produce a strong surge by virtue of the resistance of water head, friction, and inertia. Pumping the well is subsequently done with the air lift method.

High Velocity Jetting - In the high velocity jetting method, water is forced at high velocities from a plunger-type device and through the well screen to loosen fine particles from the sand pack and surrounding formation. The jetting tool is slowly rotated and raised and lowered along the length of the well screen to develop the entire screened area. Jetting using a hose lowered into the well may also be effective. The fines washed into the screen during this process can then be bailed or pumped from the well.

## 6.0 REFERENCES

Scalf, M. R., J. F. McNabb, W. J. Dunlap, R. L. Cosby, and J. Fryberger, 1981. Manual of Groundwater Sampling Procedures. R. S. Kerr Environmental Research Laboratory, Office of Research and Development, U.S. EPA, Ada, Oklahoma.

Barcelona, M. J., P. P. Gibb and R. A. Miller, 1983. A Guide to the selection of Materials for Monitoring Well Construction and Groundwater Sampling. ISWS Contract Report 327, Illinois State Water Survey, Champaign, Illinois.

U.S. EPA, 1980. Procedures Manual for Groundwater Monitoring of Solid Waste Disposal Facilities. Publication SW-611, Office of Solid Waste, U.S. EPA, Washington, D.C.

Driscoll, Fletcher G., 1986. Groundwater and Wells. Johnson Division, St. Paul, Minnesota, 1989 p.

## 7.0 RECORDS

A critical part of monitoring well installation is recording of significant details and events in the field notebook. The Geologist must record the exact depths of significant hydrogeological features screen placement, gravel pack placement, and bentonite placement.

A Monitoring Well Sheet (Attachment C) shall be used which allows the uniform recording of data for each installation and rapid identification of missing information. Well depth, length, materials of construction, length and openings of screen, length and type of riser, and depth and type of all backfill materials shall be recorded. Additional information (shall) include location, installation date, problems encountered, water levels before and after well installation, cross-reference to the geologic boring log, and methods used during the installation and development process. The documentation is very important to prevent problems involving questionable sample validity. Somewhat different information will need to be recorded.depending on whether the well is completed in overburden, in a confined layer, in bedrock with a cased well, or as an open hole in bedrock.

The quantities of sand, bentonite, and grout placed in the well are also important. The Geologist shall calculate the annular space volume and have a general idea of the quantity of material needed to fill the annular space. Volumes of backfill significantly higher than the calculated volume may indicate a problem such as a large cavity, while a smaller backfill volume may indicate a cave-in. Any problems with rig operation or down time shall be recorded and may determine the driller's final fee.

## ATTACHMENT A

### TABLE 7-4 RELATIVE COMPATIBILITY OF RIGID WELL-CASING MATERIAL (PERCENT)

| | PVC 1 | Galvanized Steel | Carbon Steel | Lo-carbon Steel | Stainless steel 304 | Stainless steel 316 | Teflon* |
|---|---|---|---|---|---|---|---|
| Buffered Weak Acid | 100 | 56 | 51 | 59 | 97 | 100 | 100 |
| Weak Acid | 98 | 59 | 43 | 47 | 96 | 100 | 100 |
| Miner Acid/High Solids | 100 | 48 | 57 | 60 | 80 | 82 | 100 |
| Aqueous/Organic Mixtures | 64 | 69 | 73 | 73 | 98 | 100 | 100 |
| Percent Overall Rating | 91 | 58 | 56 | 59 | 93 | 96 | 100 |

<u>Preliminary Ranking of Rigid Materials</u>

1 Teflon®
2 Stainless Steel 316
3 Stainless Steel 304
4 PVC 1
5 Lo-Carbon Steel
6 Galvanized Steel
7 Carbon Steel
* Trademark of DuPont

### RELATIVE COMPATIBILITY OF SEMI-RIGID OR ELASTOMERIC MATERIALS (PERCENT)

| | PVC Flexible | PP | PE Conv. | PE Linear | PMM | Viton®* | Silicone | Neoprene | Teflon®* |
|---|---|---|---|---|---|---|---|---|---|
| Buffered Weak Acid | 97 | 97 | 100 | 97 | 90 | 92 | 87 | 85 | 100 |
| Weak Acid | 92 | 90 | 94 | 96 | 78 | 78 | 75 | 75 | 100 |
| Mineral Acid/High Solids | 100 | 100 | 100 | 100 | 95 | 100 | 78 | 82 | 100 |
| Aqueous/Organic Mixtures | 62 | 71 | 40 | 60 | 49 | 78 | 49 | 44 | 100 |
| Percent Overall Rating | 88 | 90 | 84 | 88 | 78 | 87 | 72 | 72 | 100 |

<u>Preliminary Ranking of Semi-Rigid or Elastomeric Materials</u>

1 Teflon®
2 Polypropylene (PP)
3 PVC flexible/PE linear
4 Viton®
5 PE Conventional
6 Plexiglas/Lucite (PMM)
7 Silicone/Neoprene
Source: Barcelona et al., 1983
* Trademark of DuPont

## ATTACHMENT B

## COMPARISON OF STAINLESS STEEL AND PVC FOR MONITORING WELL CONSTRUCTION

| Characteristic | Stainless Steel | PVC |
|---|---|---|
| Strength | Use in deep wells to prevent compression and closing of screen/riser. | Use when shear and compressive strength not critical. |
| Weight | Relatively heavier | Lightweight, floats in water |
| Cost | Relatively expensive | Relatively inexpensive |
| Corrosivity | Deteriorates more rapidly in corrosive water | Non-corrosive--may deteriorate in presence of ketones, aromatics, alkyl sulfides, or some chlorinated HC |
| Ease of Use | Difficult to adjust size or length in the field. | Easy to handle and work in the field. |
| Preparation for Use | Should be steam-cleaned for organics sampling | Never use glue fittings--pipes should be threaded or pressure-fitted. Should be steam cleaned if used for monitoring wells. |
| Interaction with Contaminants* | May sorb organic or inorganic substances when oxidized | May sorb or release organic substances. |

* See also Attachment A.

## ATTACHMENT C

**NUS CORPORATION**
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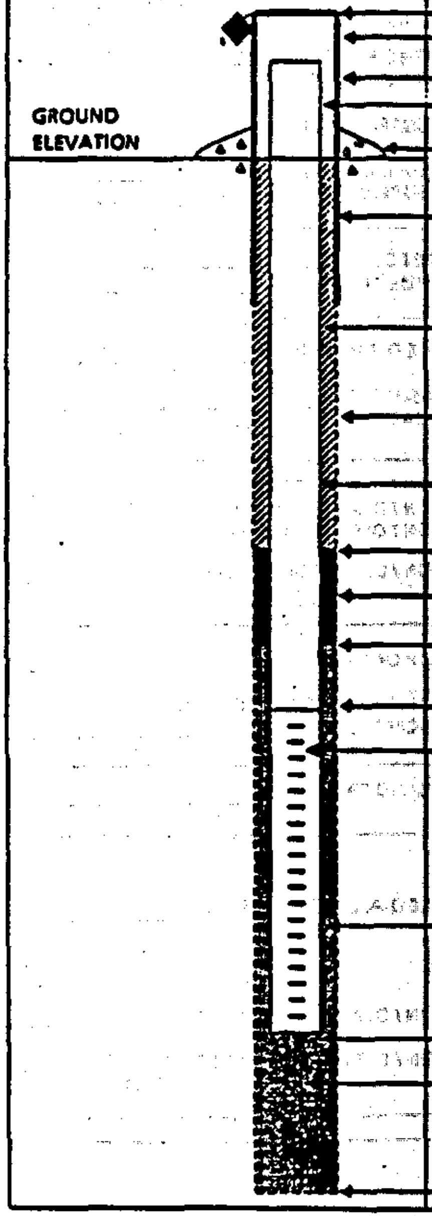
BORING NO ________

## OVERBURDEN
## MONITORING WELL SHEET

PROJECT ________ LOCATION ________
PROJECT NO. ________ BORING ________
ELEVATION ________ DATE ________
FIELD GEOLOGIST ________

DRILLER ________
DRILLING METHOD ________
DEVELOPMENT METHOD ________



ELEVATION OF TOP OF SURFACE CASING: ________
ELEVATION OF TOP OF RISER PIPE: ________
STICK - UP TOP OF SURFACE CASING: ________
STICK - UP RISER PIPE: ________
TYPE OF SURFACE SEAL: ________
I.D. OF SURFACE CASING: ________
TYPE OF SURFACE CASING: ________
RISER PIPE I.D. ________
TYPE OF RISER PIPE: ________
BOREHOLE DIAMETER: ________
TYPE OF BACKFILL: ________
ELEVATION / DEPTH TOP OF SEAL: ________
TYPE OF SEAL: ________
DEPTH TOP OF SAND PACK: ________
ELEVATION / DEPTH TOP OF SCREEN: ________
TYPE OF SCREEN: ________
SLOT SIZE x LENGTH: ________
I.D. OF SCREEN: ________
TYPE OF SAND PACK: ________
ELEVATION / DEPTH BOTTOM OF SCREEN: ________
ELEVATION / DEPTH BOTTOM OF SAND PACK: ________
TYPE OF BACKFILL BELOW OBSERVATION WELL: ________
ELEVATION / DEPTH OF HOLE: ________

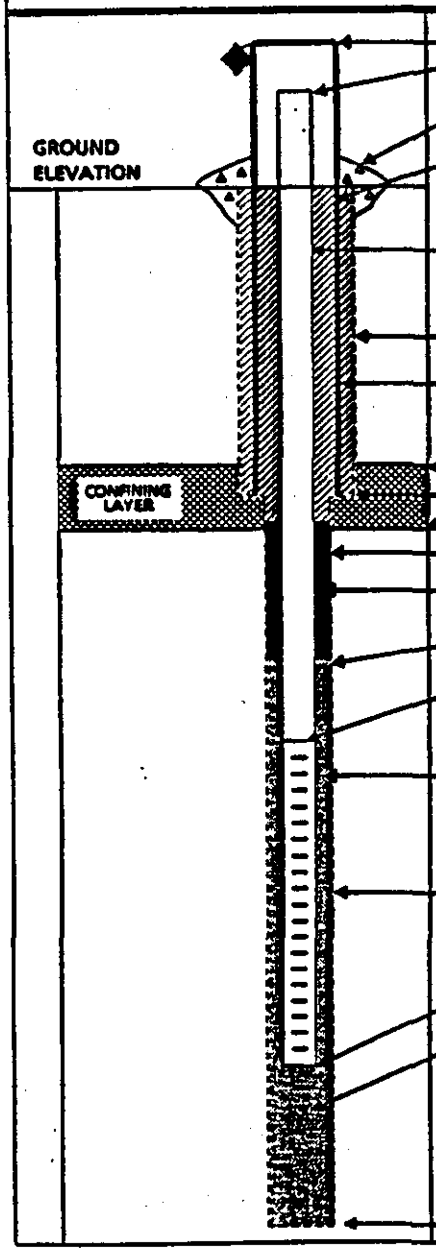
ATTACHMENT C
PAGE TWO

BORING NO.: ____________

NUS CORPORATION

## CONFINING LAYER
## MONITORING WELL SHEET

| | | |
|---|---|---|
| PROJECT ____________ | LOCATION ____________ | DRILLER ____________ |
| PROJECT NO. ____________ | BORING ____________ | DRILLING METHOD ____________ |
| ELEVATION ____________ | DATE ____________ | DEVELOPMENT METHOD ____________ |
| FIELD GEOLOGIST ____________ | | |



ELEVATION OF TOP OF PERM. CASING : ____________
ELEVATION OF TOP OF RISER PIPE: ____________
TYPE OF SURFACE SEAL: ____________
____________
I.D. OF PERM. CASING: ____________
TYPE OF SURFACE CASING: ____________
____________
RISER PIPE I.D. ____________
TYPE OF RISER PIPE: ____________
____________
BOREHOLE DIAMETER: ____________
PERM. CASING I.D. ____________
TYPE OF CASING & BACKFILL: ____________
____________
ELEVATION / DEPTH TOP CONFINING LAYER: ____________
ELEVATION / DEPTH BOTTOM OF CASING: ____________
ELEVATION / DEPTH BOT. CONFINING LAYER: ____________
ELEVATION / DEPTH TOP OF SEAL: ____________
TYPE OF SEAL: ____________
____________
DEPTH TOP OF SAND PACK: ____________
ELEVATION/DEPTH TOP OF SCREEN: ____________
TYPE OF SCREEN: ____________
____________
TYPE OF SAND PACK: ____________
____________
BOREHOLE DIA. BELOW CASING: ____________
ELEVATION / DEPTH BOTTOM OF SCREEN: ____________
ELEVATION / DEPTH BOTTOM OF SAND PACK: ____________
TYPE OF BACKFILL BELOW OBSERVATION WELL: ____________
____________
ELEVATION / DEPTH OF HOLE: ____________

**ATTACHMENT C**
**PAGE THREE**

NUS CORPORATION
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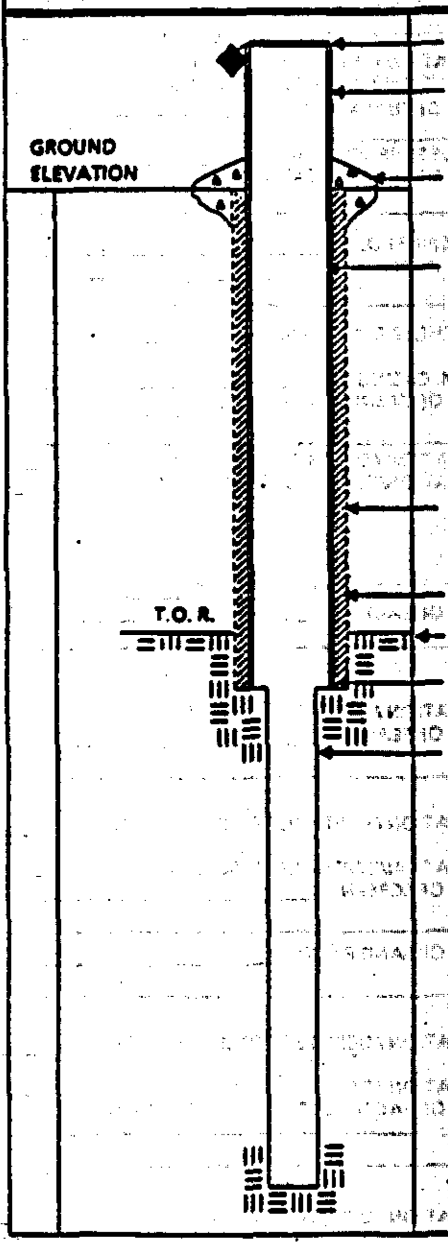
BORING NO.: ________

## BEDROCK
# MONITORING WELL SHEET
## OPEN HOLE WELL

PROJECT ________ LOCATION ________
PROJECT NO. ________ BORING ________
ELEVATION ________ DATE ________
FIELD GEOLOGIST ________

DRILLER ________
DRILLING METHOD ________
DEVELOPMENT METHOD ________



ELEVATION OF TOP OF CASING: ________

STICK UP OF CASING ABOVE GROUND SURFACE: ________

TYPE OF SURFACE SEAL: ________

________

I.D. OF CASING: ________

TYPE OF CASING: ________

TEMP. / PERM.: ________

DIAMETER OF HOLE: ________

TYPE OF CASING SEAL: ________

DEPTH TO TOP OF ROCK: ________

DEPTH TO BOTTOM CASING: ________

DIAMETER OF HOLE IN BEDROCK: ________

DESCRIBE IF CORE / REAMED WITH BIT:

________

________

________

DESCRIBE JOINTS IN BEDROCK AND DEPTH:

________

________

________

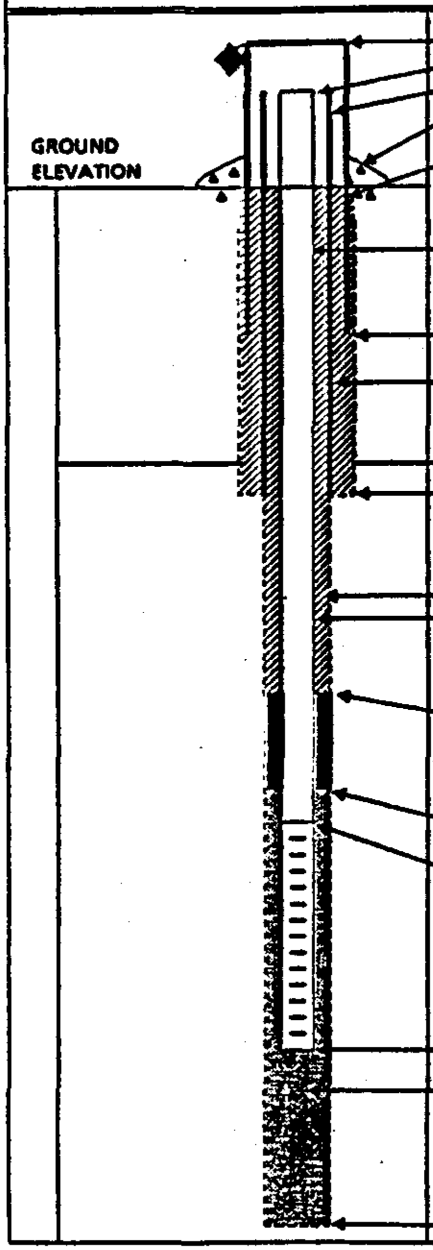
ELEVATION / DEPTH OF HOLE: ________

ATTACHMENT C
PAGE FOUR

BORING NO.: ________

# BEDROCK
# MONITORING WELL SHEET
# WELL INSTALLED IN BEDROCK

PROJECT ________
PROJECT NO. ________
ELEVATION ________
FIELD GEOLOGIST ________
LOCATION ________
BORING ________
DATE ________
DRILLER ________
DRILLING METHOD ________
DEVELOPMENT METHOD ________



ELEVATION OF TOP OF SURFACE CASING : ________
ELEVATION OF TOP OF RISER PIPE: ________
ELEVATION TOP OF PERM. CASING: ________
TYPE OF SURFACE SEAL: ________
I.D. OF SURFACE CASING: ________
TYPE OF SURFACE CASING: ________
RISER PIPE I.D. ________
TYPE OF RISER PIPE: ________
BOREHOLE DIAMETER: ________
PERM. CASING I.D. ________
TYPE OF CASING & BACKFILL: ________
ELEVATION / DEPTH TO BEDROCK: ________
ELEVATION/DEPTH BOTTOM OF CASING: ________
BOREHOLE DIA. BELOW CASING: ________
TYPE OF BACKFILL: ________
ELEVATION / DEPTH TOP OF SEAL: ________
TYPE OF SEAL: ________
ELEVATION / DEPTH TOP OF SAND PACK: ________
ELEVATION/DEPTH TOP OF SCREEN: ________
TYPE OF SCREEN: ________
TYPE OF SAND PACK: ________
ELEVATION / DEPTH BOTTOM OF SCREEN: ________
ELEVATION / DEPTH BOTTOM OF SAND PACK: ________
TYPE OF BACKFILL BELOW OBSERVATION WELL: ________
ELEVATION / DEPTH OF HOLE: ________

ATTACHMENT C
PAGE FIVE

**NUS CORPORATION**
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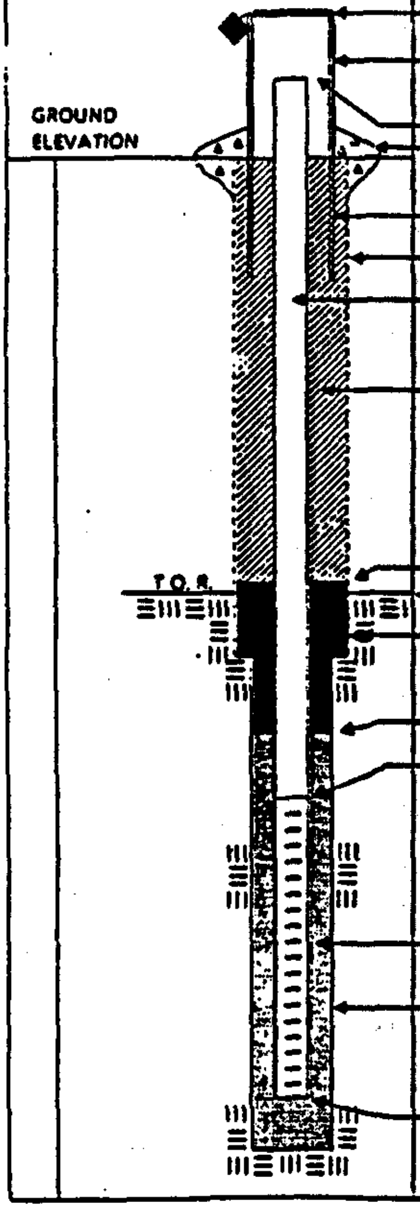
BORING NO.: ________

## BEDROCK
## MONITORING WELL SHEET
## WELL INSTALLED IN BEDROCK

PROJECT ________ LOCATION ________
PROJECT NO. ________ BORING ________
ELEVATION ________ DATE ________
FIELD GEOLOGIST ________

DRILLER ________
DRILLING METHOD ________
DEVELOPMENT METHOD ________



ELEVATION OF TOP OF SURFACE CASING: ________
STICK UP OF CASING ABOVE GROUND SURFACE: ________
ELEVATION TOP OF RISER: ________
TYPE OF SURFACE SEAL: ________
I.D. OF SURFACE CASING: ________
DIAMETER OF HOLE: ________
RISER PIPE I.D.: ________
TYPE OF RISER PIPE: ________
TYPE OF BACKFILL: ________
ELEVATION / DEPTH TOP OF SEAL: ________
ELEVATION / DEPTH TOP OF BEDROCK: ________
TYPE OF SEAL: ________
ELEVATION / DEPTH TOP OF SAND: ________
ELEVATION / DEPTH TOP OF SCREEN: ________
TYPE OF SCREEN: ________
SLOT SIZE x LENGTH: ________
I.D. SCREEN: ________
TYPE OF SAND PACK: ________
DIAMETER OF HOLE IN BEDROCK: ________
CORE / REAM: ________
ELEVATION / DEPTH BOTTOM SCREEN: ________
ELEVATION / DEPTH BOTTOM OF HOLE: ________

**NUS CORPORATION**

**ENVIRONMENTAL MANAGEMENT GROUP**

# STANDARD OPERATING PROCEDURES

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| Applicability<br>EMG | |
| Prepared<br>Earth Sciences | |
| Approved<br>D. Senovich | |

Subject

## GEOLOGIC CROSS SECTIONS

## TABLE OF CONTENTS

SECTION

## 1.0 PURPOSE

The purpose of this procedure is to provide guidance on the preparation of geologic cross sections.

## 2.0 SCOPE

General guidelines only are presented for the development of cross sections. The type and amount of information incorporated into any cross section is dependent on the intended use of the cross section, which is project-specific.

## 3.0 GLOSSARY

Fence Diagram - A diagram containing 3 or more interconnected geologic cross sections, showing the relationship of one to another.

Geologic Cross Section - A diagram illustrating subsurface geologic features cut by a vertical plane.

Geologic Dip - The angle that a planar feature (typically bedding) makes with the horizontal. Dip is measured along an alignment perpendicular to strike and in the vertical plane.

Geologic Contact - The surface between two differing types or ages of rock.

Lithologic Unit - A body of rock consisting predominantly of certain lithologic features characteristic of the rock body, which enable it to be distinguished from adjacent lithologic units.

Strike - The orientation of a structural surface (bedding, fault plane, etc.) as it intersects the horizontal. Strike is aligned perpendicular to dip.

## 4.0 RESPONSIBILITIES

The Project Geologist - The project geologist is responsible for generating the required cross sections for a given project. Decisions made regarding the number of cross sections needed, the alignments of the cross sections, and the information to be included on each cross section are the responsibility of the project geologist. Actual construction of the cross sections may be performed by the project geologist or by others, however, the project geologist is responsible at a minimum for supervising and reviewing the drawings generated.

## 5.0 PROCEDURES

### 5.1 GENERAL CONSIDERATIONS

The intended use of each cross section will determine the types of information that are to be presented and the physical make-up of the cross section. Cross sections can be used to:

- Represent graphically the subsurface conditions encountered
- Summarize investigation findings
- Illustrate work performed
- Supplement discussions in text
- Aid in the interpretation of geologic/hydrogeologic conditions

As mentioned previously, the information to be provided in the cross section should be determined by the intended use of the cross section. Cross sections should be oriented to achieve a specific purpose, keeping in mind the data points available. The level of detail included in each cross section is also dependent on its intended use. Too little detail may not accurately depict subsurface conditions or show pertinent features, while too much detail may obscure the important features and result in a cross section that confuses the observer rather than aids in his understanding of the discussion. Cross sections can be combined to generate a fence diagram, which shows subsurface conditions in 3 dimensions. Flow nets may also be developed from cross sections, to illustrate groundwater flow paths and vertical movement of groundwater.

Cross sections are a tool used to enable the writer to more clearly present findings and support discussions/interpretations, therefore, at least one and preferably several references to each cross section should be made within the text discussion.

Most project-specific cross sections are developed using boring logs, well construction logs, and/or excavation logs as the basis for the data presented. Field mapping of geologic features can provide additional information for cross section development. Published geologic maps, both in plan view and cross section, can provide general data which may aid in the development of cross sections.

Cross sections can either be aligned directly through each data point used, or can be aligned along a straight line which passes near but not directly through some of the data points shown. If data points included are not located exactly on the cross section line, they must be shown as reflected or projected data points with their corresponding distance from the cross section line noted.

## 5.2 ORIENTATIONS

Geologic cross sections are usually oriented perpendicular to the general strike of the geologic units illustrated, and therefore parallel to the direction of dip of the formations. Cross sections developed to illustrate hydrogeologic conditions are best oriented parallel to the direction of groundwater flow, especially if a flow net is to be developed from the figure. Although these are two preferred orientations, any alignment may be used depending on the purpose of the figure and the data points available. It is often useful to develop perpendicular sets of cross sections across a study area to provide maximum detail regarding subsurface conditions. Cross section orientations should be shown on a plan-view map which indicates beginning and end points for the cross sections(s) and locations of the data points included in the cross section. The beginning and end points of each cross section should be labeled using capital letter sets (A-A', B-B', etc.). The alignment of the cross section on the drawing, from left to right (A to A', B to B', etc.) , should be aligned from west to east on the plan view map, or, if the cross section is oriented exactly north-south, from south to north.

## 5.3 SCALE

Horizontal and vertical scales used are dependent on figure size limitations and the level of detail required. Most cross sections are vertically exaggerated in comparison with the horizontal scale, however, the vertical exaggeration should be kept to a minimum in order to maximize the representativeness of the figure. For a cross section that spans a long distance between two data points, the cross section can be "cut" so that the cross section will conveniently fit onto a report page. If this is done, a break in the cross section should be illustrated and the length of the cross section that was cut out noted on the figure.

When providing the vertical and horizontal scales for the cross section, bar scales should be used instead of a written scale, since if the figure is reduced or enlarged, the bar scale will remain accurate while a written scale will be no longer valid.

## 5.4 CROSS SECTION ELEMENTS

The following is a list of the elements that may be included in a cross section. Not all of these features are necessary for a given cross section, and additional features not included in this list may be shown to achieve specific purposes.

- Lithologies - written and/or symbols
- Structures - faults, unconformities, etc.
- Formation names
- Depths of geologic contacts
- Fractures
- Scale, horizontal and vertical
- Elevations - ground surface data points, subsurface data points, elevation scales at both ends of the cross section.
- Ground surface, useful surface features (roads, buildings, streams, etc.)
- Boring numbers, depths, elevations
- Well details - number, depth, screened interval, water level elevation
- Sampling points
- Subsurface cultural features - trenches, underground tanks, etc.
- Hydrogeologic observations - aquifers, aquitards, perched groundwater, potentiometric surface, etc.
- Legend describing symbols.
- Title

Correlating the subsurface units encountered in borings should be done with care. The geologic setting of the cross section should be considered when deciding whether to connect two similar appearing units in adjacent boreholes, if the correlation (or lack of) is not obvious. A thin, fine grained deposit in a lacustrine setting may be continuous over a relatively large area, while a thin, fine grained deposit in a small buried stream valley may not be. Dashed lines should be used whenever correlations are somewhat uncertain, and correlations should not be made between two units if there is substantial uncertainty regarding the connection (or lack of).

## 6.0 REFERENCES

Compton, Robert R., 1962. Manual of Field Geology. John Wiley and Sons, Inc.

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| Applicability<br>EMG | |
| Prepared<br>Earth Sciences | |
| Approved<br>D. Senovich | |

Subject
**PACKER TESTS**

## TABLE OF CONTENTS

**SECTION**

## 1.0 PURPOSE

This procedure is intended to describe methods for conducting packer (pressure) hydraulic conductivity testing in boreholes. The data obtained through packer testing is evaluated to provide information regarding the hydraulic conductivity (water transmitting capability) of the tested subsurface interval(s).

## 2.0 SCOPE

Packer testing is most commonly performed in consolidated rock formations, however, it can also be performed in unconsolidated formations under some circumstances. The testing can be performed on subsurface units either in the saturated or unsaturated zone. Packer testing may be useful in both hydrogeologic and geotechnical investigations.

## 3.0 GLOSSARY

Packer - A device used to isolate a section of a borehole which is to be hydraulically tested or sampled from upper and/or lower portions of the borehole. Pneumatic packers are typically constructed of rubber tubing slightly smaller in diameter than the borehole to be tested, and their length is several times their diameter in size. The packers are inflated with air or nitrogen (nonflammable gases) to seal off the desired test interval of the borehole. Mechanical packers also are typically made of rubber, however, sealing is achieved by shortening the length of the packer mechanically (causing an increase in diameter) rather than by inflation. Pneumatic packers are more common than mechanical packers. Packers are used either singly or in pairs to isolate portions of a borehole. Packer lengths should be at least five times as long as the borehole diameter.

Water Pressure Gauge - A gauge which measures the water pressure at which the packer test is being performed. The pressure gauge measures pressure in pounds per square inch (psi) and should be capable of measuring to a resolution and accuracy of ±2 psi. During the performance of a packer test, the water pressure gauge reading should remain constant at the desired pressure. For maximum accuracy, the pressure range of the gauge should be close to the maximum expected testing pressure. For example, if the tests are to be run at pressures up to 60 psi, a gauge with a range of 0-100 psi should be used, not one with a range of 0-2,000 psi. The water pressure gauge should be installed either on the elbow connected to the waterline coming out of the borehole or on the water line between the elbow and the packers, for maximum accuracy.

Water Flow Meter - The water flow meter is used to measure the amount of flow into the formation during the performance of a packer test. Flow meters measure in gallons or cubic feet ($ft^3$) normally, and measure the total amount of flow, not the rate of flow. Flow meters should have a resolution and accuracy of 0.1 gallons or 0.01 $ft^3$.

## 4.0 RESPONSIBILITIES

The field geologist is responsible for determining packer test intervals, testing pressures and testing times. He/she should also check the test setup to ensure that the proper equipment is being used and is connected in the proper sequence. During the actual performance of the test, the field geologist is responsible for collecting time/water flow data and obtaining the necessary data regarding the packer test setup (static water level, depth to test interval, height of swivel above ground, packer test interval, packer pressures, water pressures, borehole size, etc.).

## 5.0 PROCEDURE

### 5.1 TESTING PROCEDURE

Once the need for packer testing has been established and the required equipment gathered, the field geologist should identify the interval(s) of the borehole to be packer tested. Typical packer testing zones can be fracture zones or unfractured intervals of a formation that are thought to be permeable, for identifying water yielding zones, or intervals of suspected low permeability, to identify possible confining layers to groundwater flow. The field geologist should have the boring log present as a reference during packer testing operations, as well as any rock core obtained from the boring to be tested. When testing several discrete intervals within a borehole, a double packer assembly is generally used, with packers spaced 5-10 feet apart. The test length selected should be at least five times as long as the borehole diameter, except in special circumstances where one discrete fracture or thin water bearing zone is to be isolated and tested. If only one or two intervals near the bottom of the borehole are to be tested, a single packer assembly may be used. Prior to testing, the borehole should be flushed out to remove cuttings/mud which may affect the test.

After the final design of the packer test has been decided upon, the equipment required should be assembled and installed. Exhibit A illustrates typical packer test setups. Along with the packers, water line, air line, and air tank/valves/gauges (for pneumatic packers), the required elements of the test apparatus include a pump (to pump water into the system under pressure), a bypass value (used to control the water pressure during the test), the water flow meter, and the water pressure gauge. A surge chamber may be required if the pump does not pump at a steady pressure, to compensate for cyclic variations in pumping pressures. The flow valve can be used to isolate the downhole portion of the packer test assembly from the remaining portion, in order to perform a holding test if desired. The bypass valve may also be used for this purpose.

Once the packer testing setup is assembled and installed to the initial interval to be tested, the packers should be inflated/expanded to isolate the testing interval. Pneumatic packers should not be overpressured, as this may cause a blow out. Generally, 80-140 psi inflation pressure is adequate for most testing applications. After packer inflation, water is pumped through the system at the desired pressure. The selected water pressure(s) used vary with testing situations. The maximum testing pressure which may be used can be calculated by the formula Pmax = 10psi + 1 psi/ft of depth to the top of the tested interval. A good rule of thumb to ensure that the formation tested is not overpressured, which could hydraulically fracture or jack the rock mass, is to not exceed 1 psi/ft of depth or 100 psi total, whichever is lower. It is generally advisable to perform 2-3 tests at each test interval, which can be done at different pressures (example: 20, 40, and 60 psi) or at the same pressure. The bypass valve is used to control water pressures in the system. As more water is routed out of the bypass line, pressure in the testing portion of the system is decreased, and vice versa.

After water pressure has stabilized at the desired testing pressure, the test should be started. The flow meter reading at the beginning of the testing period should be recorded, then flow meter readings should be taken at 15-30 second intervals for the duration of the test. A minimum of 5 minutes of readings should be taken for each test. All time/flow measurements should be recorded on the packer test report form provided as Exhibit B, along with other pertinent data. If higher than expected water flow through the system occurs during the test, the test should be repeated using the same water pressure but increasing the packer air pressure, to check for leakage around the packers. If the flow rate decreases, then leakage occurred during the previous test. Also, if water levels rise in the borehole/borehole casing during the test, leakage around the packers may be occurring, invalidating the test results. If no measurable flow occurs within 5-10 minutes of testing, a holding test can be performed for several minutes as a check. The flow or bypass value is shut to completely isolate the system, then the water pressure gauge is checked for a drop in pressure over time. The water pressure should remain essentially unchanged during the period of isolation if the formation tested is not taking any water. Generally, if the formation does not take water at the initial test pressure, there is no need to repeat the test at a higher water pressure. After the completion of testing at one interval, the downhole packer assembly should be moved to the next interval to be tested, and the testing procedure repeated.

## 5.2 DATA EVALUATION

Formulas for evaluating pressure testing data are given in U.S. Department of Interior publication; Groundwater Manual (1981). The formulas have the best validity when stratum thickness is at least 5 times the length of the hole tested and are considered more accurate for tests in the saturated zone than unsaturated zone. For convenience the formula for pressure testing can be written:

$$K\left(\frac{Ft}{Yr}\right) = C_p \frac{Q\,(gal/min)}{H\,(feet)}$$

Where: H = head of water acting on the test length. In tests in the saturated zone H is the distance from the water table to the swivel plus the applied pressure in units of feet of water. Where the test zone is above the water table in the unsaturated zone H is the distance from the center of the length tested to the swivel plus the applied pressure in feet of water. For gravity tests, where water is added but no pressure is applied, measurements for H are made to the water level inside the casing. For highly permeable formations, head loss due to friction in the piping may significantly alter the testing results. If desired, the head loss due to friction can be factored in using the tables provided in the Ground Water Manual. Alternatively, head loss curves can be determined more accurately by laying out and connecting the water pipe on the ground, attaching pressure gauges to both ends of the piping,then pumping water through the piping at varying pressures and generating head loss curves through the pressure gauge readings. The outflow end of the pipe must be constricted by use of a valve so that varying pressure build-ups within the piping can be created and maintained.

K = Hydraulic conductivity, ft/yr
Q = Rate of inflow, gallons per minute (gpm)
L = Length of test section, ft

Values of Cp for common borehole sizes are given in the following table:

| Length of Test Section in Feet, L | Cp Values | | | |
|---|---|---|---|---|
| | Boring Sizes | | | |
| | EX(1.5") | AX(1.875") | BX(2.37") | NX(3.0") |
| 1 | 31,000 | 28,500 | 25,800 | 23,300 |
| 2 | 19,400 | 18,100 | 16,800 | 15,500 |
| 3 | 14,400 | 13,600 | 12,700 | 11,800 |
| 4 | 11,600 | 11,000 | 10,300 | 9,700 |
| 5 | 9,800 | 9,300 | 8,800 | 8,200 |
| 6 | 8,500 | 8,100 | 7,600 | 7,200 |
| 7 | 7,500 | 7,200 | 6,800 | 6,400 |
| 8 | 6,800 | 6,500 | 6,100 | 5,800 |
| 9 | 6,200 | 5,900 | 5,600 | 5,300 |
| 10 | 5,700 | 5,400 | 5,200 | 4,900 |
| 15 | 4,100 | 3,900 | 3,700 | 3,600 |
| 20 | 3,200 | 3,100 | 3,000 | 2,800 |

When testing a borehole with a diameter other than those listed above, the appropriate Cp value can be calculated using the formula $Cp = (1/2\pi) \ln (L/r) (70, 315.5)$ where $r$ = borehole radius in feet.

An example of pressure testing data evaluation is presented below:

Nx casing set to a depth of 5 feet
Q = 2.2 gal/min
L = 1 foot
h(gravity) = distance from groundwater level to gauge
= 3.5 feet
h(pressure) = 5 psi x 2.31 = 11.6 feet of water
H = h(gravity) + h(pressure) = 15.1 feet
From table Cp = 23,300

$$K = Cp\frac{Q}{H}$$

$$= \frac{(23{,}300)(2.2)\ \text{feet}}{15.1\ \text{yr}}$$

= 3,395 ft/yr
= $3.3 \times 10^{-3}$ cm/sec

This SOP presents guidelines for performing packer pressure testing to determine formation hydraulic conductivities. Packers can also be utilized to perform gravity tests (slug tests) or to perform groundwater sampling operations. Slug testing using packers can be performed by applying the methodologies described in ES-11.0, In-Situ Hydraulic Conductivity Testing. It should be noted that the radius of the water pipe should be used in place of well casing radius in calculations for evaluating slug test data when packers are used. Sampling can be performed using packers, by installing a submersible pump in between the packers and modifying the design of the system appropriately.

## 5.3 REVIEW, REVISION, AND APPROVAL

All packer testing data and calculations should be reviewed by senior level personnel to check for completeness and accuracy. The person reviewing the calculations should indicate approval of the data/calculations by initialing the data/calculation sheets.

## 5.4 DISTRIBUTION

A copy of the approved data and calculations should be retained by the responsible geologist. Other copies should be distributed to project personnel as needed. The original data/calculation sheets should be placed in the project file. Copies may also be included in project reports when appropriate.

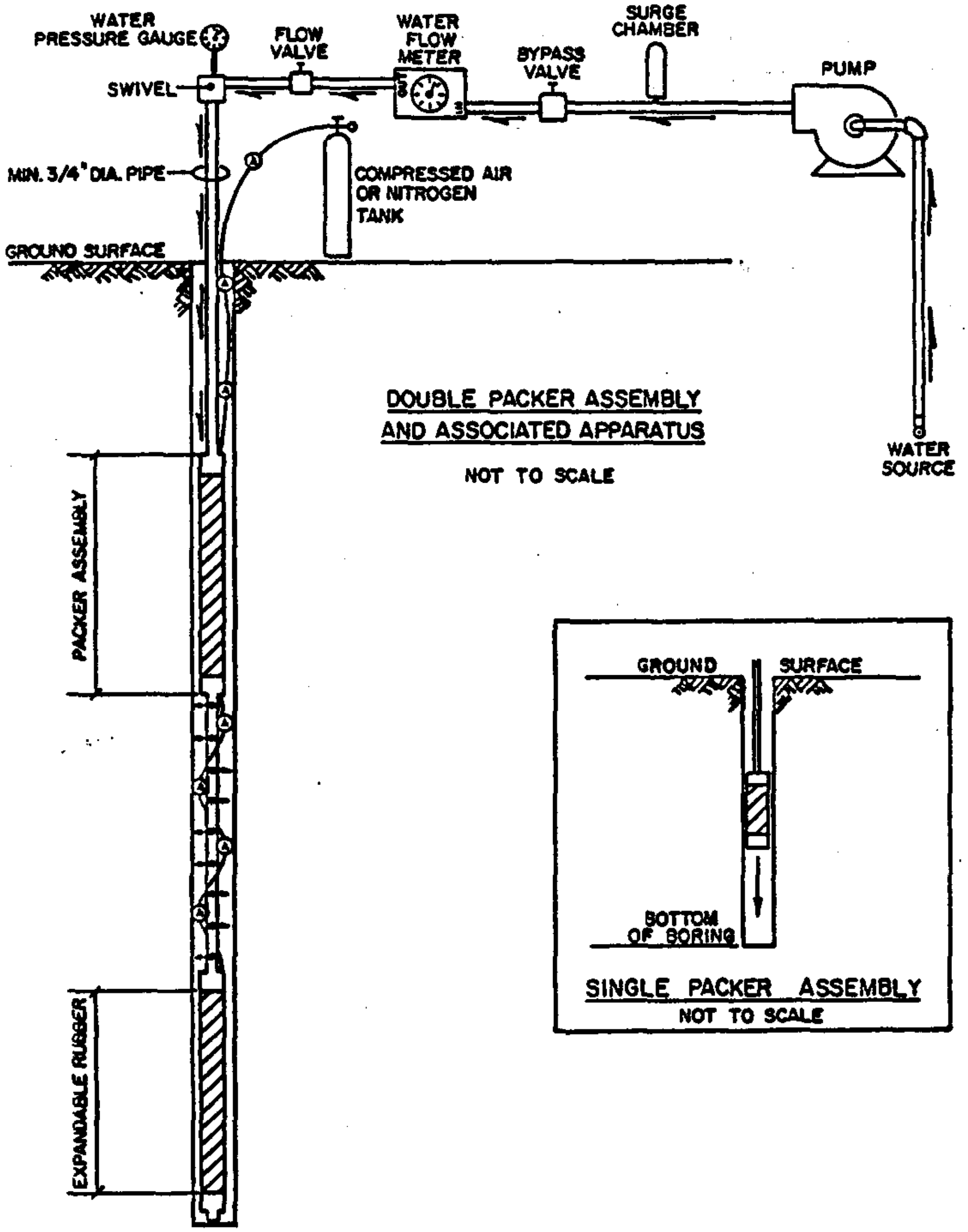
## 6.0 REFERENCES

U.S. Department of the Interior, 1974. Earth Manual, Section Edition. U.S. Government Printing Office, Washington, D.C.

U.S. Department of the Interior, 1981. Ground Water Manual. U.S. Government Printing Office, Denver, Colorado.

## 7.0 RECORDS

The Packer Testing Report Form (Exhibit B) should be used to record testing data. Supplemental information, if required, should be recorded in the field logbook. The boring log should be available for use as a reference during packer testing and data analysis activities.



DOUBLE PACKER ASSEMBLY AND ASSOCIATED APPARATUS

NOT TO SCALE

SINGLE PACKER ASSEMBLY

NOT TO SCALE

EXHIBIT A

TYPICAL PACKER TEST SETUPS

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# EXHIBIT B
# PACKER TESTING REPORT FORM

## PACKER TEST REPORT

PROJECT: ______________________
BORING NO.: ____________ CASING DEPTH: ____________
TEST INTERVAL: ______________________
PROJECT NO.: ______________ TEST NO: ____________
CONTRACTOR: ______________________
BY: ______________ CHECKED: ____________
PAGE ____ OF ____
STATIC WATER LEVEL ________
PACKER PRESSURE ________

| Flow Test | | | | | Calculated Results | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Pressure, P (psi) | Elapsed Time (min) | Flow Reading | Δ Flow, ΔQ (ft³) | Δ Flow, ΔQ (gal) | Flow Rate Q (gal/min) | $H_1$* (ft) | Hp(ft) = 2.31·(psi) | $H_2$* (ft) | H = Hp + (H1 or H2) | Cp | K (ft/yr) = Cp·Q/H | K (cm/sec) = 9.67 x 10⁻⁷ · K (ft/yr) |
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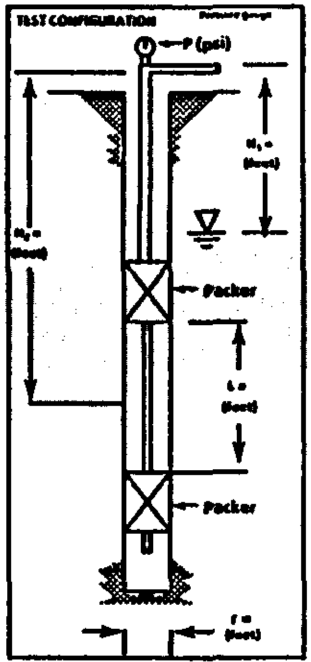
CP = (1/(2 x L)) ln (L/r) (70,315.5)
7.48 Gallons = 1 Ft³
1 psi = 2.31 ft head
Remarks: ______________________

* $H_1$ is used when the test length is below the water table.
$H_2$ is used when the test length is above the water table.



| * Length of test section in feet, L | Cp | | | |
|---|---|---|---|---|
| | Boring Size | | | |
| | [illegible] | [illegible] | [illegible] | [illegible] |
| 1 | [illegible] | [illegible] | [illegible] | [illegible] |
| 2 | [illegible] | [illegible] | [illegible] | [illegible] |
| 5 | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 10 | [illegible] | [illegible] | [illegible] | [illegible] |
| 15 | [illegible] | [illegible] | [illegible] | [illegible] |
| 20 | [illegible] | [illegible] | [illegible] | [illegible] |

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| Applicability<br>EMG | |
| Prepared<br>Earth Sciences | |
| Approved<br>D. Senovich | |

Subject
AQUIFER PUMPING TESTS

## TABLE OF CONTENTS

## 1.0 PURPOSE

The objective of this procedure is to provide general reference information and technical guidance on the performance and evaluation of pumping tests.

## 2.0 SCOPE

This procedure gives overall technical guidance for the performance and evaluation of pumping tests performed as a part of a field investigation. The methodologies presented should be modified to meet the requirements/constraints of specific projects.

Pumping test data analysis is subject to much interpretation, therefore, evaluation of the test results should be performed by an experienced hydrogeologist familiar with pumping test analytical techniques and interpretation. Due to the complexity of some of the evaluation methods and the wide variety of corrections which may be required to be factored into the data obtained, this guideline presents only a general overview of the pumping test evaluation process. The references provided in Section 6.0 should be consulted for detailed discussions regarding pumping test evaluation techniques.

## 3.0 GLOSSARY

Cone of Influence - The area around a discharging well where the hydraulic head in the aquifer has been resultingly lowered. Also called cone of depression.

Confined Aquifer - An aquifer that is overlain and underlain by strata of lower permeability. The potentiometric surface of a confined aquifer is higher than the base of the upper confining layer at any given point.

Discharge (Q) - Volume of water removed per unit time.

Drawdown (S) - Difference between the elevation of initial static water level and the water level position at a given time during pumping.

Hydraulic Conductivity (K) - A quantitative measure of the ability of porous material to transmit water. Volume of water that will flow through a unit cross sectional area of porous material per unit time under a head gradient. Hydraulic conductivity is dependent upon properties of the medium and fluid.

Pumping Test - A test made by pumping a well for a period of time and observing the resulting change in hydraulic head in the aquifer. A pumping test may be used to determine the hydraulic characteristics of the aquifer and the capacity of the pumped well.

Specific Capacity (SC) - Rate of yield per unit drawdown. Often expressed as gallons per minute per foot of drawdown.

Specific Storage - The amount of water released from or taken into storage per unit volume of aquifer per unit change in head.

Specific yield - The ratio of the volume of water a rock or soil will yield by gravity drainage to the total volume of the rock or soil.

Storage Coefficient (S) - Volume of water an aquifer releases from or takes into storage per unit volume of aquifer per unit change in head. The product of specific storage times saturated thickness. Also called storativity.

Transmissivity (T) - A quantitative measure of the ability of an aquifer to transmit water. The product of the hydraulic conductivity times saturated thickness.

## 4.0 RESPONSIBILITIES

Project Hydrogeologist - The project hydrogeologist has the responsibility of determining the need to perform a pumping test or tests for a site investigation. Factors that should be taken into account when considering whether a pumping test should be performed or not include:

- Project objectives and the data required to meet these objectives.
- The amount and accuracy of hydrogeologic data currently available.
- Cost and schedule constraints.
- Physical site limitations (discharge of contaminated/uncontaminated water, aquifer water yielding capability, access, etc.)

Pumping tests (especially long-term tests) can be time consuming, labor intensive, and costly. On the other hand, pumping tests generally yield the most accurate data regarding aquifer characteristics that can be obtained, when designed, performed, and evaluated properly. Specific uses for pumping tests include:

- Determination of aquifer hydraulic characteristics.
- Determination of the extent of influence of a pumped well.
- Design of groundwater withdrawal systems (for groundwater treatment or water supply).
- Determination of the interconnection between water bearing formations.
- Identification of aquifer boundaries (recharge/discharge boundaries).

Once the need to perform a pumping test has been established, the project hydrogeologist is responsible for the design and oversight of the pumping test, including identifying the wells to be used, designing and locating the pumping and observation wells as needed, specifying methodologies to be used, and determining the length of time of the test. The project hydrogeologist should ensure that all field personnel involved are familiar with the planned test and the field operations related to the performance of the test. During the startup of the pumping test, the project hydrogeologist may need to be onsite to ensure that proper field procedures are used. Data generated during the performance of the pumping test should be concurrently reviewed by the project hydrogeologist to identify any modifications to the planned procedure that may be required during the performance of the test. Data reduction/evaluation should be performed under the supervision of the project hydrogeologist.

Field Personnel - All field personnel should be familiar with the overall methodology of performing pumping tests, as well as being familiar with the specific requirements of each individual test that they will participate in. The field personnel should be familiar with the types and uses of the various field equipment required for the performance of a pumping test (surface or submersible pumps, generators, water level measuring devices, data sheets, support equipment). It is the responsibility of the field personnel to alert the project hydrogeologist/project manager to any unexpected conditions that may be encountered that would require modifications to the planned procedure, and perform the test as described in the Field Operations Plan (with approved modifications as required). Once the pumping test has been completed, field personnel are to assist the project geologist in the process of data reduction/evaluation.

## 5.0 PROCEDURES

### 5.1 PLANNING FOR A PUMPING TEST

The need for and design of a pumping test is determined largely by the project goals and geologic/hydrogeologic conditions within the study area. The pumping test should be set up so that the results obtained will be representative of the area under study.

As much information as possible should be collected and evaluated before running a pumping test. This includes data regarding physical and hydraulic characteristics of the aquifer, groundwater flow direction, hydraulic gradients, velocity, regional water level trend, the existence of other pumping wells in the vicinity of the test area, and the expected quality/quantity of the discharge water.

The placement and design of the pumping well is critical to the success of the pumping test. Placement of the well is dependent on pumping test objectives and local geologic conditions. In general, the pumping well should fully penetrate the aquifer to be pumped, and be screened across the entire saturated interval of the aquifer. Due to project constraints, this is often not the case, and corrections must be factored into the data analysis.

If an existing well is to be used for a test, the well should closely conform to the requirements for aquifer testing. Boring logs, construction data, and performance characteristics of other wells in the area should be examined to develop a preliminary estimate of the aquifer characteristics. Transmissivities can be estimated from the boring logs and preliminary testing.

Any number of observation wells may be used. The number chosen depends on maintaining a balance between cost and need to obtain the maximum amount of accurate and reliable data. If three of four observation wells are to be installed in the pumped aquifer, all but one well should be installed along a radial line from the pumping well, with the remaining well placed along a line normal to the line of observation wells and passing through the pumping well, to detect any radial anisotropy within the aquifer. If two observation wells are to be installed, they should be placed in a straight line away from the pumping well. In a fracture controlled bedrock flow system, joint orientations should be considered when deciding where to place observation wells.

When a pumping well does not fully penetrate an unconfined aquifer (any well with an 85 percent or more open or screened hole in the saturated thickness may be considered as fully penetrating), the observation wells should be located at a minimum distance equal to 1-1/2 to 2 times the aquifer thickness from a partially penetrating pumping well, to minimize the effect of flow field distortions resulting from pumping a partially penetrating well.

If the confined aquifer is not thick, the pumping well should be screened for the entire thickness of the aquifer. The nearest observation well should be located at least 25 feet from the pumping well and should penetrate and be screened in the middle portion of the aquifer.

Observation wells screened within the aquifer that is being pumped will provide information regarding aquifer characteristics. Wells screened in an overlying or underlying aquifer will provide information regarding the degree of interconnection between aquifers. If an observation well is screened in an overlying aquifer, it should be placed close to the pumping well so that the response of the overlying aquifer is monitored at a point where the difference in head between aquifers is relatively large.

The pumping and observation well configurations and locations described above are not requirements, but are suggested setups to maximize the accuracy of the data generated. In many instances, less than ideal conditions regarding screened intervals/depths and observation well numbers/locations will be encountered due to project constraints. Valid pumping tests can still be performed if the wells used do not conform to the ideal setup.

Single well pumping tests can be performed when project constraints do not allow for the installation of observation wells. The data obtained from these tests is less accurate than for tests performed using observation wells, and specific yield/specific storage cannot be determined. Drawdown measurements in a pumped well may not reflect the actual drawdown in the adjacent aquifer due to well inefficiency, so this factor must be considered when interpreting results.

## 5.2 PREPARATION FOR A TEST

For a few days before starting a long term pumping test, water levels in the pumping well and observation wells should be measured at about the same time each day to determine whether there is a measurable trend in groundwater levels. If such a trend is apparent, a graph of the change in water level versus time should be prepared and used to correct the water levels obtained during the test.

Pumping wells should undergo a preliminary pumping prior to the actual test to ensure that the well will function at it's maximum efficiency. This will enable fines to be flushed from the formation and a steady flow rate to be established. The preliminary pumping should determine the maximum drawdown in the well at a given pumping rate and establish the pumping rate for the later test. The aquifer should then be given adequate time to fully recover before the pumping test is begun.

Step-drawdown tests can be performed prior to the actual pumping test, to determine the optimum pumping rate for the test. A step-drawdown test consists of pumping a well at several successively higher rates, for a given time period (1/2-2 hours) for each rate, and measuring the rate of drawdown for each pumping rate. If possible, the well should be allowed to recover between tests. The resulting data generated can be used to predict drawdown versus time over an extended period for various pumping rates.

Barometric changes may affect water levels in wells. An increase in barometric pressure may cause a decrease in the water level. The response of wells to changes in barometric pressure should be determined in order to correct the measurement of water levels during a long term pumping test.

A record should be maintained of the pumping times and discharge rates of other pumping wells in the vicinity if their radius of influence intersects the cone of depression of the pumping test well.

In areas of severe winter climate, where the frostline may extend to depths of several feet, pumping tests should be avoided during the winter where the water table is near ground surface. Under some circumstances, the frozen soil acts as a confining bed, combining with leaky aquifer and delayed yield characteristics to make the results of the test unreliable.

## 5.3 CONDUCTING A TEST

Immediately before the pump is started, the water levels should be measured in the pumping well and all observation wells to determine the static water levels upon which drawdowns will be based. These data and the time of measurement should be recorded on the pumping test data sheet (see Attachment 1).

It may be useful to collect water samples from the pumping well (at least) before and after pumping. This data can give an indication of changes in groundwater quality due to pumpage.

Critical data that must be collected for each pumping test includes the time that pumping started and ended, water level measurements during the test, periodic measurements of the pumping rate, and the distances between the pumping well and the observation wells.

Pump selection depends on the expected pumping rate and the physical constraints of the test (depth to water, expected total drawdown, pumping well diameter). Pump size is related to the required discharge capacity and the well diameter. Submersible pumps or air-lift set-ups are required when the drawdown of the water level is expected to exceed 25 feet below ground surface. Suction pumps can be used if total drawdown is not expected to exceed 25 feet.

Once pumping is initiated, the flow rate should immediately be measured and adjusted as necessary to achieve a constant discharge at the desired rate. The discharge rate should be checked, adjusted, and recorded frequently during the performance of the test, especially during the early stages of the test. The initial pumping rate should not be the maximum rate that the pump is capable of, as progressive drawdown may decrease the pump's efficiency, thereby reducing the discharge rate. If the pump is initially operating at less than full capacity, the decrease in efficiency can be countered by *increasing the pump speed or, if the discharge rate is controlled through a valve (as is more typical),* opening the value further. Pumping rates can be monitored using a flowmeter or, for low volume pumping tests, a stopwatch and calibrated bucket can be used to measure discharge rates.

The tone or rhythm of an internal-combustion engine provides a check of performance. If there i sudden change in tone, the discharge should be checked immediately and proper adjustments made to the gate valve or to the engine speed if necessary.

At least 10 observations of drawdown within each log cycle of time should be measured in the pumping well and observation wells. Continuous water level recording for the nearest observation wells to the pumping well can be extremely useful. A suggested schedule for measurements is as follows:

- 0 to 10 minutes: 0.0, 0.5, 1, 1.5, 2, 2.5, 3, 4, 5, 6.5, 8, and 10 minutes. It is important in the early part of the test to record with maximum accuracy the time at which readings are taken.
- 10 to 100 minutes: 10, 15, 20,25, 30, 40, 50, 60, 80, and 100 minutes.
- 1- to 2-hour intervals: To the end of 1 day.
- 500- to 1,000-minute intervals: After first day

Initially, there should be enough manpower available to station a minimum of one person at each well used in the pumping test, unless continuous water level recorders or pressure transducers and *data loggers are used. After the first two hours of the pumping test, two people are usually sufficient* to continue the test.

The total *pumping time for a test depends on the type of aquifer and degree of accuracy desired, and* can range from less than 2 hours to several days. Economizing on the period of pumping is no recommended. More reliable results are obtained if pumping continues until the cone of depression reaches a stabilized condition, however, this is not always practical or necessary. The cone of depression will continue to expand at a progressively slower rate until recharge of the aquifer equals the pumping rate and a steady state condition is established. The time required to achieve steady state flow conditions may vary from less than an hour to beyond the practical limits of a pumping test. Under average conditions it is good practice to run a large scale pumping test in a confined aquifer for at least 24 hours and in an unconfined aquifer for a minimum of 72 hours. A longer period of pumping may reveal the presence of boundary conditions not previously known. Single well pumping tests or small scale tests may be run for shorter time periods. Preliminary field plotting of drawdown data should be conducted during the test to evaluate how the test is progressing and how much longer it should continue.

Water pumped from an unconfined aquifer during a pumping test should be disposed of in such a way so that the aquifer is not recharged by discharge water infiltration during the test, as recharge would influence the results obtained. Also, if contaminated water is pumped during the test, the water may have to be stored and treated or disposed of in an acceptable manner.

The method of disposal of discharge water from the pumping well should be planned. The discharge water could be routed to a storm sewer or surface water body if uncontaminated, or temporarily stored in tanks, drums or in a lined pit if collection is required. If necessary it should be transported and deposited to a designated secure area.

## 5.4 RECOVERY TEST

When pumping is stopped after completing the drawdown portion of the pumping test, the cumulative drawdown and time at which pumping was discontinued are recorded. The rate of recovery of the water levels in the wells should then be measured.

The same procedure and time pattern are followed as at the beginning of a pumping test, that is, the depth-to-water is periodically measured during the recovery test in the pumping well and observation wells. Recovery data should follow the same general trend as drawdown data, and is considered in many cases to be more accurate and useful for pumping test analysis than drawdown data.

The recovery data should be recorded until the aquifer fully recovers, or as long as possible within project constraints.

## 5.5 DATA ANALYSIS

A constant rate pumping test can be run to determine transmissivity and hydraulic conductivity. If the effects of pumping the well can be measured in one or more observation wells at known distances from the pumping well, the specific yield or storage coefficient can also be determined. A good check of the transmissivity value can be made using recovery data from the pumped well and of transmissivity and storage coefficient from recovery rate measurements in observation wells.

The data collection form for a sample pumping test is illustrated in Attachment A. The form can be used to record data for either the pumping well or an observation well. It should be noted that some different types of data are to be recorded for pumping versus observation wells.

The effects of all extraneous factors such as barometric pressure, tidal influence, injection interference, or other pumpage in the nearby area, can be adjusted and corrected from the measured data by applicable correlation techniques.

After correction of the raw data to eliminate or reduce the amount of extraneous interference, graphs are prepared showing resulting drawdowns versus time and/or distance; these are plotted on semi-log or log-log paper. The graphs are used to determine aquifer characteristics by matching type curves or by straight line slope analysis processes. Analytical methods not requiring the use of a graph have also been developed. Selection of the most appropriate evaluation technique is dependent on the test setup and results.

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Kruseman, G. P. and N. A. DeRidder, 1979. Analysis and Evaluation of Pumping Test Data. International Institute for Land Reclamation and Improvement, P.O. Box 45, 6700 AA Wageningen, Netherlands.

Lohman, S. W., 1979. Ground-Water Hydraulics - Geological Survey Professional Paper 708. United States Department of the Interior, U.S. Government Printing Office, Washington, D.C.

United States Department of the Interior, 1981. Groundwater Manual. United States Government Printing Office, Denver, Colorado.

## 7.0 ATTACHMENTS

Attachment A, the Pumping Test Data Sheet, should be used to record data from pumping and observation wells. A written log of the field setup and performance of the pumping test should also be kept, describing procedures used, daily activities, and any other pertinent observations made prior to, during, and following the test.

***PUMPING TEST DATA SHEET*** ***NUS CORPORATION***

PROJECT NAME: ____________ MEASURED WELL: ________
PROJECT NO.: ____________ DATE: ________ PUMPING WELL: ________
GEOLOGIST: ____________ CHECKED: ________ TEST NO.: ________
DISTANCE FROM PUMPING WELL(ft.)(r): ________ PUMP SETTING, FEET BELOW MONITORING POINT: ________
STATIC $H_2O$ LEVEL (ft.)($s_o$): ________ MONITORING POINT: ________
TIME PURGE START OR STOP ($t_o$): ________ ELEVATION OF MONITORING POINT (ft. above MSL): ________

| TIME | (t) MIN. SINCE PUMP START OR STOP | WATER LEVEL MEASUREMENTS (ft.) | | | (s) DD Or RECOVERY (ft.) | PUMPING RATE (Q) GPM | REMARKS |
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| **NUS CORPORATION**<br>**ENVIRONMENTAL MANAGEMENT GROUP** | **STANDARD OPERATING PROCEDURES** | Number<br>GH-2.4 | Page<br>1 of 7 |
| | | Effective Date<br>05/04/90 | Revision<br>2 |
| | | Applicability<br>EMG | |
| | | Prepared<br>Earth Sciences | |
| Subject<br>IN-SITU HYDRAULIC CONDUCTIVITY TESTING | | Approved<br>D. Senovich | |

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## 1.0 PURPOSE

This guideline is intended to describe procedures for performing in-situ hydraulic conductivity testing (slug testing) in boreholes and monitoring wells, and provide a short description of commonly used evaluation techniques for the data generated. Slug tests are used to provide data regarding the hydraulic properties of the formation tested. A variation of the slug test, called a constant-head test, is also briefly described.

## 2.0 SCOPE

Slug tests are short-term tests designed to provide approximate hydraulic conductivity values for the portion of a formation immediately surrounding the screened/open interval of a well or boring. These tests are less accurate than pumping tests, as a much more localized area is involved, so a number of slug tests are performed and averaged to determine a representative hydraulic conductivity value for the formation tested. Slug tests may be preferable to pumping tests in situations where handling of large volumes of contaminated water is a concern or when time/budget constraints preclude the more expensive and time-consuming setup and performance of a pumping test.

Constant-head tests also are used to determine hydraulic conductivity values and are similar to slug tests in regards to the quality of data obtained and time/cost considerations. A disadvantage to constant-head tests is that a significant volume of water may be added to the formation, potentially affecting short-term water quality.

## 3.0 GLOSSARY

Hydraulic Conductivity (K) - A quantitative measure of the ability of porous material to transmit water. Volume of water that will flow through a unit cross sectional area of porous material per unit time under a head gradient. Hydraulic conductivity is dependent upon properties of the medium and fluid. Common units of expression include centimeters per second (cm/sec), feet per day (ft/day), and gallons per day per foot$^2$ (gpd/ft$^2$).

Transmissivity (T) - A quantitative measure of the ability of an aquifer to transmit water. The product of the hydraulic conductivity x saturated thickness.

Slug-test - A rising head or falling head test used to measure hydraulic conductivity. A slug test consists of instantaneously changing the water level within a well and measuring the rate of recovery of the water level to equilibrium conditions. Slug tests are performed by either withdrawing a slug of water (rising head test) or adding a slug of water (falling head test), then measuring recovery over time. A solid slug of known volume can be used to displace a volume of water, thereby simulating the addition or removal of water.

## 4.0 RESPONSIBILITIES

The project geologist shall evaluate the type(s) and extent of hydraulic testing required for a given project during the planning process, and design the field program accordingly. The project geologist also shall ensure that field personnel have the necessary training and guidance to properly perform the tests, and oversee data reduction activities, including selecting the appropriate evaluation techniques and checking calculations for accuracy.

The field geologist is responsible for performing the planned field tests as specified in the planning documents, or as directed by the project geologist shall the field program require modification, and generally assists in the data evaluation process. The field geologist shall be knowledgeable in the testing methodologies required and is responsible for obtaining the necessary support equipment required to perform the field tests. All applicable data regarding testing procedures, equipment used, well construction, and geologic/hydrogeologic conditions shall be recorded by the field geologist. The field geologist shall be familiar enough with testing procedures/requirements to be able to recommend changes in methodology, should unanticipated field conditions be encountered.

## 5.0 PROCEDURES

### 5.1 IN-SITU HYDRAULIC CONDUCTIVITY TESTING IN WELLS

Slug tests are commonly performed in completed wells. Prior to testing, the well shall be thoroughly developed and allowed to stabilize, in order to obtain accurate results. Once the water level within the well has stabilized, it shall be quickly raised or lowered and the rate of recovery measured.

One of the basic assumptions of slug testing is that the initial change in water level is instantaneous; therefore, an effort shall be made to minimize the time involved in raising or lowering the water level initially. Various methods can be used to induce instantaneous (or nearly instantaneous) changes in water level within the well. A rise in water levels can be induced by pouring water into the well. A solid slug of known volume, quickly lowered below the water level within the well, will displace an equivalent volume of water and raise the water level within the well. The slug can be left in place until the water level restabilizes at the static water level, then suddenly removed to create a drop in water level within the well. An advantage of using a solid cylinder of known volume to change the water level (slug test) is that no water is removed or added to the monitoring well. This eliminates the need to dispose of contaminated water and/or add water to the system, which might raise doubts regarding the representativeness of future groundwater samples. A bailer or pump can be used to withdraw water from the well. (If a pump is used, pumping shall not continue for more than several seconds so that a cone of depression is not created which would adversely impact testing results. The pump hose shall also be removed from the well during the recovery period, as data analysis techniques involve volume of recovery versus time, and leaving the hose within the well would distort the calculated testing results by altering the apparent volume of recovery.) Falling head slug tests should only be performed in wells with fully submerged screens, while rising head slug tests can be performed in wells with either partially or fully submerged screens/open intervals.

Other methods that can be used to change water levels within a well include creating a vacuum or a high pressure environment within the well. The vacuum method will raise water levels within the well, while the pressure method will depress the water level in the well. These methods are particularly useful in highly permeable formations where other methods are ineffective in creating measurable changes in water levels. Both methods are limited to wells which have completely submerged screens.

Rate of recovery measurements shall be obtained from time zero (maximum change in water level) until water level recovery exceeds 90 percent of the initial change in water level. In low permeability formations, the test may be cut off short of 90 percent recovery due to time constraints. Time intervals between water level readings will vary according to the rate of recovery of the well. For a moderately fast recovering well, water level readings at 0, 0.1, 0.2, 0.3, 0.4, 0.5, 0.75, 1.0, 1.25, 1.5, 2.0, 2.5, 3.0, 4.0, . . . minutes may be required. With practice, readings at down to 0.05-minute (3 seconds) time intervals can be obtained with reasonable accuracy, using a pressure transducer and hand held readout. For wells which recover very fast, a pressure transducer and data logger may be required to obtain representative data. Time intervals between measurements can be extended for slow recovering wells. A typical schedule for measurements for a slow recovering well would be 0, 0.25, 0.5, 0.75, 1.0, 1.5, 2.0, 3.0, 4.0, 6.0, 8.0, 10.0, 15.0, 20.0, 30.0, . . . minutes from the beginning the test. Measurements shall be taken from the top of the well casing.

Water level measurements can be obtained using an electric water level indicator, popper, or pressure transducer. Steel tape, coated with chalk or water sensitive paste although very accurate, is a slower method of obtaining water levels and is generally not recommended for use due to the frequency at which water levels need to be taken during the performance of a slug test.

The following data shall be recorded when performing slug tests in wells or borings:

- Well/boring ID number
- Total depth of well/boring
- Screened/open interval depth and length
- Gravel pack interval depth and length
- Well and boring radii
- Well stickup above ground surface
- Gravel pack radius
- Static water level
- Aquifer thickness
- Depth to confining layer
- Time/recovery data
- Gravel pack porosity

A variation of the slug test is a test in which water is added to the well at a measured rate sufficient to maintain the water level in the well at a constant height above the static water level, and is called a constant-head test. Once a stable elevated water level has been achieved, discharge (pumping) rate measurements shall be recorded in place of time/recovery data for approximately 10 to 20 minutes, then the hydraulic conductivity calculated from this. This type of test is generally not recommended for monitoring wells as large volumes of water may be introduced into the screened formation, potentially impacting later sampling events.

## 5.2 IN-SITU HYDRAULIC CONDUCTIVITY TESTING IN BORINGS

Slug tests can be performed in borings while the boring is being advanced. This permits testing of formations at different depths throughout the drilling process. Boreholes to be tested shall be drilled using casing, so that discrete depths may be investigated. Various tests and testing methods are described below. The most appropriate test and testing method to be used in a situation varies with drilling, geologic, and general site conditions and shall be selected after a careful evaluation of the above factors.

Rising head or falling head slug tests can be performed in saturated and unsaturated formations during drilling. There are two ways that the tests can be performed. One way entails setting the casing flush with the bottom of the boring when the desired testing depth has been reached. The hole is then cleaned out to remove loose materials, the drill bit and rods are carefully withdrawn from the boring, and a few feet of sand (of higher permeability than the surrounding formation) is added to the bottom of the boring. After the water level in the boring has stabilized (for saturated formations), the static water level shall be measured and recorded. The water level shall then be raised (falling head test) or lowered (rising head test) and the change in water level measured at time intervals as determined by the field hydrogeologist. Only falling head tests can be performed for depth intervals within the unsaturated (vadose) zone. As described for wells, time intervals for water-level measurements will vary according to the formation's hydraulic conductivity. The faster the rate of recovery expected, the shorter the time intervals between measurements shall be. A predetermined pattern of time intervals shall be used during each test. The rate of change of water level will be used to calculate hydraulic conductivity. The test shall be conducted until the water level again stabilizes, or for a minimum of 20 minutes. In low permeability formations, it is not always practical to run the test until the water level stabilizes, as it may take a long time to do so. The top of the casing shall be used as the reference point for all water level measurements.

The second method consists of placing a temporary well with a short screen into the cleaned out boring, pulling the drilling casing back to expose the screen, allowing the formation to collapse around the screen (or placing a sand/gravel pack around the screen), and performing the appropriate hydraulic conductivity test in the well, as described for the first method. Again, the test shall be conducted until the water level stabilizes or for a minimum of 20 minutes. this method allows for. *testing a larger section of the formation and results in more reliable hydraulic conductivity estimates.*

Constant head tests may also be performed in borings. As described for monitoring wells, once a stable elevated level has been achieved, the discharge rate into the boring is measured for a period of time, usually 10 to 20 minutes, and the hydraulic conductivity calculated from this. This method is the most accurate method depicted in this section and shall be given preference over others if the materials are available to perform the test and the addition of water to the boring does not adversely impact project objectives. Once the test is over, additional information can be gathered by measuring the rate of the drop in water level in the boring (for saturated formations). A limitation of the test is that foreign water is introduced into the formation which must be removed from the well area by natural or artificial means before a representative groundwater sample can be obtained.

Detailed descriptions regarding the performance of borehole hydraulic conductivity tests and subsequent data analysis techniques are provided in Ground Water Manual (1981).

## 5.3 DATA ANALYSIS

There are a number of data analysis methods available for use to reduce and evaluate slug testing data. The determination of which method is most appropriate shall be made based on the testing conditions (including physical setup of the well/boring tested, hydrogeologic conditions, and testing methodology) and the limitations of each test analysis method. Well construction details, aquifer type (confined or unconfined), and screened/open interval (fully or partially penetrating the aquifer) shall be taken into account in selecting an analysis method. Cooper, et al. (1967), and Papadapulos, et al. (1973), have developed test interpretation procedures for fully penetrating wells in confined aquifers. Hvorslev (1951) developed a relatively simple analytical procedure for point piezometers in an infinite isotropic medium. In Cedergren (1967), Hvorslev presents a number of analytical procedures which cover a wide variety of hydrogeologic conditions, testing procedures, and well/boring/ piezometer configurations. Bouwer and Rice (1976) developed an analytical technique applicable to both unconfined and confined conditions, factors in partial/full penetration, and discusses well screen gravel pack considerations. The Ground Water Manual (1981) presents a number of testing and test analysis procedures for wells and borings open above or below the water table, and for both falling-head and constant-head tests. The methods described above do not represent a complete listing of test analysis methods available, but are some of the more commonly used and accepted methods. Other methods can be used, at the discretion of the project hydrogeologist.

One consideration to be noted during data analysis is the determination of the screened/open interval of a tested well. If a well with a fully submerged screen is installed in a relatively low permeability formation, and a gravel pack which is significantly more permeable is installed around the screen, the length of the gravel pack (if longer than the screened interval) may be used as the screened/open length, rather than the screen length itself. In situations where the formation permeability is judged to be comparable to the gravel pack permeability (within about an order of magnitude) this adjustment is not required.

All data analysis applications and calculations shall be reviewed by technical personnel thoroughly familiar with testing and test analysis procedures. Upon approval of the calculations and results, the calculation sheets shall be initialed and dated by the reviewer. Distribution copies shall be supplied to appropriate project personnel and the original copy stored in the project file.

## 6.0 REFERENCES

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Bouwer, H. and R. C. Rice, 1976. "A Slug Test for Determining Hydraulic Conductivity of Unconfined Aquifers with Completely or Partially Penetrating Wells." Water Resources Research, 12:423-28.

United States Department of the Interior, 1981. Ground Water Manual. U.S. Government Printing Office, Denver, Colorado.

## 7.0 RECORDS

Field data shall be recorded on the data sheet included as Attachment A*. Any notes regarding testing procedures, problems encountered, and general observations not included on the data sheet shall be noted in the field logbook. The boring log and well construction diagrams for each well/boring tested shall be used as references during testing and data analysis activities. Original data sheets shall be placed in the project file, along with the field logbook.

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* If an automated data recorder is used, the data may be displayed using the printer output from the unit. Such printouts should be annoted to include the relevant data form, or attached to the form shown as Attachment A.

## ATTACHMENT A
## HYDRUALIC CONDUCTIVITY TESTING DATA SHEET

***HYDRAULIC CONDUCTIVITY TESTING DATA SHEET*** ***NUS CORPORATION***

**PROJECT NAME:** .................................................................... **WELL/BORING NO.:** ..............................
**PROJECT NO.:** .............................. **GEOLOGIST:** ..............................................................................
**WELL DIAMETER:** .............................. **SCREEN LENGTH/DEPTH:** ..............................**TEST NO.:** ..............
**STATIC WATER LEVEL (Depth/Elevation):** ............................../...................... **DATE:** ..............................
**TEST TYPE (Rising/Falling/Constant Head):** ................................................ **CHECKED:** ..............................
**METHOD OF INDUCING WATER LEVEL CHANGE:**.............................................................. **PAGE** ____ **OF** ____

| TIME | ELAPSED TIME (min. or sec.) | MEASURED DEPTH TO WATER (ft.) | CORRECTION | DEPTH TO WATER (ft.) | DRAWDOWN OR HEAD (ft.) | REMARKS |
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**NUS CORPORATION**

**ENVIRONMENTAL MANAGEMENT GROUP**

# STANDARD OPERATING PROCEDURES

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| Number | GH-2.5 |
| Page | 1 of 10 |
| Effective Date | 05/04/90 |
| Revision | 1 |
| Applicability | EMG |
| Prepared | Earth Sciences |
| Approved | D. Senovich |

Subject
WATER LEVEL MEASUREMENT/CONTOUR MAPPING

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## 1.0 PURPOSE

The objective of this procedure is to provide general reference information and technical guidance on the measurement of hydraulic head levels and the determination of the direction of groundwater flow, using contour maps of the water table or the potentiometric surface of an unconfined or confined aquifer.

## 2.0 SCOPE

This procedure gives overall technical guidance for obtaining hydraulic head measurements in wells (frequently conducted in conjunction with groundwater sampling) and preparation of groundwater contour maps. The specific methods could be modified by requirements of project-specific plans.

## 3.0 GLOSSARY

Hydraulic Head - The height to which water will rise in a well.

Water Table - A surface in an unconfined aquifer where groundwater pressure is equal to atmospheric pressure (i.e., the pressure head is zero).

Potentiometric Surface - A surface which is defined by the levels to which water will rise in wells which are screened or open in a specified zone of an unconfined or confined aquifer.

Unconfined (water table) Aquifer - An aquifer in which the water table forms the upper boundary.

Confined Aquifer - An aquifer confined between two low permeability layers (aquitards).

Artesian Conditions - A common condition in a confined aquifer in which the water level in a well completed within the aquifer rises above the top of the aquifer.

Flow Net - A diagram of groundwater flow, showing flow lines and equipotential lines.

Flow Line - A line indicating the direction of groundwater movement within the saturated zone. Flow lines are drawn perpendicular to equipotential lines.

Equipotential Line - A contour line on the potentiometric surface or water table showing uniform hydraulic head levels. Equipotential lines on the water table are also called water-table contour lines.

## 4.0 RESPONSIBILITIES

Project Hydrogeologist - has overall responsibility for obtaining water level measurements and developing groundwater contour maps. The hydrogeologist shall specify the reference point from which water levels are measured (usually a specific point on the upper edge of the inner well casing), the number of data points needed and which wells shall be used for a contour map, and how many complete sets of water levels are required to adequately define groundwater flow directions (e.g., if there are seasonal variations).

Field Personnel - must have a basic familiarity with the equipment and procedures involved in obtaining water levels, and must be aware of any project-specific requirements.

## 5.0 PROCEDURES

### 5.1 GENERAL

Groundwater level measurements can be made in monitoring wells, private or public water wells, piezometers, open boreholes, or test pits (after stabilization). Groundwater measurements should generally not be made in boreholes with drilling rods or auger flights present. If groundwater sampling activities are to occur, groundwater level measurements shall take place prior to well evacuation or sampling.

All groundwater level measurements shall be made to the nearest 0.01 foot, and recorded in the geologist's field notebook or on the Groundwater Level Measurement Sheet (Attachment A), along with the date and time of the reading. The total depth of the well shall be measured and recorded, if not already known. Weather changes that occur over the period of time during which water levels are being taken, such as precipitation and bariometric pressure changes, should be noted.

In measuring groundwater levels, there shall be a clearly-established reference point of known elevation, which is normally identified by a mark on the upper edge of the inner well casing. The reference point shall be noted in the field notebook. To be useful, the reference point should be tied in with an established USGS benchmark or other properly surveyed elevation datum. An arbitrary datum could be used for an isolated group of wells if necessary.

Cascading water within a borehole or steel well casings can cause false readings with some types of sounding devices (chalked line, electrical). Oil layers may also cause problems in determining the true water level in a well. Special devices (interface probes) are available for measuring the thickness of oil layers and true depth to groundwater if required.

*Water level readings shall be taken regularly, as required by the site hydrogeologist. Monitoring* wells or open-cased boreholes that are subject to tidal fluctuations should be read in conjunction with a tidal chart (or preferably in conjunction with readings of a tide staff or tide level recorder installed in the adjacent water body); the frequency of such readings shall be established by the site hydrogeologist. All water level measurements at a site used to develop a groundwater contour map shall be made in the shortest practical time to minimize affects due weather changes, and at least during the same day.

### 5.2 WATER LEVEL MEASURING TECHNIQUES

There are several methods for determining standing or changing water levels in boreholes and monitoring wells. Certain methods have particular advantages and disadvantages depending upon well conditions. A general description of these methods is presented, along with a listing of various advantages and disadvantages of each technique. An effective technique shall be selected for the particular site conditions by the onsite hydrogeologist.

In most instances, preparation of accurate potentiometric surface requires that static water level measurements be obtained to a precision of 0.01 feet. To obtain such measurements in individual accessible wells, the Chalked Tape or Electrical Water Level Indicator methods have been found best, and thus are the most often utilized. Other, less precise methods, such as the Popper or Bell Sound or Bailer Line methods, may be appropriate for developing preliminary estimates of hydraulic conditions. When a large number of (or continuous) readings are required, time-consuming individual readings are not usually feasible. In such cases, it is best to use the Float Recorder or Pressure Transducer methods. When conditions in the well limit readings (i.e., turbulence in the water surface or limited access through small diameter tubing), less precise, but appropriate, methods such as the Air Line or Capillary Tubing methods can be used.

### 5.2.1 Methods

Water levels can be measured by several different techniques, but the same steps shall be followed in each case. The proper sequence is as follows:

1. Check operation of recording equipment above ground. Prior to opening the well, don personal protective equipment as required.

2. Record all information specified below in the geologist's field notebook or on the Groundwater Level Measurement Sheet.

   a. Well number.
   b. Record water level to the nearest 0.01 foot (0.3 cm). Water levels shall be taken from the surveyed reference mark on the top edge of the inner well casing.
   c. Record the time and day of the measurement.

*Water level measuring devices with permanently marked intervals shall be used when possible.* If water level measuring devices marked by metal or plastic bands clamped at intervals along the measuring line are used, the spacing and accuracy of these bands shall be checked frequently as they may loosen and slide up or down the line, resulting in inaccurate reference points (see Section 5.2.3).

### 5.2.2 Water Level Measuring Devices

**Chalked Steel Tape**

The water level is measured by chalking a weighted steel tape and lowering it a known distance (to any convenient whole foot mark) into the well or borehole. The water level is determined by subtracting the wetted chalked mark from the total length lowered into the hole.

The tape shall be withdrawn quickly from the well because water has a tendency to rise up the chalk due to capillary action. A water finding paste may be used in place of chalk. The paste is spread on the tape the same way as the chalk, and turns red upon contacting water.

*Disadvantages to this method include the following: depths are limited by the inconvenience of* using heavier weights to properly tension longer tape lengths; ineffective if borehole/well wall is wet or inflow is occurring above the static water level; chalking the tape is time consuming; difficult to use during periods of precipitation.

**Electric Water Level Indicators**

These devices consist of a spool of small-diameter cable and a weighted probe attached to the end. When the probe comes in contact with the water, an electrical circuit is closed and a meter, light, and/or buzzer attached to the spool will signal the contact.

There are a number of commercial electric sounders available, none of which is entirely reliable under all conditions likely to occur in a contaminated monitoring well. In conditions where there is oil on the water, groundwater with high specific conductance, water cascading into the well, steel well casing, or a turbulent water surface in the well, measuring with an electric sounder may be difficult.

For accurate readings, the probe shall be lowered slowly into the well. The electric tape is marked at the measuring point where contact with the water surface was indicated. The distance from the mark to the nearest tape band is measured using an engineer's folding ruler or steel tape and added to the band reading to obtain the depth to water. If band is not a permanent marking band, spacing shall be checked periodically as described in Section 5.2.3.

### Popper or Bell Sounder

A bell- or cup-shaped weight that is hollow on the bottom is attached to a measuring tape and lowered into the well. A "plopping" or "popping" sound is made when the weight strikes the surface of the water. An accurate reading can be determined by lifting and lowering the weight in short strokes, and reading the tape when the weight strikes the water. This method is not sufficiently accurate to obtain water levels to 0.01 feet, and thus is more appropriate for obtaining only approximate water levels quickly.

### Float Recorder

A float or an electromechanically actuated water-seeking probe may be used to detect vertical changes of the water surface in the hole. A paper-covered recording chart drum is rotated by the up and down motion of the float via a pulley and reduction gear mechanism, while a clock drive moves a recording pen horizontally across the chart. To ensure continuous records, the recorder shall be inspected, maintained, and adjusted periodically. This type of device is useful for continuously measuring periodic water level fluctuations, such as tidal fluctuations or influences of pumping wells.

### Air Line

An air line is especially useful in pumped wells where water turbulence may preclude the use of other devices. A small-diameter weighted tube of known length is installed from the surface to a depth below the lowest water level expected. Compressed air (from a compressor, bottled air, or air pump) is used to purge the water from the tube, until air begins to escape the lower end of the tube, and is seen (or heard) to be bubbling up through the water in the well. The pressure needed to purge the water from the air line multiplied by 2.307 (feet of water for 1 psi) equals the length in feet of submerged air line. The depth to water below the center of the pressure gauge can be calculated by subtracting the length of air line below the water surface from the total length of the air line.

The disadvantages to this method include the need for an air supply and lower level of accuracy (unless a very accurate air pressure gauge is used, this method cannot be used to obtain water level readings to the nearest 0.01 ft).

### Capillary Tubing

In small diameter piezometer tubing, water levels are determined by using a capillary tube. Colored or clear water is placed in a small "U"-shaped loop in one end of the tube (the rest of the tube contains air). The other end of the capillary tube is lowered down the piezometer tubing until the water in the loop moves, indicating that the water level has been reached. The point is then measured from the bottom of the capillary tube or recorded if the capillary tube is calibrated. This is the best method for very small diameter tubing monitoring systems such as Barcad and other multilevel samples. Unless the capillary tube is calibrated, two people may be required to measure the length of capillary tubing used to reach the groundwater. Since the piezometer tubing and capillary tubing usually are somewhat coiled when installed, it is difficult to accurately measure absolute water level elevations using this method. However, the method is useful in accurately measuring differences or changes in water levels (i.e., during pumping tests).

**Pressure Transducer**

Pressure transducers can be lowered into a well or borehole to measure the pressure of water and therefore the water elevation above the transducer. The transducer is wired into a recorder at the surface to record changes in water level with time. The recorder digitizes the information and can provide a printout or transfer the information to a computer for evaluation (using a well drawdown/recovery model). The pressure transducer should be initially calibrated with another water level measurement technique to ensure accuracy. This technique is very useful for hydraulic conductivity testing in highly permeable material where repeated, accurate water level measurements are required in a very short period of time. A sensitive transducer element is required to measure water levels to 0.01 foot accuracy.

**Borehole Geophysics**

Approximate water levels can be determined during geophysical logging of the borehole (although this is not the primary purpose for geophysical logging and such logging is not cost-effective if used only for this purpose). Several logging techniques will indicate water level. Commonly-used logs which will indicate saturated/unsaturated conditions include the spontaneous potential (SP) log and the neutron log.

**Bailer Line Method**

Water levels can be measured during a bailing test of a well by marking and measuring the bailer line from the bottom of the bailer (where water is first encountered) to the point even with the top of the well casing. This is a useful technique during bailing tests (particularly if recovery is rapid) if the bailer is heard hitting the water. However, it is not recommended for measuring static water levels because it is not usually as accurate as some of the other methods described above.

### 5.2.3 Data Recording

Water level measurements, time, data, and weather conditions shall be recorded in the geologist's field notebook or on the Groundwater Level Measurement Sheet. All water level measurements shall be measured from a known reference point. The reference point is generally a marked point on the upper edge of the inner well casing that has been surveyed for an elevation. The exact reference point shall be marked with permanent ink on the casing since the top of the casing may not be entirely level. It is important to note changes in weather conditions because changes in the barometric pressure may affect the water level within the well.

### 5.2.4 Specific Quality Control Procedures for Water Level Measuring Devices

All groundwater level measurement devices must be cleaned before and after each use to prevent cross contamination of wells.

Some devices used to measure groundwater levels may need to be calibrated. These devices shall be calibrated to 0.01 foot accuracy periodically. A water level indicator calibration sheet shall be completed each time the measuring device is checked. A water level indicator calibration form is shown in Attachment A. The "actual reading" column on the sheet is the actual length of the interval from the end of the indicator to the appropriate marked depth interval. In many cases, these measurements are different because the water level measuring device is connected to the end of the measuring tape or line, and may extend beyond "0" feet on the measuring line.

## 5.3 POTENTIOMETRIC SURFACE MAPPING

### 5.3.1 Selection of Wells

All wells used to prepare a flow net in a plan or map view should represent the same hydrogeologic unit, be it aquifer or aquitard. All water level measurements used shall be collected on the same day.

Before mapping, review the recorded water levels and monitoring-well construction data, site geology and topographic setting to ascertain that the wells are completed in the same hydrogeologic unit and to determine if strong vertical hydraulic gradients may be present. Such conditions will be manifested by a pronounced correlation between well depth and water level, or by a difference in water level between two wells located near each other but set to different depths or having different screen lengths. Professional judgment of the hydrogeologist is important in this decision. If vertical gradients are significant, the data to be used must be limited vertically, and only wells finished in a chosen vertical zone of the hydrogeologic unit can be used.

At least three wells must be used to provide an estimation of the direction of groundwater flow, and many more wells will be needed to provide an accurate contour map. Generally, shallow systems require more wells than deep systems for accurate contour mapping.

### 5.3.2 Construction of Equipotential Lines

Plot the water elevations in the chosen wells on a site map. Other hydrogeologic features associated with the zone of interest -- such as seeps, wetlands, and surface-water bodies -- should also be plotted along with their elevations.

The data should then be contoured, using mathematically valid and generally accepted techniques. Linear interpolation is most commonly used, as it is the simplest technique. However, quadratic interpolation or any technique of trend-surface analysis or data smoothing is acceptable. Computer-generated contour maps may be useful for large data sets. Contour lines shall be drawn as smooth, continuous lines which never cross one another.

Inspect the contour map, noting known features, such as pumping wells and site topography. The contour lines must be adjusted in accordance with these, utilizing the professional judgment of the hydrogeologist. Closed contours should be avoided unless a known sink exists. Groundwater mounding is common under landfills and lagoons; if the data imply this, the feature must show in the contour plot.

### 5.3.3 Determination of Groundwater-Flow Direction

Flow lines shall be drawn so that they are perpendicular to equipotential lines. Flow lines will begin at high head elevations and end at low head elevations. Closed highs will be the source of additional flow lines. Closed depressions will be the termination of some flow lines. Care must be used in areas with significant vertical gradients to avoid erroneous conclusions concerning gradients and flow directions.

## 5.4 HEALTH AND SAFETY CONSIDERATIONS

Groundwater contaminated by volatile organic compounds may release toxic vapors into the air space inside the well pipe. The release of this air when the well is initially opened is a Health/Safety hazard which must be considered. Initial monitoring of the well headspace and breathing zone concentrations using a PID (HNU) or FID (OVA) and combustible gas meters shall be performed to determine required levels of protection.

## 6.0 REFERENCES

Freeze, R. A. and J. A. Cherry, 1979. Groundwater. Prentice-Hall, Englewood Cliffs, New Jersey, 604 pp.

Cedergren, H. R., 1977. Seepage, Drainage and Flow Nets (2nd edition). John Wiley and Sons, New York.

Fetter, C. W., 1980. Applied Hydrogeology. Me l, Columbus, Ohio, 488 pp.

## 7.0 ATTACHMENTS

Attachment A - Groundwater Level Measurem neet

Attachment B - Water Level Indicator Calibration Sheet.

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## ATTACHMENT A

## GROUNDWATER LEVEL MEASUREMENT SHEET

**Project Name:** ____________________
**Project No.:** ____________________
**Personnel:** ____________________
**Date:** ____________________

### LOCATION

**Municipality:** ____________________
**County:** ____________________
**State:** ____________________
**Street or Map Location (If Off-Site)** ____________________

### WEATHER CONDITIONS

**Temperature Range:** ____________________
**Precipitation:** ____________________
**Barometric Pressure:** ____________________

**Equipment No.:** ____________________
**Equipment Name:** ____________________
**Latest Calibration Date:** ____________________

**Tidally-Influenced:** [ ] Yes [ ] No

| Well or Piezometer Number | Date/Time | Elevation of Reference Point (Feet)* | Water Level Indicator Reading (Feet)* | Adjusted Depth (Feet)* | Groundwater Elevation (Feet)* |
|---|---|---|---|---|---|
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* All elevations to nearest 0.01 foot.

## ATTACHMENT B

## WATER LEVEL INDICATOR CALIBRATION SHEET

Project Name ____________________ Date ____________________

Project No. ____________________

Equipment No. ____________________

Equipment Name ____________________

| Water Level Indicator Marking (Feet) | Actual Reading* (Feet) |
|---|---|
| 0.0 | |
| 5.0 | |
| 10.0 | |
| 15.0 | |
| 20.0 | |
| 25.0 | |
| 30.0 | |
| 35.0 | |
| 40.0 | |
| 45.0 | |
| 50.0 | |
| 55.0 | |
| 60.0 | |
| 65.0 | |
| 70.0 | |
| 75.0 | |
| 80.0 | |
| 85.0 | |
| 90.0 | |
| 95.0 | |
| 100.0 | |

* Record readings to the nearest 0.01 foot. The actual reading may be different than marking because the water level measuring device (electrode, popper, etc.) may extend beyond the "0" feet mark on the measuring line.

| | | | |
|---|---|---|---|
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| | | Effective Date<br>05/04/90 | Revision<br>1 |
| | | Applicability<br>EMG | |
| | | Prepared<br>Earth Sciences | |
| Subject<br>**VERTICAL AND HORIZONTAL MOVEMENT OF GROUNDWATER** | | Approved<br>D. Senovich | |

## TABLE OF CONTENTS

**SECTION**

## 1.0 PURPOSE

The purpose of this guideline is to provide a basic understanding of the approaches used to identify and quantify the direction and rate of groundwater flow and contaminant plume movement.

## 2.0 SCOPE

This guideline provides only a general overview of the field techniques, mathematical and physical relationships and data handing procedures for determining the groundwater flow direction and rate. The references identified herein can provide a more complete explanation of particular methods cited, as well as a more comprehensive discussion on the interpretation of hydrogeologic data.

## 3.0 GLOSSARY

Aquifer - A geologic formation capable of transmitting usable quantities of groundwater to a well or other discharge point.

Aquitard - A geologic formation which retards the flow of groundwater due to its low permeability.

Confined Aquifer - An aquifer that is overlain and underlain by zones of lower permeability (aquitards). If the aquifer is "artesian," the potentiometric head of the aquifer at a given point is higher than the top of the zone comprising the aquifer at that point.

Equipotential Line - A line connecting points of equal elevation of the water table or potentiometric surface. Equipotential lines on the water table are also called water-table contour lines.

Flow Line - A flow line indicates the direction of groundwater movement within the saturated zone. Flow lines are drawn perpendicular to equipotential lines.

Flow Net - A diagram of groundwater flow showing flow lines and equipotential lines.

Hydraulic Conductivity (K) - A parameter relating the volume of fluid flowing through a cross-sectional area of a saturated permeable medium to the driving force for the flow (hydraulic gradient). The hydraulic conductivity is a function both of the aquifer characteristics (porosity and interconnection of pores) and of the characteristics of the fluid (density and viscosity) passing through the aquifer. Thus, an aquifer will have a different hydraulic conductivity for water compared to pure phase organic liquids.

Hydraulic Gradient (i) - The rate of change of hydraulic head per unit distance of flow at a given point and in the downgradient direction.

Hydraulic Head - The height to which water will rise inside a well casing, equal to the elevation head plus the pressure head. In a well screened across the water table, hydraulic head equals the elevation head, as the pressure head equals 0. In wells screened below the water table in an unconfined aquifer or screened at any interval within a confinded aquifer, the head is the sum of the elevation of the aquifer (the elevation head) and the fluid pressure of the water confined in the aquifer (the pressure head).

Permeability - The capacity of a porous medium to transmit water. The degree of permeability depends on the size and shape of the pores, and the extent of their interconnections.

Porosity - Percentage of the total volume of a rock or soil which is occupied by voids (pore space).

Potentiometric (piezometric) Surface - A hypothetical surface that coincides with the static level of the water in an aquifer (i.e., the maximum elevation to which water will rise in a well or piezometer penetrating the aquifer). The term "potentiometric surface" is usually applied to confined aquifers, although the water table is the potentiometric surface of an unconfined aquifer.

Unconfined Aquifer - An aquifer in which the water table forms the upper boundary.

Water Table - The surface in the groundwater system at which the fluid pressure is equal to atmospheric pressure (i.e., the net pressure head is zero) and below which all strata are saturated with water.

## 4.0 RESPONSIBILITIES

Hydrogeologist - (or geologist, engineer, or other scientist who is performing groundwater data interpretation) is responsible for understanding the field and analytical methods being used so that they are used correctly to obtain meaningful and accurate results.

Field Technicians - Under supervision of the hydrogeologist, geologist or engineer, are responsible for ensuring that measurements are taken correctly and that accurate records are kept.

## 5.0 PROCEDURES

### 5.1 GROUNDWATER FLOW CHARACTERISTICS

Groundwater movement is an integral part of the hydrologic cycle. Recharge to the groundwater environment generally occurs by infiltration from surface water bodies or infiltration through an upper unsaturated soil zone. Movement is downward under the force of gravity until the water reaches the saturated zone of the water table aquifer. Once water is part of the water table aquifer, movement is controlled by differences in hydraulic head with movement from areas of high head to areas of low head. Areas of low head include natural discharge areas such as springs, lakes, rivers, and, ultimately, the ocean. These features can be considered as outcrops of the water table. Points of low head also are created by pumping wells.

Head differences can occur within an aquifer because of differences in elevation, loss of potential energy due to frictional resistance to flow within the aquifer, or where the aquifer discharges directly to a low head feature. Head differences between the water table aquifer and an underlying confined aquifer, or between two confined aquifers, can create a tendency for groundwater to move into the aquifer with lower hydraulic head.

Aquifers are generally composed of sand and gravel or porous/fractured rock which will transmit water freely. Movement of groundwater in the aquifer is generally horizontal toward the nearest discharge feature. Local variations may occur, especially near discharge or recharge features where flow may be upward or downward, respectively. Aquitards are composed of less permeable material such as unfractured shale, clay, or consolidated rock which restrict the flow of groundwater. As long as the hydraulic conductivity of an aquitard is at least 100 times lower than the adjacent aquifers, movement of groundwater that does occur in an aquitard can be assumed to be in a vertical direction driven by head differences in the aquifers on either side of the aquitard.

Local head differences and consequent vertical flow patterns within an aquifer can be detected by well clusters. A well cluster consists of several adjacent wells, generally installed within a few feet of each other, and screened at different depths. Variations in water levels in these closely spaced wells indicates the vertical component of groundwater flow within an aquifer, provided that the wells are all screened within the same aquifer.

## 5.2 DETERMINATION OF FLOW DIRECTIONS

The first step in determining the direction of groundwater flow is to obtain water level elevations for all available points at the water table and potentiometric surface(s).

Elevations are obtained from measurements of the depth to water in a monitoring well or piezometer taken from the top of the well casing (see SOP GH-2.5) and then referencing the elevation of the casing to a chosen and consistent datum point, usually mean sea level. Subtracting the depth to water from the casing elevation provides the elevation of the potentiometric surface. Elevations of points and areas of groundwater discharge or recharge such as springs, seeps, streams, rivers, and lakes also need to be determined. Comparison of these elevations, which represent hydraulic heads, will reveal the direction of flow because groundwater flows from areas of high head to areas of low head.

The number, location, and extent of geologic units and their properties with regard to aquifer or aquitard characteristics must be understood to properly interpret water level data gathered from the monitoring system. This firm understanding of the hydrogeologic system must be developed through a program of soil borings and interpretation of subsurface geology. The adequacy of the positions and depths of borings used to define relevant subsurface hydrogeologic conditions must also be assessed. The location of surface water discharge or recharge points must be considered. Surface water features influence the system as flow is most likely toward them (if they are discharge points) or away from them (if they are recharge points). Manmade discharge or recharge features such as pumping or injection wells, ditches, and trenches can also affect the flow of groundwater.

Graphical methods available for depicting the flow of groundwater include the use of equipotential lines and flow lines to construct potentiometric surface maps and vertical flow nets (see SOP GH-2.5). If the hydrogeologic system consists of a water table aquifer and one or more confined aquifers, separate contour maps should be prepared for each aquifer system. Water table maps should be developed using water level measurements obtained from monitoring wells screened at the unsaturated-saturated interface. Water level measurements collected from monitoring wells screened in the deeper portions of an unconfined aquifer should be contoured as a separate potentiometric surface map. Surface water discharge or recharge features are contoured in the water table system. Vertical flow nets should be constructed using a cross-section aligned parallel to the direction of groundwater flow. All water level measurements along this cross-section, both deep and shallow, are used in devloping equipotential lines and flow lines for the flow net.

## 5.3 DETERMINATION OF FLOW RATE

Darcy's Law states that the quantity of water flowing through a geologic material is dependent upon the permeability of the material, the hydraulic gradient, and the cross-sectional area through which the water flows. This relation is expressed in the equation:

$$Q = KiA$$

where:

$Q$ = volume of water flowing through the cross-sectional area of the formation ($L^3/T$).
$K$ = hydraulic conductivity ($L/T$).
$i$ = hydraulic gradient ($L/L$, i.e., dimensionless).
$A$ = cross-sectional area of formation being considered ($L^2$).

The relation is similar to one used in stream flow measurements where:

$$Q = VA$$

where:

$Q$ = discharge from the cross-sectional area of a stream or pipe ($L^3/T$).
$V$ = average velocity of flowing water ($L/T$)
$A$ = cross-sectional area through which water flows ($L^2$).

The velocity of water movement in a geologic formation depends on the specific formation properties and the head differences across the formation. This relation is defined in the equation:

$$V = \frac{Ki}{n}$$

where:

$V$ = average linear velocity of groundwater through the formation ($L/T$)
$K$ = hydraulic conductivity ($L/T$)
$i$ = hydraulic gradient (dimensionless)
$n$ = porosity (expressed as a fraction).

Values of porosity for several geologic materials are given in Attachment A. More accurate and specific values of porosity can be obtained by laboratory analysis of a formation sample.

Hydraulic conductivity is related to the permeability of the formation and depends on the interconnection of the pore spaces. In isotropic and homogeneous formations, the hydraulic conductivity will be the same vertically and horizontally. However, in anisotropic formations, horizontal and vertical conductivity can be markedly different and the vertical hydraulic conductivity can be up to several orders of magnitude lower than the horizontal hydraulic conductivity. For example, an unfractured shale has a very high porosity; but because of its layered nature, the pore spaces are not connected vertically. Consequently, unfractured shale often has a moderate horizontal hydraulic conductivity but a very low vertical hydraulic conductivity.

Generally, hydraulic conductivity is high for sands, gravels, and limestone containing large solution cavities and low for clays and most unfractured rock. Attachment A gives values of hydraulic conductivity for several geologic materials. More accurate values can be obtained during field testing of aquifers or from laboratory measurements on undisturbed cores. However, results from field testing usually indicate higher hydraulic conductivities than laboratory testing, because full-scale field testing includes the effects of the formational macrostructure (i.e., secondary permeability due to jointing or fractures) which is not reflected in the testing of a small sample in the laboratory.

The hydraulic gradient, i, is determined from field measurements of hydraulic head obtained from water level measuring points. Once a potentiometric surface map has been generated using the hydraulic head data, the hydraulic gradient can be calculated using the following formula:

$$i = \frac{dh}{dl}$$

where:

$dh$ = change in head (L)
$dl$ = distance between equipotential lines (L)

The hydraulic gradient along any flow line can be calculated from a potentiometric surface map by dividing the contour interval by the length of the flow line between contour lines.

When chemical solutes are traveling in groundwater, as in cases of groundwater contamination, the calculated groundwater velocity may predict flow rates in excess of what is actually observed. This difference in chemical versus water velocities may be due to attentuation or biodegradation of the chemical species in the aquifer. Attenuation is most often caused by adsorption of the chemical contaminant onto the formation grains or matrix. The result is that the chemical does not appear at the downgradient sampling point as quickly as the velocity calculation predicts. An equation to correct for this attenuation is

$$V_c = V_w/(1 + K_d P_b/n)$$

where:

$V_c$ = velocity of the chemical solute flow (L/T)
$V_w$ = velocity of groundwater flow (L/T)
$P_b$ = formation mass bulk density ($M/L^3$)
$n$ = formation porosity (expressed as a fraction)
$K_d$ = distribution coefficient = ($L^3/M$)

The $K_d$ is equal to the mass of solute per unit mass of solid phase divided by the concentration of solute in solution. The term in the denominator is known as the retardation factor.

Density differences between water and contaminants can also cause velocity determination errors. Light hydrocarbons such as gasoline are less dense than water and consequently float on the water table. These contaminants can migrate along the water table surface at rates faster or slower than the rate of groundwater movement, depending on specific conditions, and may also volatilize into unsaturated soil pore spaces. On the other hand, contaminants denser than water such as heavy hydrocarbons (e.g., coal tar) or chlorinated compounds (e.g., TCE, PCE) tend to sink to the bottom of an aquifer if present in concentrations exceeding their solubility limit. Here, the contamination may move at faster or slower rates than the overlying groundwater or may actually move in a direction opposite to that of the groundwater, depending on the geologic characteristics of the aquifer base and direction of dip of the underlying aquitard.

Other factors involving the physiochemical interaction between the chemical and the groundwater, such as dilution (mixing contaminated water or chemicals with additional quantities of groundwater) and dispersion (molecular diffusion of the chemical throughout the groundwater regime), can also affect the observed rates of travel of contaminants in groundwater. In addition to such physiochemical characteristics, all of the aquifer and aquitard properties and groundwater flow characteristics described above must be known so that adequate and accurate estimations of the extent and severity of groundwater contamination can be developed.

## 6.0 REFERENCES

Davis, S. N. and R. J. DeWiest, 1966. Hydrogeology. John Wiley and Sons, New York.

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## 7.0 ATTACHMENTS

Attachment A - Generalized Porosity and Hydraulic Conductivity Values for Geologic Materials.

## ATTACHMENT A

### GENERALIZED POROSITY AND HYDRAULIC CONDUCTIVITY VALUES FOR GEOLOGIC MATERIALS

| Material | Porosity Range (%) | Hydraulic Conductivity Range | |
|---|---|---|---|
| | | cm/sec | ft/day |
| Gravel | 30-40 | $10^{-1}$ to $10^{-2}$ | 280 to $2.8 \times 10^5$ |
| Coarse sand (clean) | 30-40 | $10^{-1}$ to 1 | 280 to 2,800 |
| Medium sand (clean) | 35-45 | $10^{-2}$ to $10^{-1}$ | 28 to 280 |
| Fine sand (clean) | 40-50 | $5 \times 10^{-4}$ to $10^{-2}$ | 1.4 to 28 |
| Silty Sand | 25-40 | $10^{-5}$ to $10^{-2}$ | 0.03 to 280 |
| Glacial Till | Variable | $10^{-10}$ to $10^{-4}$ | $3 \times 10^{-7}$ to 0.3 |
| Unweathered Clay/Shale | 45-55 (clay) | $10^{-7}$ to $10^{-4}$<br>$10^{-10}$ to $10^{-6}$ | $3 \times 10^{-4}$ to 0.3 (horizontal)<br>$3 \times 10^{-7}$ to $3 \times 10^{-3}$ (vertical) |
| Karst Limestone | - | $10^{-4}$ to 1 | 0.3 to 2,800 |
| Fractured Igneous/ Metamorphic rocks | - | $10^{-6}$ to $10^{-1}$ | $3 \times 10^{-3}$ to 280 |
| Sandstone | 5-30 | $10^{-8}$ to $10^{-4}$ | $3 \times 10^{-5}$ to 0.3 |

Source: References 1 and 2.

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| | | Effective Date<br>05/04/90 | Revision<br>1 |
| | | Applicability<br>EMG | |
| | | Prepared<br>Earth Sciences | |
| Subject<br>SEISMIC REFRACTION SURVEYS | | Approved<br>D. Senovich | |

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## 1.0 PURPOSE

The purpose of this guideline is to provide a general description of, and technical management guidance on, the use of Seismic Refraction Surveys.

## 2.0 SCOPE

This guideline provides a description of the principles of operation, instrumentation, applicability and implementability of standard geophysical methods using seismic refraction. The document is intended to be used by the Site Manager (SM), RI Leader, Field Operations Leader, or Site Geologist to develop an understanding of the method to permit work planning and scheduling, resource planning, subcontractor procurement and evaluation, and manipulation and use of the technical data during remedial investigations and feasibility studies. This guidance is not intended to provide a detailed description of methodology and operation. The highly specialized nature of the seismic refraction method requires inclusion of project-specific, site-specific, and subcontractor-specific information prior to development of detailed operating procedures, during both planning and execution.

## 3.0 GLOSSARY

<u>Critical Angle</u> - An angle of incidence (determined from Snell's Law) at which an incident wave is refracted parallel to a stratigraphic boundary.

<u>Dip</u> - The angle from the horizontal at which a planar surface is inclined.

<u>Geophone</u> - A device used for detecting seismic waves at the earth's surface.

<u>Seismic Refraction</u> - The bending of seismic wave paths (according to Snell's Law) as they propagate over a boundary of different seismic velocities.

<u>Seismic Wave</u> - A form of energy that can be transmitted through rocks, soils, and liquids, and results from mechanical vibrations.

<u>Seismograph</u> - A device used for recording the detection times and magnitudes of seismic waves.

<u>Shotpoint</u> - The location of the seismic energy used in refraction studies. Vibration may be induced by a sledgehammer, dropweight, vibrating plates, or explosive charges.

<u>Snell's Law</u> - Fundamental relation governing wave refraction at a boundary; relates the angles of incidence and refraction to the velocity of the waves in the two media.

<u>Travel-time</u> - The calculated time of travel of a seismic wave from the moment of its initiation until its detection at a receiver.

## 4.0 RESPONSIBILITIES

<u>Site Manager</u> - Working with the RI Leader, Site Geologist and Site Geophysicist, is responsible for the scoping of seismic refraction surveys during development of the Work Plan.

<u>Site Geophysicist</u> - As a specialist in this field, the Site Geophysicist plays a central role in determining the appropriateness of the technique for providing necessary data. Field work for these surveys is

supervised by the site geophysicist, with support from geophysical technical specialists and other personnel as needed. Data reduction and interpretation are performed by the site geophysicist or technical specialists.

Field Operations Leader - Responsible for the overall management and coordination of the field work.

## 5.0 PROCEDURES

## 5.1 DESCRIPTION OF METHODS

### 5.1.1 Theory and Principles of Operation

Seismic refraction surveys utilize the natural energy transmitting properties of rocks and soils to delineate subsurface structure. In a refraction survey, mechanical vibrations are initiated as seismic waves at the surface. The subsurface velocity of these waves are dependent upon the physical properties of each stratigraphic unit through which they pass. The direction of the waves are refracted at boundaries of different seismic velocity. At each boundary, wave energy is redirected towards the surface where it can be detected by receivers on the ground surface. The recorded arrival times of these refracted waves, can be analyzed to produce a vertical profile of the subsurface. Information such as the number, thickness, and depths of stratigraphic layers, as wells as clues to the composition of these units can be ascertained.

The behavior of seismic waves at the interface between layers of different velocities, forms the basis of seismic refraction techniques. When energy is released at the source, or shotpoint, it propagates in all directions in the subsurface. As wave fronts move toward a velocity boundary, various waves will approach it at different angles. Most waves will either be reflected from the boundary or be refracted through it into the next layer. However, any waves that hit the boundary at its "critical angle" are refracted so as to propagate along the boundary. Such "critically refracted" waves always move within the layer with the highest velocity. In addition, the wave continuously releases energy back toward the surface as they propagate.

At the same time seismic energy is traveling downward and being refracted toward the surface, some energy is moving along the surface directly toward the receivers. Near the source, the direct waves constitute the first arrivals since they follow the shortest path. However, at a certain distance from the source, the refracted waves overtake the direct waves. Even though refracted waves travel a greater distance, they can arrive at the receiver before direct waves because a sufficient portion of their path occurs in higher velocity layers. At a distance further from the source, shallow refracted waves may themselves by overtaken by more deeply-refracted waves. When the first arrival times at each receiver (geophone) are analyzed systematically they can yield the velocities, depths, and thickness of each stratigraphic unit. Seismic refraction on the scale of hazardous waste sites is usually capable of resolving 3 or 4 layers.

To determine if the stratigraphy is dipping, reversed profiling must be completed. In reversed profiling, refraction data over the survey line are collected twice. The geophones are kept in the same location, but the source is placed at opposite ends of the receiver array. The two data sets are solved geometrically to obtain the true velocities, depths, and dips of the boundaries.

If, as is often the case, seismic velocities consistently increase with depth, then seismic waves are always refracted in the same direction and a clear record of interfaces is produced. In many instances, interpretation of seismic refraction data is complicated by the presence of low-velocity layers, layers too thin to be detected, or layers with insufficient differences in velocity. Refraction data is most effectively interpreted from a graph with travel-time plotted against source-receiver distance. A large degree of scatter on the resulting figure may indicate that the waves are being refracted through an inhomogeneous medium such as glacial till or irregularly-cemented limestone. Scatter could also indicate a highly irregular velocity boundary. A local zone of scatter or break in an otherwise regular figure could indicate the presence of a subsurface disruption such as a waste disposal trench.

The seismic vibrations utilized in refraction surveys are very weak. Therefore geophones will pick up a great deal of random noise along with the desired signals. Sources of seismic noise include the movement of nearby trees or structures due to strong winds; heavy rainfall; airplane sounds; surface traffic such as vehicles; railroads; or even footsteps. The deleterious effect of seismic noise may be reduced in refraction surveys by the use of filtering devices and/or repeated measurements. Summation of the repeated data sets enhances the refracted signals to a greater degree than spurious background noise.

As with many remote sensing technologies, seismic refraction data does not allow a unique interpretation. Relative and absolute seismic velocities, point scatter and other features do provide clues to the subsurface structure. But they must be interpreted in light of other independent geologic evidence such as boring logs. This is especially true if the presence of low velocity or other hidden layers is suspected. In order to obtain meaningful results, seismic refraction surveys must be planned, completed and interpreted by experienced geophysical personnel.

### 5.1.2 General Applicability

Seismic refraction is an effective method of determining the depth and thickness of subsurface geologic layers, including the depth to rock and the water table. The seismic velocities can be related to physical properties of the strata including composition, density, and elasticity. This method can also detect and allow mapping of disturbed areas such as burial trenches at hazardous waste sites. It is especially useful at locations where drilling is not possible, poses serious risks, or could open a pathway for potential vertical migration of contaminants.

Limitations of the seismic refraction method are that it is a relatively slow field technique, and interpretation requires fairly uniform site conditions and independent geologic observations for accurate results. The method is highly susceptible to seismic noise. Furthermore, seismic refraction is only useful in delineating a subsurface composed of stratigraphic layers of generally increasing velocity, and of sufficient thickness and velocity contrast to effectively refract the seismic waves. Another limitation is that the seismic line must be 3 to 5 times the maximum depth of interest.

### 5.1.3 Instrumentation

The equipment utilized in refraction surveys as the source and receiver varies considerably, depending on the size of the survey area, the desired resolution, and the desired depth of profiling.

Source equipment can be quite simple for a small survey area and shallow depths. A 10 pound sledge hammer is useful for obtaining seismic data to depths of 10 to 15 meters. For depths of 50 to 100 meters, a 500 pound dropweight is necessary. To perform deeper surveys, a more powerful seismic source is required.

Detection of the refracted waves requires both sensitive receiving devices and a recorder. Geophone receivers consist of a magnet-coil assembly similar to a microphone that converts mechanical vibration into electrical signals. The magnet-coil assembly is mounted inside a plastic case with a spike on the bottom for coupling the geophone with the ground. A special cable connects the geophones with the recording unit. Typical surveys use from 4 to 24 geophones in a line array.

The recorder is a seismograph containing up to 24 channels and an equal number of amplifiers and filters, (one for each geophone). It records the arrival times at each geophone in units of milliseconds since initiation of the signal. The recording medium may be a paper chart, magnetic tape or a thermal printer (commonly used on multi-channel systems). A seismograph may also include an oscilloscope for signal display. The recorder must contain special circuitry to synchronize it with the seismic source. Certain recorders also include circuitry for the algebraic summation of repeated signals, and control over gain and signal filtering. These are especially useful in areas of high noise.

For relatively simple cases of 2 to 3 layers, refraction survey data can be analyzed in the field by the use of graphs and algebraic equations. In more complex cases of 3 or 4 dipping layers, a small computer may be necessary to solve the seismic equations.

## 5.2 DATA ACQUISITION

### 5.2.1 Field Procedures

Seismic refraction surveys are conducted in a grid, at discrete points, or along a straight line, depending on the type of data required, site size, schedule, and budget constraints. Each geophone array produces data at only one point. Setting out a grid of shotpoints allows a three-dimensional subsurface stratigraphic map to be produced, but is very time consuming. Alternately, arrays can be set up at specific points of interest, or one line can be shot, allowing the production of a two-dimensional subsurface cross-section.

In setting up a reversed profile shot, the geophones are spaced at regular intervals over the area of interest. The spacing is determined by the desired resolution. The distance from the shotpoint to geophones must be great enough so that the first arrival is due to the critically refracted wave along each boundary. It is common practice when starting a refraction survey in a new area to tightly group the geophones and then systematically increase the source-receiver spacing. This technique results in a highly detailed time-distance curve. In general, the length of a seismic line must be 3 to 5 times the depth of interest.

Data recorded in the field must include the precise coordinates of all receiver locations and shotpoints as well as specifics of the seismic energy source, electronic filtering and amplification used and the travel times in milliseconds.

### 5.2.2 Data Format

The data output of a seismograph depends upon the number of geophones used and the style of recording output. Multi-channel seismographs may product a travel-time versus distance chart which can be utilized directly to determine velocities and depths. Single channel recorders will require the operator to manually produce a travel-time chart of each shot as the source-receiver distance is changed. In all cases, the preferred format of data presentation is a graph in which travel time in milliseconds is plotted against source-receiver distance. From this chart, the velocities of each layer are obtained directly as the increased slope of each straight line segment, and information on layer parameters are then calculated.

## 5.3 DATA INTERPRETATION

Interpretation of a seismic refraction profile involves solving a number of complicating factors. Where reverse profiles indicate dipping boundaries, calculation of dips, true depths, and true velocities involve more complicated equations. Furthermore, corrections for differing elevations and varying thicknesses of weathered zones must often be made. Very thin layers or low velocity zones often complicate the travel-time chart as well.

Irregular boundaries cannot be adequately resolved with time-distance analysis. Instead, another form of analysis involving delay-time is used in these situations. Overall, the best interpretation of refraction data is performed by computers using time-distance and delay-time techniques. It is essential that an experienced geophysicist be available to interpret the quantitative and qualitative data obtained during a refraction survey.

Although seismic refraction is very useful in confirming subsurface structures and performing reconnaissance surveys, it should be noted that multiple interpretations for each data set are possible. Independent geologic data is important to the interpretation.

## 5.4 APPLICATIONS MANAGEMENT

### 5.4.1 Prerequisites

Appropriate planning of seismic refraction surveys requires at least a basic understanding of general site features and geohydrologic characteristics. If site conditions are not known, then the variability in conditions should be indicated. A statement of work should be generated that describes, in as much detail as possible, the known site conditions that may affect the measurements, and the objectives of proposed survey efforts. The type and degree of data interpretation and the desired format for data presentation should be specified if possible.

### 5.4.2 Work Planning and Scheduling

Refraction profiling should not be performed concurrently with other field geotechnical investigation such as drilling, if these studies will be a source of seismic noise. Ideally, geophysical surveys should be conducted in advance, allowing sufficient time for data interpretation and use of the results in planning subsequent field exercises.

The time and effort required for seismic refraction surveys vary greatly depending on the site-specific objectives and site conditions. Typically, from 1/4 to 1/2 acre, corresponding to 10 to 50 shots, can be covered by a two-person survey team in one day.

Data reduction and interpretation will require at least twice the amount of time as the field work. Weather conditions, terrain, and obstructive noise features cause considerable variability.

## 5.5 QUALITY CONTROL

Seismic refraction surveys are subject to misapplication, non-unique interpretations, and use of incomplete data, all of which can impact both the cost of subsequent site investigations and the validity of the site characterization. This susceptibility to misuse and potential for negative impact demands an that appropriate controls be implemented. Aspects common to field programs include the following:

- Program Management personnel (i.e. the Project Geologist, RI Leader, or Site Manager) with technical expertise in the subject for preparation of Statements of Work, review of proposals, work plans and reports, and technical supervision of subcontracts.
- No data point should be rejected from a data set without appropriate justification; field data sheets should contain all observed data and the conditions that could impact data validation.
- All field data should be recorded in permanent ink in a bound logbook, and each page signed and dated by the operator. Original unaltered logbooks should be retained in the files.
- An evaluation should be made of noise, interferences and obstructions at a site and such measurements, inferences, and explanations should be recorded in the field. These real-time quality control procedures aid field personnel in correction of noise over which they have control, in validating suspected external sources, and in early detection of problems that may jeopardize the survey objectives.

### 5.5.2 Seismograph Calibration

For application of the instruments described above, the only device requiring calibration is the seismograph recorder. Electronic calibration for time-peak accuracy and internal timing may be accomplished, although the circuits are crystal controlled and have inherently low drift. Normal annual factory maintenance should include such calibration..

## 5.6 POTENTIAL PROBLEMS

Seismic refraction surveying is a geophysical method which, although frequently applied, is subject to a wide variety of problems that may be encountered. Problems may be encountered to arise in the following areas:

- Planning and Execution - Rarely is a survey accomplished exactly according to the original plan. Site features not previously specified and other variations can occur that force changes in the details of the approach. However, the objectives of the survey, the general methodology, the amount of data required and the degree of data interpretation requested should remain unchanged. Project work scopes should be written with some degree of latitude to allow a change in plans whenever justified.
- Noise and Interferences - Measurements can be affected severely both by natural and by man-made sources of seismic noise as described in Section 5.1.1. These problems generally can be overcome, but must be recognized so that appropriate corrective measures can be implemented. Known or suspected sources of interference should be included in the initial planning for a project.

- Weather Conditions - It is possible to conduct the surveys under almost any condition that permit traverse of the site. However, high winds and rain may induce significant seismic noise due to the motion of nearby trees and buildings. Snow cover, standing water, heavy rainfall, or thoroughly saturated surface soils may also severely restrict the ability to meet project objectives and schedules. Scheduling contingencies should be included whenever possible, especially during periods when inclement weather is expected.

- Technical Difficulties - Preventable difficulties include equipment malfunction or misapplication, poor operator training, and lack of applications experience, or required permits (e.g., for blasting). Other difficulties may arise because the stratigraphic or seismic character of the site is not as initially conceptualized, or because multiple interpretations of data are possible. The effect of these problems can be minimized by early recognition and responsive and responsible technical management. Interim, real-time scrutiny of the data by the site geophysicists and management personnel is essential. The geophysical subcontractor must be responsible regarding equipment replacement, repair, or changes in personnel. The Field Operations Leader and the Site Geologist should be cognizant of technical difficulties beyond the control of the field personnel, and should recognize the need to change plans, change performers, or cancel a survey, as appropriate.

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McKown, G.L., G.A. Sandness and G.W. Dawson, 1980. Detection and Identification of Buried Waste and Munitions, Proceedings of the 11th American Defense Preparedness Association Environmental Systems Symposium, Arlington, Virginia.

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## 7.0 RECORDS

None.

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# STANDARD OPERATING PROCEDURES

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| Number | GH-3.5 |
| Page | 1 of 11 |
| Effective Date | 05/04/90 |
| Revision | 1 |
| Applicability | EMG |
| Prepared | Earth Sciences |
| Approved | D. Senovich |

Subject
BOREHOLE GEOPHYSICAL SURVEYS

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SECTION

## 1.0 PURPOSE

The purpose of this guideline is to furnish a guide to planning and implementing a program of borehole geophysics applicable to hazardous waste site investigations.

## 2.0 SCOPE

This guideline provides a description of the principles of operation, instruments, applicability, and implementability of borehole geophysics to determine subsurface stratigraphy and groundwater conditions at hazardous waste sites. The document is intended to allow personnel to develop an understanding of the available tools to permit work planning, scheduling and resource planning. This guidance is not intended to provide a detailed description of operations. The highly specialized nature of borehole geophysics requires inclusion of site-specific information prior to development of detailed operating plans.

## 3.0 GLOSSARY

Dead Time - Measurement errors in nuclear logging occurring from the inability to record all of the pulse energy within the resolving time.

Density - Mass per unit volume (g/cm$^3$). Bulk rock densities vary mainly because of porosity and range from 1.9 to 2.8 g/cm$^3$.

Electric Logs - The generic term for a well log that displays electrical measurements of induced current flow between electrodes. Electric logs discussed in this subsection include only single-point resistivity and spontaneous potential.

Nuclear Logs - The generic term for a well log that either measures natural or induces and measures radioactive isotopes in the borehole environment. Discussion in this text is limited to natural gamma, gamma-gamma, and neutron.

Sonde - The elongate cylindrical tool assembly used in a borehole to acquire well log information.

## 4.0 RESPONSIBILITIES

Field Operations Leader - Responsible for overall management and coordination of the field work.

Site Geophysicist - As a specialist in this field, the site geophysicist plays a central role in determining the appropriateness of this technique for providing necessary data. Field work for these surveys is supervised by the site geophysicist, with support from geophysical technical specialists and other personnel as needed. Data reduction and interpretation are performed by the site geophysicist or technical specialist.

Site Manager - Responsible for scoping of borehole geophysical surveys during development of the Work Plan, with input from the RI leader, site geologist, and site geophysicist.

## 5.0 PROCEDURES

### 5.1 APPLICABILITY

Discussion in this subsection will introduce a variety of borehole geophysical methods. The general logging categories discussed are electrical, nuclear, sonic, and mechanical. Although other borehole techniques are available, such as three-dimensional vertical seismic profiling, borehole televiewing, and a variety of crossbore techniques, these are not discussed in detail because of their limited application and the very specialized nature of their use. A combination of surface and borehole techniques offers a three-dimensional understanding of subsurface conditions, but that approach is also beyond the introductory detail in this compendium.

### 5.2 PRELIMINARY CONSIDERATIONS

Equipment discussed in this guideline is capable of performing electric, nuclear, and mechanical logging. This equipment is available from a variety of vendors and can usually be rented for short periods of time or leased on a long-term basis. In any case, the application of these techniques is quite complex, and the project geophysicist should provide input for planning and implementing borehole programs.

The following general types of information can be expected from borehole measurements:

- Vertical changes in porosity
- Relative vertical changes in permeability and transmissivity
- Lithology and structure
- Lithologic conditions
- Vertical distribution of leachate plumes
- Groundwater gradients, flow direction, and rate
- Water quality parameters

To determine a logging program that will enhance evaluation of the site, the SM must thoroughly evaluate two key items. First, the SM must identify the regional bedrock geology (i.e., igneous, sedimentary, metamorphic) and typical surficial units. Then the SM must gather as much local information as possible regarding geologic units (i.e., boring logs of monitoring wells, domestic water supply depths, and well yields) and any hydrogeologic reports or information.

Second, the SM must identify which logs are applicable in the site's geologic setting and which logs will provide the required information for meeting program objectives. Table GH-3.5.-1 is a general guide to data collection objectives that will aid in the selection process. However, each function under consideration must be researched in more detail using publications listed as information sources in this manual and consult with borehole geophysical logging specialists.

There are, of course, limiting factors for each of the logging techniques. Table GH-3.5-2 identifies some limiting factors for the logs.

## TABLE GH-3.5-1

## GENERAL GUIDE TO DATA COLLECTION OBJECTIVES

| Data Collection | Available Techniques |
|---|---|
| Lithology and stratigraphic correlation | Electric, caliper, nuclear, and sonic |
| Total porosity or bulk density | Gamma-gamma, neutron, and sonic |
| Effective porosity or true resistivity | Long-normal resistivity (records the resistivity beyond the invaded zone) |
| Clay or shale content | Natural gamma |
| Secondary permeability (fractures, solution openings) | Caliper, electric, sonic, and borehole televiewer |
| Specific yields of unconfined aquifer | Neutron |
| Water level and saturated zones | Electric, neutron, gamma-gamma, temperature, and fluid conductivity |
| Moisture content | Neutron |
| Dispersion, dilution, and movement of waste | Fluid conductivity and temperature |
| Groundwater movement through a borehole | Flowmeter (vertical) |
| Cementing | Caliper, temperature, gamma-gamma, and sonic |
| Casing corrosion | Caliper |

## TABLE GH-3.5-2

## LOGGING FUNCTION BOREHOLE LIMITATIONS

| Logging Function | Limiting Factors | | Fluid Filled |
|---|---|---|---|
| | Uncased Open Boreholes | Minimum Diameter (inches) | |
| Spontaneous potential | X | 2.5 | X |
| Single-point resistance | X | 2.5 | X |
| Natural gamma | | 2.5 | |
| Gamma-gamma | | 2.5 | |
| Neutron | | 2.5 | |
| Caliper | | 2.0 | |
| Temperature | X | 2.0 | X |
| Fluid conductivity | X | 2.5 | X |
| Fluid movement | X | 2.5 | X |
| Sonic | X | 2.5 | X |

X = Required condition

Once the geologic environment has been evaluated and the logging functions narrowed, the SM must select the appropriate equipment. Portable units that can be carried on a backpack, enable access to most well locations; however, they are limited to logging functions requiring low power operation (e.g., battery packs).

Functions that require 110 volt AC usually operate from a larger unit that is typically mounted in a vehicle. These units cost considerably more, and access to well locations can present problems in swampy areas. However, these units are able to run the majority of log functions available today.

A basic description of available logs, the parameters that affect response, and the sensing devices are presented in the following sections to aid in evaluating the applicability of logging functions.

### 5.2.1 Electrical

Electrical logging includes spontaneous potential and single point resistance.

Spontaneous potential (SP) - The response is the result of small differences in voltage caused by chemical and physical contacts between the borehole fluid and the surrounding formation. These voltage differences appear at lithology changes or bed boundaries, and their response is used quantitatively to determine bed thickness or formation water resistivity. Qualitative interpretation of the data can help identify permeable beds.

In a consolidated rock aquifer system where groundwater flow is controlled by secondary permeability (i.e., fractures), SP response may be generated from a streaming potential caused by a zone gaining or losing water.

The SP log is a graphic plot of potentials between the downhole sonde and a surface electrode. The system consists of a moveable lead electrode (located in the sonde) that traverses the borehole and a surface electrode (mud plug) that measures potentials in millivolts. Noise and anomalous potentials are relatively common in SP logs and are discussed in electric log anomalies later in this manual.

Single-point resistance - This technique is based on the principle of Ohm's Law ($E = Ir$) where E is voltage measured in volts, I is current measured in amperes, and r is resistance measured in ohms. Single-point resistance measures the resistance of in-situ materials (of the rock and the fluid) between an in-hole electrode and a surface electrode. Resistance logging has a small radius of investigation and is very sensitive to the conductivity of the borehole fluid and changes in hole diameter (caving, washouts, and fractures). This condition is advantageous for the operator in that any change in the formation (resistance or fractures) will produce a corresponding change in resistance on the log. These changes in resistance are interpreted to be a result of lithology changes. The single-point log is very desirable for geologic correlation because of its special response to lithology changes.

In crystalline rock (high resistance formations), single-point resistance logs are useful in locating fractures and often appear as mirror images (opposite deflections) to the caliper log. Hole enlargement, caving, washouts, and fractures appear as excursions to the left (indicating less resistance in normal operation) of the more typical response observed in this log.

The principle of the function is quite simple. The current (I) remains constant while the voltage (E) is measured between the movable lead electrode and the surface electrode. Voltage is then converted internally to resistance using Ohm's Law. SP and single-point resistance logs are designed to be run simultaneously since single-point resistance operates in alternating current (AC) (110 volt) while the SP operates in direct current (DC).

### 5.2.2 Nuclear

Nuclear logging includes natural gamma, gamma-gamma, and neutron.

Natural gamma - This log measures the total of naturally occurring gamma radiation that is emitted from the decay of radioisotopes normally found in rocks. Typical elements that emit natural gamma radiation and cause an increase on the log are potassium 40 and daughter products of the uranium and thorium decay series. The primary use of natural gamma logging is lithology identification in sediments where the fine-grained (most often clay) units have the highest gamma intensity. A natural gamma log can be quite useful to the hydrologist, hydrogeologist, or geohydrologist, because clay tends to reduce permeability and effective porosity within a sedimentary unit. This log can also be used to estimate (within one geohydrologic system) which zones are likely to have high yields of water.

The sensing device is a scintillation-type receiver that converts the radioactive energy into electrical current, that is transmitted to the instrument and generates the natural gamma log.

Natural gamma logs can be run in open or cased boreholes filled with water or air. The sensing device is often built into the same sonde that conducts SP and single-point resistance logs. In essence, three functions are available from the use of one sonde.

Gamma-gamma - This nuclear log uses an activated source and measures the effect of the induced radiation and its degradation. Gamma-gamma logs are widely used to determine bulk density that is correlated with lithology. The log is also used to calculate porosity when the fluid and grain density are known. The radius of investigation is dependent on two factors: source strength and source-detector spacing. Typically, 90 percent of the response is from within 6 to 10 inches of the borehole.

Neutron - The neutron log response is primarily a function of the hydrogen content in the borehole environment and surrounding formation. This content is measured by introducing neutrons into the borehole and surrounding environment, and measuring the loss of energy caused by elastic collision. Because neutrons have no electrical charge and have approximately the same mass as hydrogen, hydrogen atoms are responsible for the majority of energy loss. Neutron logging is used to determine moisture content above the water table and total porosity below the water table. Information derived from this log is used to determine lithology and stratigraphic correlation of aquifers and associated rocks. Inferred data can be used to determine effective porosity and specific yield of unconfined aquifers. Neutron logging is also effective for locating perched water tables.

The equipment is identical to that described for the gamma-gamma log except for use of a different source and the fact that the equipment must be able to handle higher count rates.

### 5.2.3 Mechanical

Mechanical logging includes caliper, temperature, fluid conductivity, and fluid movement.

Caliper - This log is defined as a continuous record of the average diameter of a drill hole. Caliper sondes can have from one to four arms. The two basic types are bowstring units, which are connected at two hinges, and finger devices, which have single hinges.

Caliper resolution is broken into two categories: horizontal and vertical. The horizontal resolution is the ability of the tool to measure the true size of the hole regardless of its shape (circular or elliptical). Vertical resolution is controlled by the length of the feeler contact on the borehole wall.

Traditionally, caliper logs have been run to correct other logging functions. If this is the primary reason for running caliper, the bowstring or single-hinged unit will both provide adequate data. Calipers using single-hinged feelers provide the best vertical resolution. Interchangeable arms are available for the single-hinged tools and should be selected on the basis of the hole diameter. Single-hinged tools can be used to identify fractures in igneous and metamorphic rocks and solution openings in limestone.

Temperature - The temperature log provides continuous records of the borehole fluid environment. Response is caused by temperature changes of the fluid surrounding the sonde, and generally relates to the formation water temperature. The borehole fluid temperature gradient is influenced by fluid movement in the borehole and adjacent rocks. In general, the temperature gradient is greater in low-permeability rocks than high-permeability rocks, which is probably the result of groundwater flow. Therefore, temperature logs can provide the hydrologist with information regarding groundwater movement.

Logging speed should be slow enough to allow adequate sonde response with depth, because there is a certain amount of lag time. The probe is designed to be run from top to bottom (downward) in the borehole to channel water past the sensor. Because some disturbance is inevitable when the sonde moves through the water column, repeat temperature logs should be avoided until the borehole fluid has had time to reach thermal equilibrium.

Fluid conductivity - These logs provide a continuous measurement of the conductivity of the borehole fluid between two electrodes. The contrast in conductivity can be associated with water quality and possibly with recharge zones. Conductivity logs are helpful when interpreting electric logs, because both are affected by fluid conductivity.

The most common sonde measures the AC voltage drop across closely spaced electrodes. These electrodes actually measure the fluid resistivity (which is the reciprocal of conductivity), but are called fluid conductivity logs to avoid confusion with resistivity logs. Simply, conductivity logs actually measure the resistance of the borehole fluid; resistance logs measure the resistance of the rocks and the fluid they contain.

Fluid movement - Fluid movement logging can be broken into two components: horizontal and vertical. Horizontal logging uses either chemical or radioactive tracers, is generally unacceptable for hazardous waste investigations, and will not be discussed in detail.

Vertical movement of fluid in the borehole is measured by either an impeller flowmeter or chemical tracers. Tracers will not be discussed in this subsection for the reason mentioned above. The impeller flowmeter response is affected by the change in vertical velocity within the borehole. The best application of this log is defining fluid movement in a multiaquifer artesian system.

The sonde consists of a rotor or vanes housed inside a protective cage or basket. This log should be run both downhole and uphole. The logs should be compared side by side; only those anomalies that have mirror (opposite) deflections are the zones that are providing the vertical movement.

Sonic - This logging technique (also called acoustic logging) uses sound waves to measure porosity and to identify fractures in consolidated rock. Two general types of measurements are internal transit time, (the reciprocal of velocity), and amplitude (the reciprocal of attenuation). The amplitudes of the P- and S-waves are directly related to the degree of consolidation, porosity, and the extent and orientation of fractures.

The instrumentation of acoustic logging is very complex; it includes a downhole sonde with a transmitter and two to four receivers. Sound waves are emitted from the transmitter and their propagation is measured by the receivers.

## 5.3 SURVEY DESIGN

### 5.3.1 Log Selection

Once the SM has defined the logging program and has identified the general category of logs that will supply the necessary information, the specific logging function(s) can be selected. Table GH-3.5-3 describes the type of log, a basic description, and the primary use of the technique.

There are many combinations of logging functions. Generally, several borehole techniques are performed simultaneously or in a series to define any one of the geologic or hydrologic parameters.

## 5.4 INTERFERENCES/ANOMALIES

Electrical - Both SP and resistance logs are susceptible to the same types of interference. Buried cables, pipelines, magnetic storms, and the flow of groundwater can all cause anomalous readings. The most common noise in the SP logs is known as the battery effect and is caused by the polarization of the wetted cable. This condition is most troublesome in highly resistive surface formations. A common interference with the resistance log is the result of ground currents from power lines and other electrical sources that interfere with the alternating current used in logging. This interference appears as a sine wave superimposed on the resistance curve.

Nuclear - The most common problems with nuclear logs are that they are all affected by borehole diameter changes and changes in borehole media (air, water, mud). These problems are why caliper logs are essential to correlate the results. A natural gamma log is the sum of the radiation emitted from the formation and does not distinguish between elements (i.e., potassium, uranium, thorium). In quantitative applications of nuclear logs, the calibration, standardization, and correction for dead time are essential. However, when the logs are used for qualitative interpretations (e.g., stratigraphic correlation), such corrections may be unnecessary.

Mechanical - Caliper logging is a straightforward mechanical technique and exhibits few anomalies. Instrumental malfunctions are more likely to cause anomalous readings than borehole parameters.

Impeller flow anomalies are most often caused by varying the probe position radially in the borehole. Bouncing of the probe from side to side will erroneously indicate flow. Corrective action may include a device that would hold the sonde in the middle of the borehole.

Temperature logs are susceptible to thermal lag time, self-heating, drift from the electronics in the sonde, and borehole conditions. A slow logging speed and additional logging functions (i.e., caliper, fluid conductivity) can aid in temperature log interpretation. Another problem with temperature logs is that after one pass of the sonde, the thermal gradient is disturbed and repeat logs may not be representative. In large diameter wells, convection can cause a disturbance of the thermal gradient.

## TABLE GH-3.5-3

## TYPES OF LOGS, DESCRIPTIONS, AND USES

| Type of Log | Description | Primary Utilization |
|---|---|---|
| Caliper | A caliper produces a record of the average diameter of the drill hole. | Used for correction of other logs, identification of lithology changes, and locations of fractures and other openings in bedrock. |
| Single-Point Resistivity | This log measures the resistance of the earth material between an in-hole electrode and a surface electrode. | Used to determine stratigraphic boundaries, changes in lithology, and the identification of fractures in resistive rock. |
| Spontaneous Potential (SP) | SP is a graphic plot of the small differences in voltage that develop between the borehole fluid and the surrounding formation. | Used for geologic correlation, determination of bed thickness, and separation of nonporous from porous rocks in shale-sandstone and shale-carbonate sequences. |
| Natural Gamma | This log measures natural gamma radiation emitted from potassium 40, uranium, and thorium decay series elements. | Used for lithology identification and stratigraphy correlation; most advantageous in sediment environments where the fine-grained units have the highest gamma intensity. |
| Gamma-Gamma | Gamma photons are induced in the borehole environments, and the absorption and scattering are measured to evaluate the medium they travel through. | Used for identification of lithology, measurement of bulk density, and porosity of rocks. |
| Neutron | Neutrons are introduced into the borehole, and the loss of energy is measured from elastic collision with hydrogen atoms. | Used to measure the moisture content above the water table and the total porosity below the water table. |
| Temperature | A temperature log is the continuous record of the thermal gradient of the borehole fluid. | Used to determine groundwater flow in a borehole. |
| Fluid Conductivity | This log provides a measurement of the conductivity of the in-hole fluid between the electrodes. | Used primarily in conjunction with electric logs to aid in their interpretation; useful for identifying saltwater intrusion into freshwater systems, can be useful in evaluating water quality. |
| Acoustic (sonic) | A transmitter and a receiver or series of receivers that use acoustic frequencies. These signals are introduced into the borehole, and the elastic waves generated are measured. | Used to measure porosity and identify fractures in igneous and metamorphic rock. |

Disturbances to the borehole fluid caused by changes in fluid density and thermal convection can cause an erroneous log. Since fluid conductivity response is affected by the water chemistry, chemical equilibrium must be reached before measurements are taken. Well water may take months to obtain chemical equilibrium with the surrounding formation after drilling, and water wells with much internal movement may never reach chemical equilibrium. Repeat logs are not usually representative because the sonde disturbs the water column.

Cycle skipping is the most obvious unwanted signal in acoustic logging. It is caused by excessive signal attenuation in the fluid or by equipment malfunction. A problem with interpreting acoustic logs is that the velocity is dependent on a variety of lithologic factors, and the widely used time-average equation does not account for most of the factors.

## 6.0 REFERENCES

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## 7.0 RECORDS

None.

| | | | |
|---|---|---|---|
| **NUS CORPORATION**<br>**ENVIRONMENTAL MANAGEMENT GROUP** | **STANDARD OPERATING PROCEDURES** | Number<br>SA-1.1 | Page<br>1 of 14 |
| | | Effective Date<br>05/04/90 | Revision<br>2 |
| | | Applicability<br>EMG | |
| | | Prepared<br>Earth Sciences | |
| Subject<br>GROUNDWATER SAMPLE ACQUISITION | | Approved<br>D. Senovich | |

## TABLE OF CONTENTS

## 1.0 PURPOSE

The purpose of this procedure is to provide general reference information on the sampling of groundwater wells. The methods and equipment described are for the collection of water samples from the saturated zone of the subsurface.

## 2.0 SCOPE

This procedure provides information on proper sampling equipment and techniques for groundwater sampling. Review of the information contained herein will facilitate planning of the field sampling effort by describing standard sampling techniques. The techniques described shall be followed whenever applicable, noting that site-specific conditions or project-specific plans may require adjustments in methodology.

## 3.0 GLOSSARY

None.

## 4.0 RESPONSIBILITIES

Site Hydrogeologist or Geochemist - responsible for selecting and detailing the specific groundwater sampling techniques and equipment to be used, documenting these in the Project Operations Plan (POP), and properly briefing the site sampling personnel.

Site Geologist - The Site Geologist is primarily responsible for the proper acquisition of the groundwater samples. When appropriate, such responsibilities may be performed by other qualified personnel (engineers, field technicians).

Site Manager - The Site Manager is responsible for reviewing the sampling procedures used by the field crew and for performing in-field spot checks for proper sampling procedures.

## 5.0 PROCEDURES

### 5.1 GENERAL

To be useful and accurate, a groundwater sample must be representative of the particular zone of the water being sampled. The physical, chemical, and bacteriological integrity of the sample must be maintained from the time of sampling to the time of testing in order to keep any changes in water quality parameters to a minimum.

Methods for withdrawing samples from completed wells include the use of pumps, compressed air, bailers, and various types of samplers. The primary considerations in obtaining a representative sample of the groundwater are to avoid collection of stagnant (standing) water in the well and to avoid physical or chemical alteration of the water due to sampling techniques. In a non-pumping well, there will be little or no vertical mixing of water in the well pipe or casing, and stratification will occur. The well water in the screened section will mix with the groundwater due to normal flow patterns, but the well water above the screened section will remain isolated and become stagnant. To safeguard against collecting non-representative stagnant water in a sample, the following approach shall be followed prior to sample acquisition:

1. All monitoring wells shall be purged prior to obtaining a sample. Evacuation of three to five volumes is recommended for a representative sample. In a high-yielding groundwater formation and where there is no stagnant water in the well above the screened section, evacuation prior to sample withdrawal is not as critical.

2. For wells that can be purged to dryness with the sampling equipment being used, the well shall be evacuated and allowed to recover prior to sample acquisition. If the recovery rate is fairly rapid, evacuation of more than one volume of water is preferred.

3. For high-yielding monitoring wells which cannot be evacuated to dryness, there is no absolute safeguard against contaminating the sample with stagnant water. One of the following techniques shall be used to minimize this possibility:

- A submersible pump, intake line of a surface pump or bailer shall be placed just below the water surface when removing the stagnant water and lowered as the water level decreases. Three to five volumes of water shall be removed to provide reasonable assurance that all stagnant water has been evacuated. Once this is accomplished a bailer may be used to collect the sample for chemical analysis.

- The inlet line of the sampling pump (or the submersible pump itself) shall be placed near the bottom of the screened section, and approximately one casing volume of water shall be pumped from the well at a rate equal to the well's recovery rate.

Stratification of contaminants may exist in the aquifer formation, both in terms of a concentration gradients due to mixing and dispersion processes in a homogeneous layer, and in layers of variable permeability into which a greater or lesser amount of the contaminant plume has flowed. Excessive pumping can dilute or increase the contaminant concentrations in the recovered sample compared to what is representative of the integrated water column at that point, and thus result in the collection of a non-representative sample.

## 5.2 SAMPLING, MONITORING, AND EVACUATION EQUIPMENT

Sample containers shall conform with EPA regulations for the appropriate contaminants.

The following equipment shall be on hand when sampling ground water wells:

- Sample packaging and shipping equipment - Coolers for sample shipping and cooling, chemical preservatives, appropriate packing containers and filler, ice, labels and chain-of-custody documents.

- Field tools and instrumentation - Thermometer; pH paper/meter; camera and film; tags; appropriate keys (for locked wells); engineers rule; water-level indicator; where applicable, specific-conductivity meter.

- Pumps

  - Shallow-well pumps--Centrifugal, pitcher, suction, or peristaltic pumps with droplines, air-lift apparatus (compressor and tubing) where applicable.

  - Deep-well pumps--submersible pump and electrical power generating unit, or air-lift apparatus where applicable.

- Other sampling equipment - Bailers and monofilament line with tripod-pulley assembly (if necessary). Bailers shall be used to obtain samples for volatile organics from shallow and deep groundwater wells.

- Pails - Plastic, graduated.

- Decontamination solutions - Distilled water, Alconox, methanol, acetone.

Ideally, sample withdrawal equipment shall be completely inert, economical, easily cleaned, sterilized, and reused, able to operate at remote sites in the absence of power sources, and capable of delivering variable rates for well flushing and sample collection.

## 5.3 CALCULATIONS OF WELL VOLUME

To insure that the proper volume of water has been removed from the well prior to sampling it is first necessary to know the volume of standing water in the well pipe. This volume can be easily calculated by the following method. Calculations shall be entered in the field logbook and on the field data form (Attachment A):

- Obtain all available information on well construction (location, casing, screens, etc.).

- Determine well or casing diameter.

- Measure and record static water level (depth below ground level or top of casing reference point).

- Determine depth of well (if not known from past records) by sounding using a clean, decontaminated weighted tape measure.

- Calculate number of linear feet of static water (total depth or length of well pipe minus the depth to static water level).

- Calculate one static well volume in gallons ($V = 0.163Tr^2$).

  where:

  $V$ = Static volume of well in gallons.
  $T$ = Thickness of water table in the well measured in feet, i.e., linear feet of static water.
  $r$ = Inside radius of well casing in inches.
  0.163 = A constant conversion factor which compensates for the conversion of the casing radius from inches to feet, the conversion of cubic feet to gallons, and pi.

- Determine the minimum amount to be evacuated before sampling.

## 5.4 EVACUATION OF STATIC WATER (PURGING)

### 5.4.1 General

The amount of flushing a well shall receive prior to sample collection will depend on the intent of the monitoring program and the hydrogeologic conditions. Programs to determine overall quality of water resources may require long pumping periods to obtain a sample that is representative of a large volume of that aquifer. The pumped volume may be specified prior to sampling so that the sample can be a composite of a known volume of the aquifer. Alternately the well can be pumped until the parameters such as temperature, electrical conductance, and pH have stabilized. Onsite measurements of these parameters shall be recorded on the field data form.

For defining a contaminant plume, a representative sample of only a small volume of the aquifer is required. These circumstances require that the well be pumped enough to remove the stagnant water but not enough to induce significant groundwater flow from other areas. Generally three to five well volumes are considered effective for purging a well.

The site hydrogeologist, geochemist and risk assessment personnel shall define the objectives of the groundwater sampling program in the Work Plan, and provide appropriate criteria and guidance to the sampling personnel on the proper methods and volumes of well purging.

### 5.4.2 Evacuation Devices

The following discussion is limited to those devices commonly used at hazardous waste sites. Attachment B provides guidance on the proper evacuation device to use for given sampling situations. Note that all of these techniques involve equipment which is portable and readily available.

#### 5.4.2.1 Bailers

Bailers are the simplest evacuation devices used and have many advantages. They generally consist of a length of pipe with a sealed bottom (bucket-type bailer) or, as is more useful and favored, with a ball check-valve at the bottom. An inert line is used to lower the bailer and retrieve the sample.

Advantages of bailers include:

- Few limitations on size and materials used for bailers.
- No external power source needed.
- Bailers are inexpensive, and can be dedicated and hung in a well to reduce the chances of cross-contamination.
- There is minimal outgassing of volatile organics while the sample is in the bailer.
- Bailers are relatively easy to decontaminate.

Limitations on the use of bailers include the following:

- It is time consuming to remove stagnant water using a bailer.
- Transfer of sample may cause aeration.
- Use of bailers is physically demanding, especially in warm temperatures at protection levels above Level D.

### 5.4.2.2 Suction Pumps

There are many different types of inexpensive suction pumps including centrifugal, diaphragm, peristaltic, and pitcher pumps. Centrifugal and diaphragm pumps can be used for well evacuation at a fast pumping rate and for sampling at a low pumping rate. The peristaltic pump is a low volume pump (therefore not suitable for well purging) that uses rollers to squeeze a flexible tubing, thereby creating suction. This tubing can be dedicated to a well to prevent cross contamination. The pitcher pump is a common farm hand-pump.

These pumps are all portable, inexpensive and readily available. However, because they are based on suction, their use is restricted to areas with water levels within 20 to 25 feet of the ground surface. A significant limitation is that the vacuum created by these pumps can cause significant loss of dissolved gases and volatile organics. In addition, the complex internal components of these pumps may be difficult to decontaminate.

### 5.4.2.3 Gas-Lift Samplers

This group of samplers uses gas pressure either in the annulus of the well or in a venturi to force the water up a sampling tube. These pumps are also relatively inexpensive. Gas lift samplers are more, suitable for well development than for sampling because the samples may be aerated, leading to pH changes and subsequent trace metal precipitation or loss of volatile organics.

### 5.4.2.4 Submersible Pumps

Submersible pumps take in water and push the sample up a sample tube to the surface. The power sources for these samplers may be compressed gas or electricity. The operation principles vary and the displacement of the sample can be by an inflatable bladder, sliding piston, gas bubble, or impeller. Pumps are available for 2-inch diameter wells and larger. These pumps can lift water from considerable depths (several hundred feet).

Limitations of this class of pumps include:

- They may have low delivery rates.
- Many models of these pumps are expensive.
- Compressed gas or electric power is needed.
- Sediment in water may cause clogging of the valves or eroding the impellers with some of these pumps.
- Decontamination of internal components is difficult and time-consuming.

## 5.5 SAMPLING

### 5.5.1 Sampling Plan

The sampling approach consisting of the following, shall be developed as part of the POP prior to the field work:

- Background and objectives of sampling.

- Brief description of area and waste characterization.

- Identification of sampling locations, with map or sketch, and applicable well construction data (well size, depth, screened interval, reference elevation).

- Intended number, sequence volumes, and types of samples. If the relative degrees of contamination between wells is unknown or insignificant, a sampling sequence which facilitates sampling logistics may be followed. Where some wells are known or strongly suspected of being highly contaminated, these shall be sampled last to reduce the risk of cross-contamination between wells as a result of the sampling procedures.
- Sample preservation requirements.
- Working schedule.
- List of team members.
- List of observers and contacts.
- Other information, such as the necessity for a warrant or permission of entry, requirement for split samples, access problems, location of keys, etc.

### 5.5.2 Sampling Methods

The collection of a groundwater sample is made up of the following steps:

1. HSO or designee will first open the well cap and use volatile organic detection equipment (HNU or OVA) on the escaping gases at the well head to determine the need for respiratory protection.

2. When proper respiratory protection has been donned, sound the well for total depth and water level (using clean equipment) and record these data in a well sampling data sheet (Attachment A); then calculate the fluid volume in the well pipe.

3. Calculate well volume to be removed as stated in Section 5.3.

4. Select appropriate purging equipment (see Attachment B). If an electric submersible pump with packer is chosen, go to Step 10.

5. Lower purging equipment or intake into the well to a short distance below the water level and begin water removal. Collect the purged water and dispose of it in an acceptable manner. Lower the purging device, as required, to maintain submergence.

6. Measure rate of discharge frequently. A bucket and stopwatch are most commonly used; other techniques include using pipe trajectory methods, weir boxes or flow meters.

7. Observe peristaltic pump intake for degassing "bubbles." If bubbles are abundant and the intake is fully submerged, this pump is not suitable for collecting samples for volatile organics. Never collect volatile organics samples using a vacuum pump.

8. Purge a minimum of three-to-five casing volumes before sampling. In low permeability strata (i.e., if the well is pumped to dryness), one volume will suffice.

9. If sampling using a pump, lower the pump intake to midscreen or the middle of the open section in uncased wells and collect the sample. If sampling with a bailer, lower the bailer to sampling level before filling (this requires use of other than a 'bucket-type' bailer).

Purged water shall be collected in a designated container and disposed of in an acceptable manner.

10. (For pump and packer assembly only). Lower assembly into well so that packer is positioned just above the screen or open section and inflate. Purge a volume equal to at least twice the screened interval or unscreened open section volume below the packer before sampling. Packers shall always be tested in a casing section above ground to determine proper inflation pressures for good sealing.

11. In the event that recovery time of the well is very slow (e.g., 24 hours), sample collection can be delayed until the following day.. If the well has been bailed early in the morning, sufficient water may be standing in the well by the day's end to permit sample collection. If the well is incapable of producing a sufficient volume of sample at any time, take the largest quantity available and record in the logbook.

12. Add preservative if required. Label, tag, and number the sample bottle(s).

13. Replace the well cap. Make sure the well is readily identifiable as the source of the samples.

14. Pack the samples for shipping. Attach a custody seal to the front and back of the shipping package. Make sure that traffic reports and chain-of-custody forms are properly filled out and enclosed or attached.

15. Decontaminate all equipment

### 5.5.3 Sample Containers

For most samples and analytical parameters, either glass or plastic containers are satisfactory.

### 5.5.4 Preservation of Samples and Sample Volume Requirements

Sample preservation techniques and volume requirements depend on the type and concentration of the contaminant and on the type of analysis to be performed. Procedure SF-1.2 describes the sample preservation and volume requirements for most of the chemicals that will be encountered during hazardous waste site investigations. Procedure SA-4.3 describes the preservation requirement for microbial samples.

### 5.5.5 Handling and Transporting Samples

After collection, samples shall be handled as little as possible. It is preferable to use self-contained "chemical" ice (e.g., "blue ice") to reduce the risk of contamination. If water ice is used, it shall be bagged and steps taken to ensure that the melted ice does not cause sample containers to be submerged and thus possibly become cross-contaminated. All sample containers shall be enclosed in plastic bags or cans to prevent cross-contamination. Samples shall be secured in the ice chest to prevent movement of sample containers and possible breakage. Sample packing and transportation requirements are described in SA-6.2.

### 5.5.6 Sample Holding Times

Holding times (i.e. allowed time between sample collection and analysis) for routine samples are given in Procedure SF-1.2.

## 5.6 RECORDS

Records will be maintained for each sample that is taken. The sample log sheet will be used to record the following information:

- Sample identification (site name, location, project number; sample name/number and location; sample type and matrix; time and date; sampler's identity).
- Sample source and source description.
- Purge data - prior to removal of each casing volume and before sampling, pH, electrical conductance, temperature, color, and turbidity shall be measured and recorded.
- Field observations and measurements (appearance; volatile screening; field chemistry; sampling method).
- Sample disposition (preservatives added; lab sent to, date and time; lab sample number, EPA Traffic Report or Special Analytical Services number, chain-of-custody number.
- Additional remarks - (e.g., sampled in conjunction with state, county, local regulatory authorities; samples for specific conductance value only; sampled for key indicator analysis; etc.).

## 5.7 CHAIN-OF-CUSTODY

Proper chain-of-custody procedures play a crucial role in data gathering. Procedure SA-6.1 describes the requirements for a correct chain-of-custody.

## 6.0 REFERENCES

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## 7.0 ATTACHMENTS

Attachment A - Well Sampling Data Sheet
Attachment B - Purging Equipment Selection

## ATTACHMENT A
## SAMPLE LOG SHEET

NUS CORPORATION
A Halliburton Company

## SAMPLE LOG SHEET

☐ Monitoring Well Data
☐ Domestic Well Data
☐ Other ________

Page ____ of ____
Case # ____________
By ____________

Project Site Name ____________________ Project Site Number ____________
NUS Source No. ________________ Source Location ________________

| | | | | | |
|---|---|---|---|---|---|
| Total Well Depth: | Purge Data | | | | |
| Well Casing Size & Depth: | Volume | pH | S.C. | Temp. (°C) | Color & Turbidity |
| | | | | | |
| Static Water Level: | | | | | |
| One Casing Volume: | | | | | |
| Start Purge (hrs.): | | | | | |
| End Purge (hrs.): | | | | | |
| Total Purge Time (min.): | | | | | |
| Total Amount Purged (gal.): | | | | | |
| Monitor Reading: | | | | | |
| | | | | | |
| Purge Method: | | | | | |
| Sample Method: | | | | | |
| Depth Sampled: | | | | | |
| Sample Date & Time: | Sample Data | | | | |
| | pH | S.C. | Temp. (°C) | | Color & Turbidity |
| Sampled By: | | | | | |
| Signature(s): | Observations / Notes: | | | | |

Type of Sample
☐ Low Concentration
☐ High Concentration
☐ Grab
☐ Composite
☐ Grab - Composite

| Analysis: | Preservative | | Organic | Inorganic |
|---|---|---|---|---|
| | | Traffic Report # | | |
| | | Tag # | | |
| | | | | |
| | | AB # | | |
| | | Date Shipped | | |
| | | Time Shipped | | |
| | | Lab | | |
| | | | | |
| | | Volume | | |
| | | | | |

## ATTACHMENT B
## PURGING EQUIPMENT SELECTION

### Purging Equipment Selection

| Diameter Casing | Bailer | Peristaltic Pump | Vacuum Pump | Airlift | Diaphragm "Trash" Pump | Submersible Diaphragm Pump | Submersible Electric Pump | Submersible Electric Pump w/Packer |
|---|---|---|---|---|---|---|---|---|
| **1.25-inch** | | | | | | | | |
| Water level <25 ft | | x | x | x | x | | | |
| Water level >25 ft | | | | x | | | | |
| **2-inch** | | | | | | | | |
| Water level <25 ft | x | x | x | x | x | x | | |
| Water level >25 ft | x | | | x | | x | | |
| **4-inch** | | | | | | | | |
| Water level <25 ft | x | x | x | x | x | x | x | x |
| Water level >25 ft | x | | | x | | x | x | x |
| **6-inch** | | | | | | | | |
| Water level <25 ft | | | | x | x | | x | x |
| Water level >25 ft | | | | x | | | x | x |
| **8-inch** | | | | | | | | |
| Water level <25 ft | | | | x | x | | x | x |
| Water level >25 ft | | | | x | | | x | x |

| *Manufacturer* | *Model name/ number* | *Principle of operation* | *Maximum outside diameter/length (inches)* | *Construction materials (w/lines & tubing)* | *Lift range (ft)* | *Delivery rates or volumes* | *1982 price (dollars)* | *Comments* |
|---|---|---|---|---|---|---|---|---|
| BarCad Systems, Inc. | BarCad Sampler | dedicated; gas drive (positive displacement) | 1.5/16 | PE, brass, nylon, aluminum oxide | 0-150 with std. tubing | 1 liter for each 10-15 ft of submergence | 220-350 | requires compressed gas; custom sizes and materials available; acts as piezometer |
| Cole-Parmer Inst. Co. | Master Flex 7570 Portable Sampling Pump | portable; peristaltic (suction) | <1.0/NA | (not submersible) Tygon®, silicone Viton® | 0-30 | 670 mL/min with 7015-20 pump head | 500-600 | AC/DC; variable speed control available; other models may have different flow rates |
| ECO Pump Corp. | SAMPLifier | portable; venturi | <1.5 or <2.0/NA | PP, PE, PVC, SS, Teflon®, Tefzel® | 0-100 | 0-500 mL/min depending on lift | 400-700 | AC, DC, or gasoline driven motors available; must be primed |
| Galtek Corp. | Bailer 219-4 | portable; grab (positive displacement) | 1.66/38 | Teflon® | no limit | 1075 mL | 120-135 | other sizes available |
| GeoEngineering, Inc. | GEO-MONITOR | dedicated; gas drive (positive displacement) | 1.5/16 | PE, PP, PVC, Viton® | probably 0-150 | app. 1 liter for each 10 ft of submergence | 185 | acts as piezometer; requires compressed gas |
| Industrial and Environmental Analysts, Inc. (IEA) | Aquarius | portable; bladder (positive displacement) | 1.75/43 | SS, Teflon®, Viton® | 0-250 | 0-2800 mL/min | 1500-3000 | requires compressed gas; other models available; AC, DC, manual operation possible |
| IEA | Syringe Sampler | portable; grab (positive displacement) | 1.75/43 | SS, Teflon® | no limit | 850 mL sample vol. | 1100 | requires vacuum and/or pressure from hand pump |
| Instrument Specialties Co. (ISCO)' | Model 2600 Well Sampler | portable; bladder (positive displacement) | 1.75/50 | PC, silicone, Teflon®, PP, PE, Delrin® piston | 0-150 | 0-7500 mL/min | 990 | requires compressed gas (40 psi minimum) |
| Keck Geophysical Instruments, Inc. | SP-81 Submersible Sampling Pump | portable; helical rotor (positive displacement) | 1.75/25 | SS, Teflon®, PP, EPDM, Viton® | 0-160 | 0-4500 mL/min | 3500 | DC operated |
| Leonard Mold and Die Works, Inc. | GeoFilter Small Dia. Well Pump (#0500) | portable; bladder (positive displacement) | 1.75/38 | SS, Teflon®, PC, Neoprene® | 0-400 | 0-3500 mL/min | 1400-1500 | requires compressed gas (55 PSI minimum); pneumatic or AC/DC control module |
| Oil Recovery Systems, Inc. | Surface Sampler | portable; grab (positive displacement) | 1.75/12 | acrylic, Delrin® | no limit | app. 250 mL | 125-160 | other materials and models available; for measuring thickness of "floating" contaminants |
| Q.E.D. Environmental Systems, Inc. | Well Wizard® Monitoring System (P-100) | dedicated; bladder (positive displacement) | 1.66/36 | PVC | 0-230 | 0-2000 mL/min | 300-400 | requires compressed gas; piezometric level indicator; other materials available |

Source: Barcelona et al., 1983

| *Manufacturer* | *Model name/ number* | *Principle of operation* | *Maximum outside diameter/length (inches)* | *Construction materials (w/lines & tubing)* | *Lift range (ft)* | *Delivery rates or volumes* | *1982 price (dollars)* | *Comments* |
|---|---|---|---|---|---|---|---|---|
| Randolph Austin Co. | Model 500 Vari-Flow Pump | portable; peristaltic (suction) | <0.5/N/A | (not submersible) rubber, Tygon®, or Neoprene® | 0-30 | see comments | 1200-1300 | flow rate dependent on motor and tubing selected, AC operated; other models available |
| Robert Bennett Co. | Model 180 | portable; piston (positive displacement) | 1.8/22 | SS, Teflon®, Delrin®, PP, Viton® acrylic, PE | 0-500 | 0-1800 mL/min | 2600-2700 | requires compressed gas; water level indicator and flow meter; custom models available |
| Slope Indicator Co. (SINCO) | Model 514124 Pneumatic Water Sampler | portable; gas drive (positive displacement) | 1.9/18 | PVC, nylon | 0-1100 | 250 mL/flushing cycle | 250-350 | requires compressed gas; SS available; piezometer model available; dedicated model available |
| Solinst Canada Ltd. | 5W Water Sampler | portable; grab (positive displacement) | 1.9/27 | PVC, brass, nylon, Neoprene® | 0-330 | 500 mL | 1300-1800 | requires compressed gas; custom models available |
| TIMCO Mfg. Co., Inc. | Std. Bailer | portable; grab (positive displacement) | 1.66/ custom | PVC, PP | no limit | 260 mL/ft of bailer | 20-60 | other sizes, materials, models available; optional bottom-emptying device available; no solvents used |
| TIMCO | Air or Gas Lift Sampler | portable; gas drive (positive displacement) | 1.66/30 | PVC, Tygon®, Teflon® | 0-150 | 350 mL/flushing cycle | 100-200 | requires compressed gas; other sizes, materials, models available; no solvents used |
| Tole Devices Co.* | Sampling Pump | portable; bladder (positive displacement) | 1.38/48 | SS, silicone, Delrin®, Tygon® | 0-125 | 0-4000 mL/min | 800-1000 | compressed gas required; DC control module; custom built |

**Construction Materials Abbreviations**

| | |
|---|---|
| PE | Polyethylene |
| PP | Polypropylene |
| PVC | Polyvinyl Chloride |
| SS | Stainless Steel |
| PC | Polycarbonate |
| EPDM | Ethylene-Propylene Diene (synthetic rubber) |

**Other Abbreviations**

| | |
|---|---|
| NA | Not Applicable |
| AC | Alternating Current |
| DC | Direct Current |

NOTE: Other manufacturers market pumping devices which could be used for ground-water sampling, though not expressly designed for this purpose. The list is not meant to be all-inclusive and listing does not constitute endorsement for use. Information in the table is from sales literature and/or personal communication. No skimmer, scavenger-type, or high-capacity pumps are included.

Source: Barcelona et al., 1983

| | | | |
|---|---|---|---|
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| | | Effective Date<br>05/04/90 | Revision<br>2 |
| | | Applicability<br>EMG | |
| | | Prepared<br>Earth Sciences | |
| Subject<br>SURFACE WATER AND SEDIMENT SAMPLING | | Approved<br>D. Senovich | |

## TABLE OF CONTENTS

## 1.0 PURPOSE

This procedure describes methods and equipment commonly-used for collecting environmental samples of surface water and aquatic sediment for either on-site examination and chemical testing or for laboratory analysis.

## 2.0 SCOPE

The information presented in this guideline is generally applicable to all environmental sampling of surface waters (Section 5.3) and aquatic sediments (Section 5.4), except where the analyte(s) may interact with the sampling equipment. The collection of concentrated sludges or hazardous waste samples from disposal or process lagoons often requires methods, precautions and equipment different from those described herein.

## 3.0 GLOSSARY

Environmental Sample - low concentration sample typically collected offsite and not requiring DOT hazardous waste labeling or CLP handling as a high concentration sample.

Hazardous Waste Sample - medium to high concentration sample (e.g., source material, sludge, leachate) requiring DOT labeling and CLP handling as a high concentration sample.

## 4.0 RESPONSIBILITIES

Field Operations Leader - has overall responsibility for the correct implementation of surface water and sediment sampling activities, including review of the sampling plan with, and any necessary training of, the sampling technician(s). The actual collection, packaging, documentation (sample label and log sheet, chain-of-custody record, CLP traffic reports, etc.) and initial custody of samples will be the responsibility of the sampling technician(s).

## 5.0 PROCEDURES

### 5.1 INTRODUCTION

Collecting a representative sample from surface water or sediments is difficult because of water movement, stratification or patchiness. To collect representative samples, one must standardize sampling bias related to site selection; sampling frequency; sample collection; sampling devices; and sample handling, preservation, and identification.

Representativeness is a qualitative description of the degree to which an individual sample accurately reflects population characteristics or parameter variations at a sampling point. It is therefore an important quality not only of assessment and quantification of environmental threats posed by the site, but also for providing information for engineering design and construction. Proper sample location selection and proper sample collection methods are important to ensure that a truly representative sample has been taken. Regardless of scrutiny and quality control applied during laboratory analyses, reported data are not better than the confidence that can be placed in the representativeness of the samples.

## 5.2 DEFINING THE SAMPLING PROGRAM

Many factors must be considered in developing a sampling program for surface water or sediments including study objectives; accessibility; site topography; flow, mixing and other physical characteristics of the water body; point and diffuse sources of contamination; and personnel and equipment available to conduct the study. For waterborne constituents, dispersion depends on the vertical and lateral mixing within the body of water. For sediments, dispersion depends on bottom current or flow characteristics, sediment characteristics (density, size) and geochemical properties (which affect an adsorption/desorption). The hydrologist developing the sampling plan must therefore, know not only the mixing characteristics of streams and lakes, but also must understand the role of fluvial-sediment transport, deposition, and chemical sorption.

### 5.2.1 Sampling Program Objectives

The objective of surface water sampling is to determine the surface water quality entering, leaving or remaining within the site. The scope of the sampling program must consider the sources and potential pathways for transport of contamination to or in a surface water body. Sources may include point sources (leaky tanks, outfalls, etc.) or nonpoint sources (e.g., spills). The major pathways for surface water contamination (not including airborne deposition are: (a) overland runoff; (b) leachate influx to the waterbody; (c) direct waste disposal (solid or liquid) into the water body; and groundwater flow influx from upgradient. The relative importance of these pathways, and therefore the design of the sampling program, is controlled by the physiographic and hydrologic features of the site, the drainage basin(s) which encompass the site, and the history of site activities.

Physiographic and hydrologic features to be considered include slopes and runoff direction, areas of temporary flooding or pooling, tidal effects, artificial surface runoff controls such as berms or drainage ditches (and when they were constructed relative to site operation), and locations of springs, seeps, marshes, etc. In addition, the obvious considerations such as the location of man-made discharge points to the nearest stream (intermittent or flowing), pond, lake, estuary, etc., shall be considered.

A more subtle consideration in designing the sampling program is the potential for dispersion of dissolved or sediment-associated contaminants away from the source. The dispersion could lead to a more homogeneous distribution of contamination at low or possibly non-detectable concentrations. Such dispersion does not, however, always readily occur. For example, obtaining a representative sample of contamination from a main stream immediately below an outfall or a tributary is difficult because the inflow frequently follows a stream bank with little lateral mixing for some distance. Sampling alternatives to overcome this situation are: (1) move the site far enough downstream to allow for adequate mixing, or (2) collect integrated samples in a cross section. Also, nonhomogeneous distribution is a particular problem with regard to sediment-associated contaminants, which may accumulate in low-energy environments (coves, river bends, deep spots, or even behind boulders) near or distant from the source while higher-energy areas (main stream channels) near the source may show no contaminant accumulation.

The distribution of particulates within a sample itself is an important consideration. Many organic compounds are only slightly water soluble and tend to be absorbed by particulate matter. Nitrogen, phosphorus, and the heavy metals may also be transported by particulates. Samples will be collected with a representative amount of suspended material; transfer from the sampling device shall include transferring a proportionate amount of the suspended material.

### 5.2.2 Location of Sampling Stations

Accessibility is the primary factor affecting sampling costs. The desirability and utility of a sample for analysis and description of site conditions must be balanced against the costs of collection as controlled by accessibility. Bridges or piers are the first choice for locating a sampling station on a stream because bridges provide ready access and also permit the sampling technician to sample any point across the stream. A boat or pontoon (with an associated increase in cost) may be needed to sample locations on lakes and reservoirs, as well as those on larger rivers. Frequently, however, a boat will take longer to cross a water body and will hinder manipulation of the sampling equipment. Wading for samples is not recommended unless it is known that contaminant levels are low so that skin contact will not produce adverse health effects. This provides a built in margin of safety in the event that wading boots or other protective equipment should fail to function properly. If it is necessary to wade into the water body to obtain a sample, the sampler shall be careful to minimize disturbance of bottom sediments and must enter the water body downstream of the sampling location. If necessary, the sampling technician shall wait for the sediments to settle before taking a sample.

Sampling in marshes or tidal areas may require the use of an all-terrain-vehicle (ATV). The same precautions mentioned above with regard to sediment disturbance will apply.

Under ideal and uniform contaminant dispersion conditions in a flowing stream, the same concentrations of each would occur at all points along the cross section. This situation is most likely downstream of areas of high turbulence. Careful site selection is needed in order to ensure, as nearly as possible, that samples are taken where uniform flow or deposition and good mixing conditions exist.

The availability of streamflow and sediment discharge records can be an important consideration in choosing sampling sites in streams. Streamflow data in association with contaminant concentration data are essential for estimating the total contaminant loads carried by the stream. If a gaging station is not conveniently located on a selected stream, the project hydrologist shall explore the possibility of obtaining streamflow data by direct or indirect methods.

### 5.2.3 Frequency of Sampling

The sampling frequency and the objectives of the sampling event will be defined by the work plan. For single-event site- or area-characterization sampling, both bottom material and overlying water samples shall be collected at the specified sampling stations. If valid data are available on the distribution of the contaminant between the solid and aqueous phases it may be appropriate to sample only one phase, although this is not often recommended. If samples are collected primarily for monitoring purposes, consisting of repetitive, continuing measurements to define variations and trends at a given location, water samples shall be collected at a pre-established and constant interval as specified in the work plan (often monthly or quarterly) and during droughts and floods. Samples of bottom material shall be collected from fresh deposits at least yearly, and preferably during both spring and fall seasons.

The variability in available water-quality data shall be evaluated before deciding on the number and collection frequency of samples required to maintain an effective monitoring program.

## 5.3 SURFACE WATER SAMPLE COLLECTION

### 5.3.1 Streams, Rivers, Outfalls and Drainage Features (Ditches, Culverts)

Methods for sampling streams, rivers, outfalls and drainage features at a single point vary from the simplest of hand sampling procedures to the more sophisticated multipoint sampling techniques known as the equal-width-increment (EWI) method or the equal-discharge-increment (EDI) methods (see below).

Samples from different depths or cross-sectional locations in the water course taken during the same sampling episode shall be composited. However, samples collected along the length of the watercourse or at different times may reflect differing inputs or dilutions and therefore shall not be composited. Generally, the number and type of samples to be taken depend on the river's width, depth, discharge and on the suspended sediment the river's transports. The greater number of individual points that are sampled, the more likely that the composite sample will truly represent the overall characteristics of the water.

In small streams less than about 20 feet wide, a sampling site can generally be found where the water is well-mixed. In such cases, a single grab sample taken at mid-depth in the center of the channel is adequate to represent the entire cross-section.

For larger streams, at least one vertical composite shall be taken with one sample each from just below the surface, at mid-depth, and just above the bottom. The measurement of DO, pH, temperature, conductivity, etc., shall be made on each aliquot of the vertical composite and on the composite itself. For rivers, several vertical composites shall be collected.

### 5.3.2 Lakes, Ponds and Reservoirs

Lakes, ponds, and reservoirs have as much greater tendency to stratify than rivers and streams. The relative lack of mixing requires that more samples be obtained.

The number of water sampling sites on a lake, pond, or impoundment will vary with the size and shape of the basin. In ponds and small lakes, a single vertical composite at the deepest point may be sufficient. Similarly, the measurement of DO, pH, temperature, etc., is to be conducted on each aliquot of the vertical composite. In naturally-formed ponds, the deepest point may have to be determined empirically; in impoundments, the deepest point is usually near the dam.

In lakes and larger reservoirs, several vertical composites shall be composited to form a single sample. These verticals are often taken along a transect or grid. In some cases, it may be of interest to form separate composites of epilimnetic and hypolimnetic zones. In a stratified lake, the epilimnion is the thermocline which is exposed to the atmosphere. The hypolimnion is the lower, "confined" layer which is only mixed with the epilimnion and vented to the atmosphere during seasonal "overturn" (when density stratification disappears). These two zones may thus have very different concentrations of contaminants if input is only to one zone, if the contaminants are volatile (and therefore vented from the epilimnion but not the hypolimnion), or if the epilimnion only is involved in short-term flushing (i.e., inflow from or outflow to shallow streams). Normally, however, a composite consists of several verticals with samples collected at various depths.

In lakes with irregular shape and with bays and coves that are protected from the wind, separate composite samples may be needed to adequately represent water quality since it is likely that only poor mixing will occur. Similarly, additional samples are recommended where discharges, tributaries, land use characteristics, and other such factors are suspected of influencing water quality.

Many lake measurements are now made in-situ using sensors and automatic readout or recording devices. Single and multiparameter instruments are available for measuring temperature, depth, pH, oxidation-reduction potential (ORP), specific conductance, dissolved oxygen, some cations and anions, and light penetration.

### 5.3.3 Estuaries

Estuarine areas are by definition zones where inland freshwaters (both surface and ground) mix with oceanic saline waters. Estuaries are generally categorized into three types dependent upon freshwater inflow and mixing properties. Knowledge of the estuary type is necessary to determine sampling locations:

- Mixed estuary - characterized by the absence of a vertical halocline (gradual or no marked increase in salinity in the water column) and a gradual increase in salinity seaward. Typically this type of estuary is shallow and is found in major freshwater sheetflow areas. Being well mixed, the sampling locations are not critical in this type of estuary.

- Salt wedge estuary - characterized by a sharp vertical increase in salinity and stratified freshwater flow along the surface. In these estuaries the vertical mixing forces cannot override the density differential between fresh and saline waters. In effect, a salt wedge tapering inland moves horizontally, back and forth, with the tidal phase. If contamination is being introduced into the estuary from upstream, water sampling from the salt wedge may miss it entirely.

- Oceanic estuary - characterized by salinities approaching full strength oceanic waters. Seasonally, freshwater inflow is small with the preponderance of the fresh-saline water mixing occurring near, or at, the shore line.

Sampling in estuarine areas is normally based upon the tidal phases, with samples collected on successive slack tides (i.e. when the tide turns). Estuarine sampling programs shall include vertical salinity measurements at 1 to 5 foot increments coupled with vertical dissolved oxygen and temperature profiles.

### 5.3.4 Surface Water Sampling Equipment

The selection of sampling equipment depends on the site conditions and sample type required. The most frequently used samplers are:

- Open tube
- Dip sampler
- Hand pump
- Kemmerer
- Depth-Integrating Sampler

The dip sampler and the weighted bottle sampler are used most often.

The criteria for selecting a sampler include:

- Disposable and/or easily decontaminated
- Inexpensive (if the item is to be disposed of)
- Ease of operation
- Nonreactive/noncontaminating - Teflon-coating, glass, stainless steel or PVC sample chambers are preferred (in that order)

Each sample (grab or each aliquot collected for compositing) shall be measured for:

- Specific conductance
- Temperature
- pH (optional)
- Dissolved oxygen (optional)

as soon as it is recovered. These analyses will provide information on water mixing/stratification and potential contamination.

### 5.3.4.1 Dip Sampling

Water is often sampled by filling a container either attached to a pole or held directly, from just beneath the surface of the water (a dip or grab sample). Constituents measured in grab samples are only indicative of conditions near the surface of the water and may not be a true representation of the total concentration that is distributed throughout the water column and in the cross section. Therefore, whenever possible it is recommended to augment dip samples with samples that represent both dissolved and suspended constituents and both vertical and horizontal distributions.

### 5.3.4.2 Weighted Bottle Sampling

A grab sample can also be taken using a weighted holder that allows a sample to be lowered to any desired depth, opened for filling, closed, and returned to the surface. This allows discrete sampling with depth. Several of these samples can be combined to provide a vertical composite. Alternatively, an open bottle can be lowered to the bottom and raised to the surface at a uniform rate so that the bottle collects sample throughout the total depth and is just filled on reaching the surface. The resulting sample using either method will roughly approach what is known as a depth-integrated sample.

A closed weighted bottle sampler consists of a stoppered glass or plastic bottle, a weight and/or holding device, and lines to open the stopper and lower or raise the bottle. The procedure for sampling is:

- Gently lower the sampler to the desired depth so as not to remove the stopper prematurely (watch for bubbles).

- Pull out the stopper with a sharp jerk of the sampler line.

- Allow the bottle to fill completely, as evidenced by the absence of air bubbles.

- Raise the sampler and cap the bottle.

- Decontaminate the outside of the bottle. The bottle can be used as the sample container (as long as original bottle is an approved container).

#### 5.3.4.3 Kemmerer

If samples are desired at a specific depth, and the parameters to be measured do not require a Teflon coated sampler, a standard Kemmerer sampler may be used. The Kemmerer sampler is a brass, stainless steel or acrylic cylinder with rubber stoppers that leave the ends open while being lowered in a vertical position to allow free passage of water through the cylinder. "Messenger" is sent down the line when the sampler is at the designated depth, to cause the stoppers to close the cylinder, which is then raised. Water is removed through a valve to fill sample bottles.

### 5.3.5 Surface Water Sampling Techniques

Most samples taken during site investigations are grab samples. Typically, surface water sampling involves immersing the sample container in the body of water; however, the following suggestions are made to help ensure that the samples obtained are representative of site conditions:

- The most representative samples are obtained from mid-channel at 0.6 stream depth in a well-mixed stream.
- Even though the containers used to obtain the samples are previously laboratory cleaned, it is suggested that the sample container be rinsed at least once with the water to be sampled before the sample is taken.
- For sampling running water, it is suggested that the farthest downstream sample be obtained first and that subsequent samples be taken as one works upstream. Work from zones suspected of low contamination to zones of high contamination.
- To sample a pond or other standing body of water, the surface area may be divided into grids. A series of samples taken from each grid is combined into one sample, or several grids are selected at random.
- Care should be taken to avoid excessive agitation of the water that results in the loss of volatile constituents.
- When obtaining samples in 40 ml septum vials for volatile organics, analysis, it is important to exclude any air space in the top of the bottle and to be sure that the Teflon liner faces in after the bottle is filled and capped. The bottle can be turned upside down to check for air bubbles.
- Do not sample at the surface, unless sampling specifically for a known constituent which is immiscible and on top of the water. Instead, the sample container should be inverted, lowered to the approximate depth, and held at about a 45-degree angle with the month of the bottle facing upstream.

## 5.4 SEDIMENT SAMPLING

### 5.4.1 General

Sediment samples are usually collected at the same verticals at which water samples were collected. If only one sediment sample is to be collected, the site shall be approximately at the center of water body. Generally, the coarser grained sediments are deposited near the headwaters of the reservoir. Bed sediments near the center will be composed of fine-grained materials which may, because of their lower porosity and greater surface area available for adsorption, contain greater concentrations of contaminants. The shape, flow pattern, bathometry (depth distribution), and water circulation patterns must all be considered when selecting sediment sampling sites. In streams, areas likely to have sediment accumulation (bends, behind islands or boulders, quiet shallow areas or very deep, low-velocity areas) shall be sampled while areas likely to show net erosion (high-velocity, turbulent areas) and suspension of fine solid materials shall be avoided.

Chemical constituents associated with bottom material may reflect an integration of chemical and biological processes. Bottom samples reflect the historical input to streams, lakes, and estuaries with respect to time, application of chemicals, and land use. Bottom sediments (especially fine-grained material) may act as a sink or reservoir for adsorbed heavy metals and organic contaminants (even if water column concentrations are below detection limits). It is therefore important to minimize the loss of low-density "fines" during any sampling process.

### 5.4.2 Sampling Equipment and Techniques

A bottom-material sample may consist of a single scoop or core or may be a composite of several individual samples in the cross section. Sediment samples may be obtained using on-shore or off-shore techniques.

When boats are used for sampling, life preservers must be provided and two individuals must undertake the sampling. An additional person shall remain on-shore in visual contact at all times.

The following samplers may be used to collect bottom materials:

- Scoop sampler
- Dredge samplers

#### 5.4.2.1 Scoop Sampler

A scoop sampler consists of a pole to which a jar or scoop is attached. The pole may be made of bamboo, wood or aluminum and be either telescoping or of fixed length. The scoop or jar at the end of the pole is usually attached using a clamp.

If the water body can be sampled from the shore or if it can be waded, the easiest and "cleanest" way to collect a sediment sample is to use a scoop sampler. This reduces the potential for cross-contamination. This method is accomplished by reaching over or wading into the water body and, while facing upstream (into the current), scooping in the sample along the bottom in the upstream direction. It is very difficult not to disturb fine-grained materials of the sediment-water interface when using this method.

#### 5.4.2.2 Dredges

Dredges are generally used to sample sediments which cannot easily be obtained using coring devices (i.e., coarse-grained or partially-cemented materials) or when large quantities of materials are required. Dredges generally consist of a clam shell arrangement of two buckets. The buckets may either close upon impact or be activated by use of a messenger. Most dredges are heavy (up to several hundred pounds) and require use of a winch and crane assembly for sample retrieval. There are three major types of dredges: Peterson, Eckman and Ponar dredges.

The Peterson dredge is used when the bottom is rocky, in very deep water, or when the flow velocity is high. The dredge shall be lowered very slowly as it approaches bottom, because it can force out and miss lighter materials if allowed to drop freely.

The Eckman dredge has only limited usefulness. It performs well where bottom material is unusually soft, as when covered with organic sludge or light mud. It is unsuitable, however, for sandy, rocky, and hard bottoms and is too light for use in streams with high flow velocities.

The Ponar dredge is a Peterson dredge modified by the addition of side plates and a screen on the top of the sample compartment. The screen over the sample compartment permits water to pass through the sampler as it descends thus reducing the "shock wave" and permitting direct access to the secured sample without opening the closed jaws. The Ponar dredge is easily operated by one person in the same fashion as the Peterson dredge. The Ponar dredge is one of the most effective samplers for general use on all types of substrates. Access to the secured sample through the covering screens permits subsampling of the secured material with coring tubes or Teflon scoops, thus minimizing the change of metal contamination from the frame of the device.

## 6.0 REFERENCES

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## 7.0 ATTACHMENTS

None.

**NUS CORPORATION**

**ENVIRONMENTAL MANAGEMENT GROUP**

# STANDARD OPERATING PROCEDURES

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| Effective Date 05/04/90 | Revision 2 |
| Applicability EMG | |
| Prepared Earth Sciences | |
| Approved D. Senovich | |

Subject

SOIL SAMPLING IN TEST PITS AND TRENCHES

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SECTION

## 1.0 PURPOSE

This procedure describes the method for logging and sampling of test pits and trenches to determine subsurface soil and rock conditions and recover small-volume or bulk samples. The methods apply only to data collection and do not apply to the construction of excavations.

## 2.0 SCOPE

The procedure is applicable to the collection of bulk and small-volume samples of subsurface soils for laboratory testing which are exposed through excavating at hazardous substance sites.

## 3.0 GLOSSARY

Test pit or trench - A pit or trench, either machine or manually excavated, from which large quantities of soil may be removed.

## 4.0 RESPONSIBILITIES

Site Manager - responsible for determining, in consultation with other project personnel (geologist, geochemist), the need for test pits or trenches, their approximate locations, depths and sampling objectives.

Field Operations Leader (FOL) - responsible for finalizing the location, orientation and depth of test pits/trenches based on on-site conditions and the site geologist's advice. The FOL is ultimately responsible for the proper construction, sampling and backfilling of test pits and trenches, including adherence to OSHA regulations.

Health and Safety Officer (HSO) - responsible for air quality monitoring during test pit construction and sampling, to ensure that workers and offsite (downwind) individuals are not exposed to hazardous levels of airborne contaminants. The HSO may also be required to advise the FOL on other safety-related matters regarding the test pit or trench excavation and sampling, such as mitigative measures to address potential hazards from unstable trench walls, puncturing of drums or other hazardous objects, etc.

Site Geologist/Sampler - responsible for recording all information and data on test pit/trench construction and for the proper collection and logging of samples according to this procedure.

## 5.0 PROCEDURES

### 5.1 DATA COLLECTION AND SAMPLING

#### 5.1.1 General

Test pits and trenches are usually logged as they are excavated. Records of each test pit/trench will be made on prepared forms or in a field notebook. If the log is made in a field notebook, it will be transcribed to the prepared forms. These records include plan and profile sketches of the test pit/trench showing materials encountered, their depth and distribution in the pit/trench, and sample locations. These records will also include safety and sample screening information.

Requirements for sampling shall be determined by the Site Manager, and shall be documented in the Project Operation Plan (POP). A copy of this plan shall be maintained by the Field Operations Leader. To expedite sampling, the crew shall have sufficient tools and equipment to sample each pit. The tools and equipment must be properly decontaminated prior to use.

Entry of test pits by personnel is extremely dangerous and shall be avoided unless absolutely necessary. Pits more than 4 feet deep must be shored prior to entry, the "buddy" system must be used, and all applicable H&S and OSHA requirements followed.

The final depth and type of samples obtained from each test pit will be determined at the time the test pit is excavated. Sufficient samples are usually obtained and analyzed to quantify contaminant distribution as a function of depth for each test pit. Additional samples of each waste phase and any fluids encountered in each test pit may be collected.

In some cases, samples of soil may be extracted from the test pit for reasons other than waste sampling and chemical analysis, such as to obtain geotechnical information. Such information would include soil types, stratigraphy, strength, etc., and could therefore entail the collection of disturbed (grab or bulk) or relatively undisturbed (hand-carved or pushed/driven) samples, which can be tested for geotechnical properties. The purposes of such explorations are very similar to those of shallow exploratory or test borings, but often test pits offer a faster, more cost-effective method of sampling than borings.

### 5.1.2 Sampling Equipment

The following equipment is needed for taking samples for chemical or geotechnical analysis from test pits and trenches:

- Backhoe or other excavating machinery.
- Shovels, picks and hand augers, stainless steel trowels.
- Sample container - bucket with locking lid for large samples and glass bottles for chemical or geotechnical analysis samples.
- Polyethylene bags for enclosing sample; buckets.
- Remote sampler consisting of 10-foot sections of steel conduit (1-inch diameter), hose clamps and right angle adapter for conduit (see Attachment A).

### 5.1.3 Sampling Methods

The methods discussed in this section refer to test pit sampling from grade level. If test pit entry is required, see Section 5.1.4.

- Excavate trench or pit in several depth increments. After each increment the operator will wait while the sampler inspects the test pit from grade level to decide if conditions are appropriate for sampling. (Monitoring of volatiles by the HSO will also be used to evaluate the need for sampling.) Practical depth increments range from 2 to 4 feet.

The backhoe operator, who will have the best view of the test pit, will immediately cease digging if:

- Any fluid phase or groundwater seepage is encountered in the test pit.
- Any drums, other potential waste containers, obstructions or utility lines are encountered.
- Distinct changes of material are encountered.

This action is necessary to permit proper sampling of the test pit and to prevent a breach of safety protocol. Depending upon the conditions encountered, it may be required to excavate more slowly and carefully with the backhoe.

- Remove loose material to the greatest extent possible with backhoe.
- Secure walls of pit if necessary. (There is seldom any need to enter a pit or trench which would justify the expense of shoring the walls. All observations and samples can generally be taken from the ground surface.)
- Samples of the test pit material will be obtained either directly from the backhoe bucket or from the material once it has been deposited on the ground. The sampler or Field Operations Leader directs the backhoe operator to remove material from the selected depth or location within the test pit/trench. The bucket is brought to the surface and moved away from the pit. The sampler and/or HSO then approaches the bucket and monitors its contents with a photoionization (HNU) or OVA meter. The sample is collected from the center of the bucket or pile and placed in sample jars using a clean stainless steel trowel or spatula.
- If a composite sample is desired, several depths or locations within the pit/trench are selected and a bucket is filled from each area. It is preferable to send individual sample bottles filled from each bucket to the laboratory for compositing under the more controlled laboratory conditions. However, if compositing in the field is required, each sample bottle shall be emptied into a mixing container (e.g., stainless steel bucket) and thoroughly stirred prior to being placed into the sample jars. Composite sampling is not appropriate for samples which will undergo analysis for volatile organic compounds.

- Using the remote sampler shown in Attachment A, samples can be taken at the desired depth from the side wall or bottom of the pit. The face of the pit/trench shall first be scraped (using a long-handled shovel or hoe) to remove the smeared zone that has contacted the backhoe bucket. The sample is then collected directly into the sample jar, by scraping with the jar edge, eliminating the need to utilize samplers and minimizing the likelihood of cross-contamination. The sample jar can be capped, removed from the assembly, and packaged for shipment.

- Prepare shipping papers, labels, and chain-of-custody records, as described in SA-6.2, Sample Packaging and Shipping.

### 5.1.4 In-Pit Sampling

Samples can also be obtained by personnel entering the test pit/trench. This is necessary when soil conditions preclude obtaining suitable samples from the backhoe bucket (e.g., excessive mixing of soils or wastes within the test pit/trench) or when samples from relatively small discrete zones within the test pit are required. This approach may also be necessary to sample any seepage occurring at discrete levels or zones in the test pit that are not accessible with remote samplers.

In general, personnel shall sample and log pits and trenches from the ground surface, except as provided for by the following criteria:

- The project will benefit significantly from the improved quality of the logging and sampling data obtained if personnel enter a pit or trench rather than conduct such operations from the ground surface.

- There is no practical alternative means of obtaining such data.

- The Site Health & Safety Officer determines that such action can be accomplished without breaching site safety protocol. This determination will be based on actual monitoring of the pit/trench after it is dug (including, at a minimum, measurements of volatile organics, explosive gases and available oxygen).

- An experienced geotechnical professional determines that the pit/trench is stable or is made stable prior to entrance of any personnel (by grading the sidewalls or using shoring). OSHA requirements (Reference 1) must be strictly implemented.

If these conditions are satisfied, one person will enter the pit/trench. On potentially hazardous waste sites, this individual will be dressed in safety gear as required by the conditions in the pit, usually Level B. He will be affixed to a safety rope and continuously monitored while in the pit.

A second individual will be fully dressed in protective clothing including a self-contained breathing device and on standby during all pit entry operations. The individual entering the pit will remain therein for as brief a period as practical, commensurate with performance of his work. After removing the smeared zone, samples are obtained with a clean trowel or spoon. As an added precaution, it is advisable to keep the backhoe bucket in the test pit when personnel are working below grade. Such personnel can either stand in or near the bucket while performing sample operations. In the event of a cave-in they can either be lifted clear in the bucket, or at least climb up on the backhoe arm to reach safety.

### 5.1.5 Geotechnical Sampling

In addition to the equipment described in Section 5.1.2, the following equipment is needed for geotechnical sampling:

- Soil sampling equipment, similar to that used in shallow drilled boring (i.e., open tube samplers), which can be pushed or driven into the floor of the test pit.
- Suitable driving (i.e., a sledge hammer) or pushing (i.e., the backhoe bucket) equipment which is used to advance the sampler into the soil.
- Knives, spatulas, and other suitable devices for trimming hand-carved samples.
- Suitable containers (bags, jars, tubes, boxes, etc.), labels, wax, etc. for holding and safely transporting collected soil samples.
- Geotechnical equipment (pocket penetrometer, torvane, etc.) for field testing collected soil samples for classification and strength properties.

Disturbed grab or bulk geotechnical soil samples may be collected for most soils in the same manner as comparable soil samples for chemical analysis. These collected samples may be stored in jars or plastic-lined sacks (larger samples), which will preserve their moisture content. Smaller samples of this type are usually tested for their index properties, to aid in soil identification and classification, while larger bulk samples are usually required to perform compaction tests.

Relatively undisturbed samples are usually extracted in cohesive soils using open tube samplers, and such samples are then tested in a geotechnical laboratory for their strength, permeability and/or compressibility. The techniques for extracting and preserving such samples are similar to those used in performing Shelby tube sampling in borings, except that the sampler is advanced by hand or backhoe, rather than a drill rig. Also, the sampler may be extracted from the test pit by excavation around the sampler when it is difficult to pull it out of the ground. If this excavation requires entry of the test pit the requirements described in Section 5.1.4 must be followed. The open tube sampler shall be pushed or driven vertically into the floor or steps excavated in the test pit at the desired sampling elevations. Extracting tube samples horizontally from the walls of the test pit is not appropriate, because the sample will not have the correct orientation.

A sledge hammer or the backhoe may be used to drive or push the sampler or tube into the ground. Place a piece of wood over the top of the sampler or sampling tube to prevent damage during driving/pushing of the sample. Pushing the sampler with a constant thrust is always preferable to driving it with repeated blows, to minimize disturbance to the sample. If the sample cannot be extracted by rotating it at least two revolutions (to shear off the sample at the bottom), hand excavation to remove the soil from around the sides of the sampler and slice off the sample at its bottom may be required. If this requires entry of the test pit, the requirements in Section 5.1.4 must be followed. Prepare, label, pack and transport the sample in the required manner, as described in SA-6.2, Sample Packaging and Shipping.

Hand-carved block samples are extracted in a similar manner to open tube samples, except that the sampling container (usually a large tube or box with no top or bottom) is not used to cut the sample. Instead, the surrounding sections of the test pit floor are carved away by hand to leave a sample slightly smaller in plan dimensions than the container, with the sample remaining connected to the test pit floor at its bottom. The container is slipped over the sample, and the annular space and top of the sample is covered with melted wax. The bottom of the sample is then sliced away from the test pit floor, the container is inverted, about 1/2 inch of soil removed, and the space filled with melted wax. Caps are then installed, taped, and dipped in hot wax for each end of the container, and the block sample is labeled and shipped in the same manner as a tube sample.

### 5.2 RECORDS

The following information will be recorded on the test pit/trench log form and in the field notebook:

- Name, work assignment number, and location of job.
- Date of digging or trenching.
- Surface elevation.
- Depth, surface area and orientation of pit or trench.
- Sample numbers.
- Method of taking samples, type and size of samples.
- Approximate water levels after stabilization (if below the water table), and location and depth of any seeps.
- Description of soil.
- Other pertinent information, such as HNU or OVA readings, weather conditions, etc.
- List of photographs.
- Name of contractor, backhoe (or other equipment) operator and sampler.
- Date and type of backfill.

## 6.0 REFERENCES

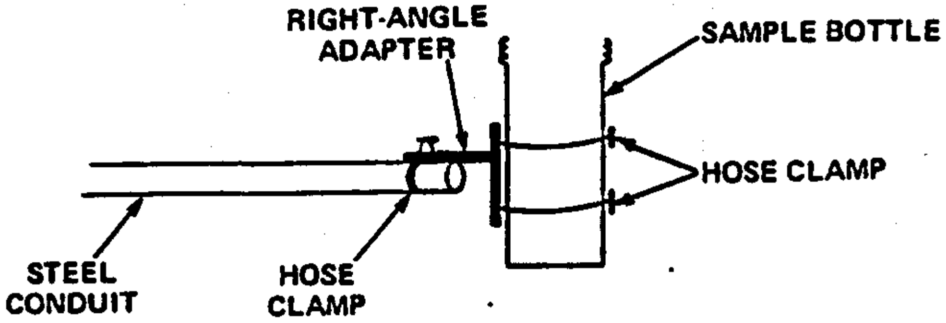
OSHA, 1979. Excavation Trenching and Shoring, 29 CFR 1926.650-653.

## 7.0 ATTACHMENTS

Attachment A - Remote Sampling/Sample Holder for Test Pit/Trench

## ATTACHMENT A
## REMOTE SAMPLE HOLDER FOR TEST PIT/TRENCH SAMPLING

# REMOTE SAMPLE HOLDER FOR TEST PIT/ TRENCH SAMPLING



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# STANDARD OPERATING PROCEDURES

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| **Effective Date** 05/04/90 | **Revision** 1 |
| **Applicability** EMG | |
| **Prepared** Earth Sciences | |
| **Approved** D. Senovich | |

**Subject** AIR SAMPLING AND METEOROLOGICAL EQUIPMENT CALIBRATION AND MAINTENANCE

## TABLE OF CONTENTS

## 1.0 PURPOSE

This procedure describes the procedure for the calibration, maintenance and storage of air sampling and *meteorological monitoring equipment used in the field.*

## 2.0 SCOPE

This procedure is applicable for use in field and shop calibration, maintenance and storage of continuous monitoring analyzers, meteorological systems, recording and data logging systems (DAS), passive dosimeters, sampling pump systems, permeation tubes, and calibrators and test equipment. This procedure will provide general information; manufacturer's manuals should be consulted for equipment-specific procedures.

## 3.0 GLOSSARY

Calibrators - Calibration instruments will vary in type with the device being calibrated, and include gas generation devices, orifices and/or bubble meters.

Continuous Monitors - Continuous monitors are designed to run 24 hours a day and are generally *compound-specific. Typical parameters measured are Nitrogen Oxides ($NO_x$), Carbon Monoxide (CO),* Hydrogen Sulfide ($H_2S$), Non-Methane Hydrocarbons (NMHC), and Sulfur Dioxide ($SO_2$).

Data Logging Systems - These systems can consist of a data logger which scans and records the output of all instruments connected to it, at predetermined intervals (generally once per minute for continuous analyzers and one per 5 seconds for meteorological systems). The data logger stores these instrument readings and, typically, averages the readings once per hour and converts the output to the proper units (i.e., *ppm, mph*). *The data logger outputs this average value to a mass storage device* (e.g., cassette tape), and also can produce a paper copy.

The data logging system may also include a modem which permits remote interrogation of the system via the telephone network.

Meteorological Systems - These systems are typically used to measure wind speed (W/S), wind direction (W/D), wind direction (W/D), temperature (Temp.), relative humidity (RH), standard deviation of wind direction (Sigma), and precipitation.

Passive Dosimeters - These devices are used for personnel monitoring. They consist of a badge which, when exposed to a specific substance, will produce a color change to the badge.

Permeation Tubes - These tubes are used to produce calibration gases for the continuous analyzers. The tubes are filled with a liquid state of the gas to be produced and when heated to a constant temperature, the gas permeates through a membrane at a constant rate.

Recorders - These devices record the indication of the continuous monitors and meteorological systems by taking the signal from the instrument (a voltage or frequency) and converting it to a trace on a strip chart. This gives a visual representation of the parameter measured as units versus time.

Sampling Pump Systems - These systems are used to draw a controlled volume of air through air sampling devices such as Tenax tubes and impingers. The system can consist of pumps, manifolds (to control flow), and bubble meters and rotometers (to calibrate the flow rate).

Test Equipment - Test equipment includes electronic test devices such as digital volt meters (DVM), oscilloscopes, function generators and variable power supplies.

## 4.0 RESPONSIBILITIES

When equipment is in use the equipment operator will be responsible for the performance of field calibration and maintenance or for ensuring that the equipment is sent to the proper calibration/maintenance facility when service is due. Performance of calibration and maintenance of equipment in storage will be the responsibility of technicians assigned to the storage facility.

After equipment is no longer required in the field, the Site Manager will ensure that it is sent to the storage facility. The technicians at the storage facility will insure that the equipment is properly stored.

## 5.0 PROCEDURES

It is important that routine calibration and maintenance be performed on a scheduled basis to insure proper performance of the equipment, and that sufficient field calibration be performed (as required) to ensure defensible QA of data generated by field equipment. Standard storage practices, should be adhered to so that equipment will not be damaged during storage and so that it will be ready for future use.

## 5.1 CALIBRATION AND MAINTENANCE

### 5.1.1 Continuous Monitoring Analyzers

The maintenance schedule for continuous monitoring equipment will generally include weekly, monthly, quarterly, semi-annual and annual action items. Weekly items generally include such actions as cleaning of the instrument. A typical quarterly item may be replacing sample inlet filters. Semi-annual and annual items would include replacement of expendable components such as catalysts and UV lamps.

The actual schedule and action items are usually determined using manufacturer's recommendations. The schedule should be modified if the time period between action items results in loss of performance of the instrument.

### 5.1.2 Meteorological Systems

The electronic portions of meteorological systems require only general cleaning as routine maintenance. The sensor portions which may be mechanical and exposed to the weather do require scheduled maintenance. For W/S and W/D sensors, the replacement of the bearings semi-annually is the most important maintenance item.

As with the other instruments the manufacturer recommendations should be used in the development of the schedule.

### 5.1.3 Recorders and Data Loggers

Recorders and data loggers are highly reliable electronic components and generally only require that they be kept clean and have expendable items such as pens, ink and paper replaced as needed.

### 5.1.4 Passive Dosimeters

Passive dosimeters do not require any maintenance.

### 5.1.5 Sampling Pumps and Manifolds

Sampling pump and manifold maintenance will include the cleaning of the manifold and rebuilding of the pump mechanism.

The schedule for maintenance should be based on manufactured suggestions and be on a hours of use basis as the equipment is not used continuously.

### 5.1.6 Additional Air Sampling Equipment

Other types of air sampling equipment can be used in the field other than continuous monitoring equipment. They are, for example, the HNU, OVA, and AID organic vapor analyzers, and the Photo 10A10 portable GC. These are most commonly used for the detection of organic compounds in air.

## 5.2 EQUIPMENT STORAGE

All equipment should be stored in a dry climate-controlled environment. Equipment should be stored in its original shipping container or box if available, or be kept covered so it stays clean.

Exceptions to this are permeation tubes and chemical reaction cells which should be kept refrigerated to increase their storage life.

## 5.3 RECORDS

An equipment calibration log and a maintenance log should be maintained for each instrument or system to record calibration and maintenance performed. These logs should be maintained with the instrument throughout its life, with copies kept at the equipment storage facility. Calibration tags should be attached to each piece of equipment requiring routine calibration, indicating when the last calibration took place and when the next one is due.

An inventory should be maintained for all equipment. At a minimum, it should contain the model number, serial number, location and condition of the equipment.

## 6.0 REFERENCES

None.

## 7.0 ATTACHMENTS

None.

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| Effective Date<br>05/04/90 | Revision<br>1 |
| Applicability<br>EMG | |
| Prepared<br>Earth Sciences | |
| Approved<br>D. Senovich | |

Subject
**AIR AND GAS SAMPLING METHODS**

## TABLE OF CONTENTS

SECTION

## 1.0 PURPOSE

This procedure describes, or provides a cross-references to other procedures which describe, the methods and equipment necessary for real-time air quality monitoring in the field, and for collecting air samples for laboratory analysis. With regard to site characterization activities, real-time monitoring will help in selection of sampling locations and screening of samples (e.g., screening of split-barrel samplers to select samples for laboratory analysis). Air samples collected for laboratory analysis can be used for characterizing the atmospheric transport of contaminants, and for risk assessment.

## 2.0 SCOPE

This guideline applies to field air quality monitoring and air sampling activities related to site characterization activities. Although the approaches and equipment used are similar, this guideline does not address air quality monitoring and air sampling with regard to health and safety issues.

## 3.0 GLOSSARY

Continuous Monitoring Instrument - An instrument which gives quantified measurements of the concentration of usually only one specific pollutant (e.g., CO, $H_2S$, $SO_2$) on a real-time basis. A variety of instruments can be used for this purpose including GC, UV and IR devices.

Detector Tubes - Small glass tubes filled with solid adsorbents such as silica gel, activated alumina, or inert granules, and impregnated with detecting chemicals through which air is aspirated at a controlled rate. The detector chemical undergoes a color change in the presence of the contaminant; the contaminant concentration is proportional to the intensity of color change, or the length of the stain. Also known variously as "colorimetric tubes" or "indicator tubes."

FID Meter - A portable air monitoring instrument (e.g., OVA-128) which operates by flame-ionization detection.

PID Meter - A portable air monitoring instrument (e.g., HNU PI-101) which operates by photo-ionization detection.

Representative Sampling - Sampling over a fixed period of time, usually 8 or 24 hours, using a sorbent medium (for volatiles) or filter (for particulate material) to determine the representative concentration of a contaminant in the air volume sampled.

Sorbent Sampling Medium - A material which quantitatively adsorbs volatile or semi-volatile organic compounds from air passing through the medium. These compounds are desorbed in the laboratory (using solvents or thermally) and analyzed. Commonly used sorbent media include Tenax, XAD resins and activated carbon.

## 4.0 RESPONSIBILITIES

Site Manager - Responsible for determining the need for, and scope of, an air monitoring/sampling program.

Field Operations Leader - Responsible for implementing the air monitoring program as it is detailed in the Field Sampling and Analysis Plan (FSAP) for the specific site. Air monitoring requirements may be included in both the FSAP and the site-specific Health and Safety Plan (HASP). In the case of air monitoring for health and safety requirements, the site H&S Officer has a lead role in evaluating the data and taking required action as detailed in the HASP.

## 5.0 PROCEDURES

The purpose of air and gas sampling is to define the concentration of airborne contaminants in a discrete air mass. Due to the wide spectrum of measurement technology and expense of instrumentation, it is critical to clearly define the data quality objectives of the air sampling program. Key considerations are: pollutant(s) of interest, turn around time required for results, sampling frequency, degree of measurement accuracy required and the level of quality control/quality assurance documentation required for the intended use of the data.

### 5.1 FIELD SCREENING

In developing the FSAP an initial screening program should be included during site reconnaissance activities for sites that may have significant onsite levels and/or offsite transport of airborne contaminants. This screening will help to refine or redefine the air monitoring requirements for the Remedial Investigation, and would be accomplished using an FID (e.g., OVA), PID (e.g., HNU), and possibly air sampling pumps and/or detector tubes. The results of the screening will provide input to the Health and Safety Plan and help in selecting the proper location and number of sampling locations.

### 5.2 AIR SAMPLING

Continuous air monitoring is performed by drawing air samples continuously from one or more fixed sampling points. The analyzing instrument may be located at or very near the point of air aspiration or may be several hundred feet from the sampling locations.

When long sampling lines are used, cognizance of transport time to the analyzer must be taken when relating the contamination episodes near the sample point to the real time analytical record reported at the analytical instrument. Similiarly, it should be noted that if the analyzer draws samples successively from several sampling points, important contaminant releasing events could be missed if sampling was not occurring from the nearest sampling point at the moment of release.

Analytical instrumentation used for continuous monitoring may utilize fixed or variable wave length UV, IR spectrographic, flame-ionization or electrochemical detection principles. Fixed site analytical devices for continuous sampling may require AC power, weatherproof housing, climate control and various laboratory grade compressed gases.

Fixed-site continuous monitoring is expensive and utilizes complex analytical equipment. It may be used to provide the detailed input necessary for atmospheric simulation modeling or may provide early emergency warning and/or legal record when extremely toxic contaminants or sensitive community relations are involved at the site.

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Representative air sampling is subdivided into two general categories: gaseous and particulate. The two principal methods for gaseous sample collection are adsorption of the compounds of interest onto sorbent media (such as Tenax, activated carbon or XAD resin) through which a metered volume of gas has been passed, or collection of a gas sample in a bag constructed of non-reactive material such as Mylar. In all cases using sorbent media, two tubes must be linked in series to evaluate breakthrough from the first tube in the series. Tables of breakthrough values are available for most common volatile organics from the sorbent suppliers, and if the concentration in the first tube approaches a breakthrough value, the second tube should be analyzed. Alternatively, a two-phase tube with tandem sorbent media may be used.

Use of sorbent media for air sampling is further described in SOP HS07. Particulate (aerosol) sampling is generally performed using a high-flow pump (about 2 liters per minute) to which a filter assembly is attached. Commonly, filters with 0.8 micron average pore size are used.

## 6.0 REFERENCES

40 CFR 58 - Appendix A
Standard Operating Procedure SOP HS07

## 7.0 ATTACHMENTS

None.

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# STANDARD OPERATING PROCEDURES

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| Applicability<br>EMG | |
| Prepared<br>Earth Sciences | |
| Approved<br>D. Senovich | |

Subject
## AQUATIC ECOLOGICAL INVENTORY AND SAMPLING

### TABLE OF CONTENTS

## 1.0 PURPOSE

The purpose of this procedure is to present methodologies for surveying and sampling aquatic organisms at hazardous waste sites to determine potential impacts on organisms at higher trophic levels.

## 2.0 SCOPE

The methodologies presented in this procedure are appropriate for: identifying aspects of aquatic ecological communities which suggest impact due to hazardous waste contamination; identifying potential trophic pathways and transport mechanisms for substances of public health concern; and providing useful input to evaluation of the feasibility and risks of remedial design alternatives. Not all of the methodologies presented herein are appropriate for all sites because of health and safety constraints which must be factored into all field sampling and analysis plans incorporating the methodologies included in this guideline.

## 3.0 GLOSSARY

Benthos - Organisms living on, in, or attached to the bottom of a water body.

Cladocera - Water fleas, a suborder within the class comprising an important food for fish.

Community - An assemblage of plant or animal species which appear to occur together or a given area.

Ecosystem - The biotic community and abiotic environment associated with a particular area.

Ichthyoplankton - Fish eggs and fish larvae sufficiently large to be captured by a 505-micron mesh plankton net.

Macrophytes - Essentially larger aquatic plants, or all plants except microscopic plants or algae.

Macrozooplankton - Larval and post larval animal plankton sufficiently large to be captured by a 505-micron mesh plankton net.

Periphyton - Organisms attached or clinging to submerged stems, leaves, rocks or other surfaces projecting above the substrate.

Plankton - Organisms which float with the current and generally lack swimming capability.

Trophic Pathway - A pattern of energy and material transfer from primary producers through successive levels of consumer organisms, and ultimately, to decomposers.

## 4.0 RESPONSIBILITIES

Site Manager - responsible for ensuring that a senior ecologist prepares, reviews, and oversees implementation of project specific plans for projects where aquatic ecological inventorying and sampling are required, and that such plans conform to this procedure. The Site Manager is also responsible to assure that the plans are reviewed by the Health and Safety Officer for conformance with Health and Safety Guidelines.

## 5.0 PROCEDURES

### 5.1 PROGRAM DESIGN

The site-specific aquatic ecology field program is designed after the following tasks have been completed:

- Review and analysis of all available site-specific information.
- Review and understanding of program objectives.
- Review and understanding of the principles and procedures of each sampling and/or measurement method to be used (including review of specific equipment manuals).
- Consultation with the Site HSO (especially if there is a potential for sampling from a boat).

Program design will be dependent upon these factors and must be considered relevant to the type of environment being investigated (marine, estuarine, freshwater), in addition to program objectives. The sampling apparatus used for a specific project is dependent upon the type of environment since not all gear is applicable in all systems (e.g., electrofishing is ineffective in saline waters). Other considerations which may be relevant to sample survey design include:

- Emphasis on indicator species - focusing the sampling effort on certain species may be of use as a quick aid to identifying stress in the environment. Additionally, observations of high incidences of pathological disorders in fish (e.g., fin rot) provides information on the probability of stress in a particular area.
- Collection of specimens for tissue analysis - chemical contaminants are often concentrated from one trophic level to the next, especially for fat soluble materials. Identification of the main food chains present in the study area will be useful in establishing which organisms to concentrate on relative to tissue analysis studies of bioaccumulation.
- Incorporation of sampling - concurrent samping of biota and the physical/chemical environment (e.g., water quality) is important for interpreting presence/absence/abundance data on species observed.
- Inclusion of downstream (or upstream) sampling - offsite sampling locations may be necessary to establish far field effects of contaminants, downgradients in species composition and recovery rates as contaminants are dispersed and diluted, or determine if differences between onsite and offsite biota are significant, and upgradient or similar but uncontaminated systems as controls.
- Tidal fluctuations - estuarine and marine environments experience tidal variations, and therefore require sampling in inter- and sub-tidal zones as well as during ebb and flood tides, to properly characterize the area. Inter-tidal zones possess unique species (spartina, mussels) which present trophic pathways to both aquatic and terrestrial organisms. These species should be considered for tissue analyses for evaluating environmental fate, effects, and risks.
- Stream and lake cross-sections - depth and rate of flow vary, based on cross-section location.

The objectives of certain hazardous waste site ecological studies can be met with utilization of available information and qualitative methodologies comprising a General Field Survey. In these *instances, program design can be accomplished by the field biologist with review by the senior* project ecologist and the site HSO. At those sites where qualitative information or sample collection is deemed necessary, the field program should be designed with input from statistician. This is required not only to ensure usefulness of data collected, but also to optimize time spent in the field.

## 5.2 DATA RECORDING

Standard aquatic ecology field data sheets (Attachment A) should be used for General Field Surveys. These sheets should be pre-printed on weather resistant paper to ensure data preservation under adverse field conditions, and include (but not be limited to) the following:

- NUS Project Number, Site Name and Location
- Date and Time
- Recorder (Investigator)
- Station Location
- Sample description and/or sample number as appropriate.
- Weather conditions
- Record of any photographs taken

## 5.3 PRE-FIELD INVESTIGATION ANALYSES

Prior to the field effort, all relevant available information should be reviewed. This phase is particularly important for hazardous waste site studies because typically-employed field accessories such as binoculars or cameras are difficult to use in combination with personnel protection requirements (respirators, SCBA, etc.). At most sites, the quality and quantity of information obtained will be limited by the investigator's ability to identify aquatic organisms and habitat through a respirator mask and by stress incurred from working in protective clothing. Hence, there is a strong need to make maximum use of available information prior to field investigation. Pre-field investigation should include the following:

- Preliminary map depicting water bodies on-site or contained within drainage area that require investigation

- Access routes (paths, trails accommodating all terrain vehicles, etc.) as well as emergency egress routes and safety stations

- Existing background information on the study area including aquatic organisms that may be found, with emphasis on species which may be indicative of existing stress or contaminant vectors, from a public health standpoint.

Sources of information to be sought and consulted include the following:

- Aerial photography

- USGS topographic maps

- Observations and photographs obtained by previous investigators (e.g., FIT team or site reconnaissance survey)

- State field biologists

- Published literature on aquatic ecosystems occurring on or near the site
- Navigational and river maps, if applicable.
- Published references on materials and methods (e.g., References 1 and 2 or this guideline)
- State or federal endangered species specialists where appropriate.

## 5.4 FIELD PREPARATIONS

Complete any field-related activities that can be performed prior to actual conduct of the field study--this includes pre-labeling of sample containers, pre-recording certain information on data sheets (e.g., site and date), and preparing any anticipated sample preservatives to proper strength.

## 5.5 GENERAL FIELD SURVEY

The General Field Survey should rely largely on observational data obtained by the field biologist, utilizing a standard data sheet (sample shown in Attachment A) developed for each site. In some instances simple techniques such as dip netting, which utilize disposable nets, can be employed to provide qualitative information on species present, or for obtaining specimens for tissue analysis.

## 5.6 DETAILED FIELD SURVEY

A Detailed Field Survey should be performed where more specific information (e.g., species abundance and bottom composition) is needed and where safety levels permit more intensive types of sampling. This type of survey would normally be performed only at Level D or C sites. Data typically obtained from this survey can include:

- Water Quality
  - pH
  - Dissolved oxygen
  - Temperature
  - Conductivity or salinity
  - Transparency
- Flow
- Average width and depth
- Circulation
- Tidal stage
- Bottom Composition - sieved samples
- Invertebrates - grab samples, drift nets
- Plankton (phyto, zoo, ichthyo) - nets, pumps
- Canopy - percent cover
- Fish - electrofishing; seining; set nets; gill nets

Data typically obtained from this survey are recorded on the data sheet in Attachment B.

Health and safety considerations are in all cases a major part of designing a detailed field survey. Health and safety implications of field sampling techniques must be considered, as well as health risks to laboratory personnel performing any subsequent analyses.

## 5.7 QUANTITATIVE STUDIES

Quantitative estimates of species abundance may be difficult to obtain at some sites, due to health risks of the repeated sampling required for statistically-sound data. If after consideration of program objectives and site-specific health and safety conditions, a quantitative study is deemed necessary, a sampling and/or monitoring program can be designed. Frequency of sampling, as well as number of stations and samples per station, should be developed on the basis of statistical advice, the site ecologist's understanding of on-site conditions, and the Site HSO's review.

Data sheets similar to those employed for Detailed Field surveys should be used, (Attachment C) and lab sheets should be developed as appropriate.

## 5.8 SPECIFIC METHODS AND MATERIALS

The methods described below are standard and, where health and safety conditions permit, appropriate for use at hazardous waste sites.

### 5.8.1 Benthic Invertebrates

Benthic invertebrates live on or in the waterbody substrate. They can constitute an important component of food chains of fish species, and consequently may link sediment-contained pollutants with the human food chain. Benthic macroinvertebrate communities are often used as indicators of stress on aquatic composition and density is largely determined by substrate types and local environmental conditions.

Many methods have been employed for obtaining benthic samples. An ideal collection technique minimizes disturbance, minimizes time during which captured organisms can escape, and provides a defined volume. Sampling devices include hand-held corers, scoops, various grabs or dredges (Ponar, Peterson, Smith-McIntyre) the Surber sampler, and artificial monitoring substrates (e.g., Hester-Dendy Sampler). Major advantages and limitations are the following:

| | Area Sampled | Advantages | Limitations |
|---|---|---|---|
| Peterson and Smith-McIntyre grabs | 700cm$^2$ | Will work in sand or gravel | Requires boat; unwieldy and heavy |
| Scoops | Variable | Simple | Non quantitative; may require hand immersion |
| Surber Sampler | 1000cm$^2$ | Semi-quantitative sample for streams appropriate for variety of substrates | Shallow water device (best when water 2' deep); requires hand immersion |
| Ponar Grab | 500cm$^2$ | Manageable, quantitative sample | Requires boat; limited to soft sediment |

| | Area Sampled | Advantages | Limitations |
|---|---|---|---|
| Artificial Substrate (e.g., Hester-Dendy Sampler) | Series of small plates or materials of fixed area | Does not require substrate extraction, simpler lab processing; quantitative estimate of species and individuals per area | Only samples the community which develops during sampling interval no measure of natural substrate |
| Hand Corer | Various, up to 10 cm diameter | Takes undisturbed, quantitative samples; easy to use and can be used in relatively coarse sediments | Cannot be used on hard substrates; unwieldy. Restricted to shallow water; may lose portion of sediment; requires hand immersion |
| Ponar Grab | 500cm$^2$ | Manageable, quantitative sample | Requires boat; limited to soft sediment |

Grab samples are usually washed through sieves in the field to prevent the loss of small animals which die and decay rapidly. Choice of sieve size is usually based on sediment grain size, but it also determines the type and size of animals retained. The most commonly used mesh size for final sieving is 0.5 mm. The material retained by the sieve is preserved in 10 percent buffered formalin and labeled for laboratory analyses. Artificial substrates are removed from the array, bagged and preserved in total for lab picking and identification.

### 5.8.2 Plankton

Zooplankton

Zooplankton form a major food source for larval and adult fish as well as larger invertebrates. As they are typically microscopic, sampling procedures involve use of a net to strain them from the water. Nets are usually towed behind a boat, and fitted with flow meters (which measure volume of water filtered) if quantitative samples are required.

General procedures are:

- If metered, record start count (volume).
- Tow for approximately 5 minutes at 1-2 feet per second.
- If metered, record end count (volume).
- Empty contents of bucket into labeled sample container.
- Add preservative.

Nets are rinsed by splashing water through the net from the outside to concentrate collected material in a sample bucket. Contents of the bucket are then emptied into labeled jars containing 5% buffered formalin. The mesh of the bucket should also be rinsed from the outside in to ensure all collected material is transferred to the sample jar. Fresh water plankton should be preserved with sucrose/4% buffered formalin in order to preserve the cladocerans in a more easily identifiable form.

The primary variables involved in program design are (a) mesh size, (b) length of tow, (c) net diameter, (d) depth of tow, and (e) time of tow (day or night). Mesh sizes for environmental studies are relatively standard (202 micron) as are length of tow (5-10 minutes with minimum volume of

100 $m^3$). Nets are usually 0.5 or 1 meter diameter. Oblique tows sample all water depths and provide data representative of the entire water column.

Ichthyoplankton and Macrozooplankton

Ichthyoplankton and macrozooplankton include drifting organisms, typically fish eggs, larvae, and invertebrates of a size sufficient to be captured by a 505-micron mesh plankton net of 0.5 or 1 meter diameter.

Large mesh (505-micron) plankton nets with large mouths (0.5-1 m) are usually towed behind a boat, although they can be anchored in a current. In order to obtain comparable data for different times and locations, similar quantities of water need to be filtered. This is generally assured by using flow meters to measure the quantity of water passing through the nets. For density estimates, flow meters are mandatory.

Samples should be preserved with 10% formalin and placed in labeled vials. Sampling procedures are similar to those described for zooplankton.

Phytoplankton

Phytoplankton are aquatic plants that can occur as unicellular, colonial or filamentous forms. They are a primary food source for herbivorous zooplankton and fish. Typical sampling gear consists of either bottles (Kemerer, Van Dorn, Niskin or Nansen) or net sampling which is either towed through the water or water is pumped through. Nets can be used to selectively sample nanoplankton (<60 µm) or microplankton (<10 µm). Samples may be preserved with buffered formalin (40ml/100ml of sample) merthiolate (36ml/1l of sample) or 95% alcohol (50/50 mix of alcohol and sample).

### 5.8.3 Periphyton

Two standard procedures are available for documenting occurrence and estimating abundance of periphyton. If information on natural substrate is required, scrape periphyton off representative natural substrates such as rocks or logs, and place the collection in a sample vial with preservative. Sampling of natural substrates provides a more complete inventory of species occurrence and can be quantified by selecting replicate rocks from each station and scraping measured areas.

For situations where in-situ scraping may be precluded by health and safety constraints, or more rigorously quantifiable estimates of abundance may be required, artificial substrates can be employed. These usually consist of racks of microscope slides held on edge with the long axis parallel to the current. Such arrays are anchored in the water for periods of 1-3 months, depending on study objectives.

Substrates (either natural or artificial) are preserved in 3-5% buffered formalin. Each individual substrate is preserved in its own labeled vial. Substrates to be used for dry weight analysis do not have preservatives added. Vials should be of a size that will keep the slides from being scraped or bumped in transport.

### 5.8.4 Macrophytes

Macrophytes, (large aquatic plants) are important to any aquatic system as food, substrate for algae and invertebrates, and fish habitat. Mapping of large areas can be most efficiently done using aerial photographs. After delineation of macrophyte beds on the photographs, the areas should be verified in the field. Spatial extent of the beds can then be determined using a planimeter. For smaller sites, the beds can be surveyed in the field.

### 5.8.5 Fish

Fish comprise an obvious and important part of the food chain for human beings as well as for wildlife such as waterfowl. The principal methods for sampling fish at hazardous waste sites will probably be seines, electroshocking, and gill netting.

#### Seines

Seine nets vary in length from 8 to 2,000 feet and in depth from 4 to 200 feet. The smaller seines (haul seines) are most frequently used for biological sampling in shallow water. Haul seines usually have a pole at each end and are drawn through the water by two people. Use of anything larger than 20 feet by 4 feet is not expected to be needed or practical at hazardous waste sites.

Entire reaches of streams can be sampled with a seine. One end of the seine is pulled along one shore while the other end is pulled (usually in the direction against the current) in a parallel fashion along the opposite shore. After a predetermined distance one end of the seine is worked to the opposite shore and the two ends beached.

Seining can also be employed to sample the shallow zones along lake, estuary, or stream banks. The technique is much the same as that described above except that one end is worked near shore and the other in deeper water. The offshore end should be slightly ahead of the nearshore end forming a "J." After a standard distance (25 feet is frequently used) to ensure comparability of different hauls (i.e., similar volumes of water scooped), the seine is beached.

Once beached, all fish in the net should be identified, counted, and measured (total length). If appropriate, reference specimens should be retained.

Haul seines are limited to use in water no more than waist deep. A clear shore for beaching should be chosen in advance. While seining the bottom the lead line should never come off the bottom and the float line should never go under the water. Substrate obstructions allow fish to escape under the net. Soft substrates allow the lead line to dig into the bottom making sampling difficult. Haul seines are selective for small, less mobile, fish.

#### Electroshocking

Electrofishing is used in freshwater sampling and can provide specimens for obtaining data on species composition, relative abundance, size distribution, or tissue chemistry.

Electroshocking involves producing an electric field between two electrodes immersed and placed in a water well or bucket in the water. Any fish entering the field are stunned which causes them to be captured with dipnets. After sampling, the fish should be measured, weighed, and identified or preserved in labeled bottles.

There are essentially two types of electrofishing equipment - those using AC current and those using DC current. With DC current fish are attracted to the anode, facilitating recovery by the sampler. The field produced using AC current has a larger effective range, but fish may be lost in turbid or swift waters, since they will not be attracted to the electrode. In addition there is a greater chance of killing the fish using AC.

If electrofishing by boat, move downstream at slow speeds especially when sampling deep pools or runs. Sample all habitats including bank areas. One person operates the boat and equipment, while another collects stunned fish from the bow of the boat with a net. Efficiency may be increased by having a second boat follow the electrofishing boat, to net any fish out of reach of the first.

If electrofishing on foot, the sampler wades upstream, taking care to sample all habitats. A second person follows to help net, carry the catch, or carry the cathode.

The electric current generated by shocking equipment (particularly AC devices) can cause serious injury to the user if safety precautions are not rigorously followed. Before field use, the investigator should become thoroughly familiar with the equipment manufacturer's instructions. Only devices with automatic cut-off (dead-man) switches should be used. Electroshocking crews should comprise three people, two samplers and an observer. Crew members entering the water or positioned on a boat must wear rubber boots and gloves. At least one member of the crew should be trained in First Aid and CPR (Cardiopulmonary Resuscitation).

### Gill Nets

Gill nets are used in marine, estuarine and freshwater environments where fish movement is expected. Experimental gill nets typically measure 40 m in length and consist of a graded series of (five) 8 m panels with mesh sizes ranging from 19 mm to 62 mm square. Nets are set for a prescribed period of time (i.e., 24 hours). Captured fish are identified, enumerated, measured and weighed. (For onsite work, these nets should be considered expendable.)

### Trawling

Trawls are nets used for sampling large deep water bodies, which may be present adjacent to a hazardous waste site. There are three basic trawl types: Try (permanent opening), otter (for demersel species), and mid-water (for various depths). Trawls are towed behind a boat against the prevailing surface current at a consistent speed and duration. Winches and booms are generallly needed to deploy and retrieve the nets. When retrieved, the cod end is opened and captured fish are identified, enumerated, measured, and weighed.

## 5.9 EQUIPMENT DECONTAMINATION, MAINTENANCE AND STORAGE

Proper decontamination, maintenance and storage procedures should be followed.

## 6.0 REFERENCES

American Public Health Association. 1981. Standard Methods, 15th Edition. American Public Health Association, Washington, D.C.

U.S. EPA, 1973. Biological Field and Laboratory Methods for Measuring the Quality of Surface Waters and Effluents. (C.I. Wever, editor). U.S. EPA, Cincinnati, Ohio.

## 7.0 ATTACHMENTS

Attachment A - General Field Survey Data Sheets (3 Sheets)
Attachment B - Detailed Field Survey Data Sheet
Attachment C - Quantitative Study Data Sheets (2 sheets)

## ATTACHMENT A
## PAGE 1 OF 3

## WATERBODY NAME OR DESCRIPTION
## HYDROLOGY

**ID**

SITE NUMBER.
ON SITE
OFF SITE

**FLOW (cfs)**

DRY BED (0)
LOW (1)
MOD (10)
HIGH (100)
TIDAL -
N/A -

**DEPTH (in)**

DRY BED (0)
LOW (6)
MOD (24)
HIGH (48)
N/A -

**SIZE (W') (Ac)**

DRY BED (0) (0)
LOW (4) (1)
MOD (12) (5)
HIGH (25) (10)

**SOURCE**

GROUND/SPRINGS
PRECIPITATION
TRIBUTARY
STORM SEWER
SITE DRAINAGE

## ATTACHMENT A
PAGE 2 OF 3

## WATERBODY NAME OR DESCRIPTION
WATERBODY

### ID

SITE NUMBER
ON SITE
OFF SITE

### MORPHOMETRY

CHANNELIZATION
POOLS
RIFFLES
CHUTES
MEANDERS

### BANKS

EROSION/STABILITY
TREES
SHRUBS
GRASSES/WEEDS
MACROPHYTES

### SUBSTRATE

CLAY
SILT/MUD
SAND
GRAVEL
COBBLE
RUBBLE

### POLLUTION

COLOR/TURBID
DEBRIS/JUNK
OIL SLICKS
FOAM/SUDS
ODOR

## ATTACHMENT A
## PAGE 3 OF 3

## WATERBODY NAME OR DESCRIPTION
## LAND USE

**ID**

SITE NUMBER
ON SITE
ADJ TO SITE

**OBSERVED LAND USES**

UNDEVELOPED
RURAL
AGRICULTURAL
PARK
RESIDENTIAL
COMMERCIAL
INDUSTRIAL
REFUSE
ABADONED

**IMPACT**

PRIMARILY PAST
SIGNIF CONT

**PRESENT ECOL/FISH**

NONE
LOW
HIGH

**POTENTIAL ECOL/FISH**

LOW
MOD
HIGH
COMMENT # (see sep sheet)
PHOTO #

**PERIPHYTON**

TYPE
PERCENT COVER

**INVERTEBRATES**

TYPES
R.A.

## ATTACHMENT B

## RECORD SHEET FOR DATA OBTAINED FROM DETAILED FIELD REVIEW

### DETAILED FIELD SURVEY DATA SHEET

STREAM SURVEY — FISH COLLECTION

County — T ______ R ______ Sec ______

STREAM — Township ____________

Point of examination  Section No. — [illegible]

GEAR USED—kind SMITH-ROOT TYPE VII ELECTROFISHER

Area covered

Immediate SHORE

TEMPERATURE—Air — Water

Weather (present and preceding)

WATER (Color, turbidity, etc.)

AVERAGE WIDTH AND DEPTH — Current velocity

BOTTOM — pH

COVER — D.O.

VEGETATION — cond.

secchi

NATURAL FOOD

REMARKS

DATE — Time — Field No.

COLLECTOR

| No. | GAME FISHES | Length | Weight | No. | FORAGE FISHES | Length | Weight |
|---|---|---|---|---|---|---|---|
| | Brook Trout | | | | | | |
| | Brown Trout | | | | | | |
| | Rainbow Trout | | | | | | |
| | COARSE FISHES | | | | | | |

## ATTACHMENT C (PAGE 1 OF 2)
## RECORD SHEET FOR DATA OBTAINED FROM DETAILED FIELD SURVEYS

### QUANTITATIVE STUDY DATA SHEET

__of__

Date:[ ][ ] / [ ][ ] / [ ][ ]     Site:________________
mo     day     year
Station:[ ][ ][ ]     Collectors:________________
Temperature: AIR (deg. C) [ ][ ][ ][.][ ]     Vegetation:__________
WATER (deg. C) [ ][ ][ ][.][ ]     ________________
% Cover: [ ][ ][ ]     Average Width and Depth:________________
________________
Secchi:[ ][ ][ ][.][ ]     ________________

pH: [ ][ ][.][ ]     Field Calibration: [ ]
D.O. (mg/l): [ ][ ][ ][.][ ]     Field Calibration: [ ]
Conductivity (umhos):[ ][ ][ ][.][ ]

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****POOL****

Width (m) [ ][ ][.][ ]     % Periphyton Cover [ ][ ][ ]

| | REP 1 | REP 2 | REP 3 |
|---|---|---|---|
| Depth (cm): | [ ][ ][ ][.][ ] / | [ ][ ][ ][.][ ] / | [ ][ ][ ][.][ ] |
| Velocity (ft./sec.) | [ ][ ][.][ ] | [ ][ ][.][ ] | [ ][ ][.][ ] |
| SIEVES (kg) | | | |
| 4 in. + | [ ][.][ ][ ] | [ ][.][ ][ ] | [ ][.][ ][ ] |
| No. 5 | [ ][.][ ][ ] | [ ][.][ ][ ] | [ ][.][ ][ ] |
| No. 10 | [ ][.][ ][ ] | [ ][.][ ][ ] | [ ][.][ ][ ] |
| No. 18 | [ ][.][ ][ ] | [ ][.][ ][ ] | [ ][.][ ][ ] |
| No. 200 | [ ][.][ ][ ] | [ ][.][ ][ ] | [ ][.][ ][ ] |
| Benthos Bot. | [ ][ ][ ][ ][ ] | [ ][ ][ ][ ][ ] | [ ][ ][ ][ ][ ] |

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****RIFFLE****

Width (m) [ ][ ][.][ ]     % Periphyton Cover [ ][ ][ ]

| | REP 1 | REP 2 | REP 3 |
|---|---|---|---|
| Depth (cm): | [ ][ ][ ][.][ ] / | [ ][ ][ ][.][ ] / | [ ][ ][ ][.][ ] |
| Velocity (ft./sec.) | [ ][ ][.][ ] | [ ][ ][.][ ] | [ ][ ][.][ ] |
| SIEVES (kg) | | | |
| 4 in. + | [ ][.][ ][ ] | [ ][.][ ][ ] | [ ][.][ ][ ] |
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REMARKS:________________________________________
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## ATTACHMENT C (PAGE 2 OF 2)
## RECORD SHEET FOR DATA OBTAINED FROM DETAILED FIELD SURVEYS

### QUANTITATIVE STUDY DATA SHEET (Cont'd)

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                                          SITE:______________________
                                          DATE:______________________
__of__                                 STATION:______________________
Periphytometer Installation: [ ][ ] / [ ][ ] / [ ][ ]
Periphytometer Removal: [ ][ ] / [ ][ ] / [ ][ ]
=====================================================================
                          FISHERIES PROGRAM

Gear Used: Smith-Root Type VII Electrofisher
Time (24 hour clock)   START: [ ][ ][ ][ ]          END: [ ][ ][ ][ ]

Species             Length (cm)     Weight       Bottle Number →
                                      (gm)
[ ][ ][ ][ ][ ]  •  [ ][ ][ ][.][ ]  •  [ ][ ][ ]  •  [ ][ ][ ][ ][ ][ ]
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| | | Prepared<br>Earth Sciences | |
| Subject<br>TERRESTRIAL ECOLOGICAL INVENTORY AND SAMPLING | | Approved<br>D. Senovich | |

## TABLE OF CONTENTS

SECTION

## 1.0 PURPOSE

The purpose of this procedure is to present methodologies for surveying and sampling terrestrial vegetation and wildlife at hazardous waste sites.

## 2.0 SCOPE

The methodologies described in this procedure are appropriate for: identifying perturbations of terrestrial ecological communities which potentially relate to hazardous waste contamination; identifying potential transport mechanisms and food chain linkages for substances of public health concern; and providing the input to evaluate the feasibility and risks of remedial design alternatives. Methodologies presented herein cannot be assumed appropriate for all sites, because of site-specific health and safety constraints.

## 3.0 GLOSSARY

Community - Populations of plant and animal species which occur together over a given area.

Food Chain - The various pathways involved in transfer of food substances from the abiotic environment or from one organism or group of organisms to another organism or group of organisms.

Transport Mechanisms - The processes by which energy or substances move from one location to another. Can also refer to movement within an organism.

Wetlands - Areas of open shallow water or land vegetated by assemblages of plant species adapted to standing water, saturated soil or regular flooding. Methodological definition is presented in the January 10, 1989 *"Federal Manual for Identifying and Delineating Jurisdictional Wetlands."*

## 4.0 RESPONSIBILITIES

Site Manager - Responsible for ensuring that project-specific plans are reviewed by a qualified ecologist and the site Health and Safety Officer, and that plans and their implementation are in compliance with this guideline.

Project Biologist - Responsible for developing and implementing the sampling program, and interpreting the results of the program.

## 5.0 PROCEDURES

## 5.1 PROGRAM DESIGN

The site-specific terrestrial ecology field program will be part of the Field Sampling and Analysis Plan and should be designed after the following tasks have been completed:

- Determination by the Site Manager and project ecologist of the objectives of ecological field investigations;
- Review and analysis of all available site-specific information; and
- Consultation with the site Health and Safety Officer (HSO).

The objectives of most terrestrial ecology studies for hazardous waste site investigations can be met with utilization of available information and qualitative methodologies comprising a General Field Survey. In these instances, program design can be accomplished by the field biologist with review by the project ecologist and the HSO.

At those sites where quantitative information or sample collection is deemed necessary, the field program should be designed with input from a statistician. This is required not only to ensure usefulness of data collected, but also to minimize time spent in the field.

### 5.2 DATA RECORDING

Standard terrestrial ecology field data sheets (Attachment A identifies the types of forms needed to conduct quantitative plant sampling) should be used for General Field Surveys. In some instances (e.g., high winds or dense understory vegetation), compact bound water-resistant notebooks may be more appropriate. One page of each notebook should list all the information required to be recorded at each sampling or observation station, for reference while in the field.

Some investigations may require specially-designed data forms. These should include the following at a minimum:

- EPA Project Number, Site Name, and Location;
- Date and Time;
- Recorder (Investigator);
- Station location;
- Sample description and/or sample number, as appropriate;
- Weather conditions; and
- Record of any photographs taken.

### 5.3 PRE-FIELD INVESTIGATION ANALYSES

Prior to the field effort, all relevant available information should be reviewed. This phase is particularly important for hazardous waste site studies because typically employed field accessories such as binoculars, camera and field keys are difficult to use at sites of level C, B or A. At many sites, the quality and quantity of information obtained will be limited by the investigator's ability to identify plant and wildlife habitat features through a respirator mask. Hence, the pre-field investigation should include the following:

- Preliminary map or a listing of vegetation community types or wildlife habitat types likely to be encountered.

- Location of known important habitats or communities (e.g., wetlands, extensive undisturbed natural areas, and habitat for game species); and

- Access routes (paths, trails accommodating all terrain vehicles, etc.) as well as emergency egress routes and safety stations.

Sources of information to be sought and consulted should include, but are not limited to, the following:

- Aerial photography;
- USGS topographic maps;
- USGS County soil survey;
- Historical flood records and 100-year flood insurance maps;
- State wetland maps;
- Observations and photographs obtained by previous investigators (e.g., FIT team or site reconnaissance survey);
- County extension agents for wildlife and forestry data;
- State field biologists;
- Published literature on natural vegetation (e.g., Kuchler, 1964; Eyre, 1980; Braun, 1950); and
- State *or federal endangered species specialists where appropriate.*

## 5.4 GENERAL FIELD SURVEY

The General Field Survey comprises a series of observations and measurements recorded at plots located to achieve a representative sampling of the site and coverage of any known important areas. Standard quantitative data sheets (see Attachment A) should be compacted at each plot location; however, if time and cost is of a concern, then a qualitative study using site characterization sheets (Attachment B) may be an option.

Vegetation observations should include a listing of characteristic species by strata:

- Lower stratum includes dominant herbaceous species and those woody plants 50 cm (knee-high) or less high;
- *Middle stratum includes woody plants higher than 50 cm and of stem diameter less than* 2.5 cm;
- Lower canopy stratum includes woody plants with stems of diameter ranging from (2.5 cm to 10 cm) 1 inch to 4 inches at chest height; and
- Upper canopy stratum includes trees with stem diameter greater than 10 cm (4 inches).

Emphasis is on plant species which, because of their abundance appear to define a community type; are potentially part of the human food chain (e.g., berries and nuts); or are consumed by game species. Wetland communities warrant greater detail because they can constitute important wildlife habitat, particularly for waterfowl, and are likely sinks for water-borne contaminants. At a minimum, the field investigator should record sufficient data for applying in a qualitative manner the "Federal Manual for Identifying and Delineating Jurisdictional Wetlands."

Observations relating to wildlife may also be recorded. In addition to actual sightings, observations includes tracks, dens, nests, scat, browsing signs, etc. Particular attention should be accorded to game species, which can constitute a link between contaminants and the human food chain. Important classes of game species to be considered include waterfowl, mourning dove, upland game birds, deer, rabbit and squirrel. Waterfowl, are of particular concern at hazardous waste sites since they can be abundant, are mobile, utilize wetland habitats serving as contaminant sinks, and can be heavily harvested for human consumption.

Observations of perturbations are important for interpreting cycling processes and identifying potential transport mechanisms. Typical observations of stress include:

- Bare soil resulting from erosion, flooding, vehicular use or toxicity;
- Occurrence of contaminant residues;
- Construction and other human induced disturbances;
- Fire;
- Heavy grazing or browsing;
- Unexplained mortality (e.g., standing dead tree boles); and
- Insect and disease damage

An inventory of selected areas adjacent to the site can greatly improve the usefulness of the General Field Survey. In some instances, off-site areas will support the same kinds of ecosystem occurring on-site, but in less disturbed states. Comparison of off-site with on-site ecosystems may provide some indication of the nature and degree of any on-site stresses. It is also important to identify and characterize possible off-site ecosystems that may serve as receptors for air-borne or water-borne contaminants originating on-site. An inventory of productive wildlife habitat in the region surrounding the site can provide a better estimate of potential wildlife usage of on-site areas by mobile species.

## 5.5 SPECIAL INVESTIGATIONS

At some hazardous waste sites it may be necessary to quantitatively estimate abundance of plant or animal species, or collect samples for chemical analysis. For these objectives, methodologies may have to meet statistical criteria as well as the site-specific health and safety considerations. Methodologies described below are standard, but not necessarily appropriate for all sites because of health and safety constraints. Selection of appropriate methodologies for quantitative studies at a particular site must include the involvement of an ecologist, statistician and health and safety specialist.

### 5.5.1 Abundance Estimates

Vegetation

Vegetation abundance may be measured in terms of stem density or cover. These measurements are obtained from nested plots, or quadrats; smaller-sized plots, used to sample the lower and middle strata, are contained ("nested") within larger plots used for sampling lower and upper canopy plants. Quadrat and nested sub-plot size may vary with sampling objectives.

Stem density is obtained by counting number of stems per plot. Cover is the percent of ground shaded by all the individuals of one species with the sun directly overhead, and may be estimated by eye to the nearest percent. Where more precise measures of cover of herbaceous and low shrubs is required, the point-frequency and line-intercept methods, respectively, may be considered.

Plots are regularly spaced along transects. Number of transects and number of plots will depend on floral diversity and objectives of program. Sampling adequacy can be based on species-area curves.

Wildlife

Determination of wildlife species occurrence and estimation of density require special techniques depending on species of interest, season, and site features. Standard methods for detecting presence of secretive species include, but are not limited to, the following:

- Live and snap trapping (small mammals);
- Pit trapping (small mammals, reptiles, and amphibians);
- Spot-light surveys (nocturnal species);
- Tape recordings and call counts (amphibians and birds);
- Mist netting (birds and bats);
- Berlese or Tullgren funnels (soil invertebrates); and
- Sweep netting (insects).

Use of most of these techniques is discussed in Schemnitz, (1980). For information on use of funnels for sampling soil invertebrates, consult Bender et al. (1972), and on sweep netting and insect sampling in general, consult Menhinick (1963) and Southwood (1966).

Traps should be set at roughly regular intervals along survey lines located in each of the habitat types to be sampled. Spacing and number of traps will depend on species, territory size, trapping efficiency, program objectives, and investigator's knowledge of species-specific behavior patterns. Spotlight searches and the playing of sound recordings are conducted at regular intervals along survey lines, with consideration for territory size and individual species behavior. Mist nets are located in areas likely to intercept low-flying birds; and likely locales can be selected based on feeding habits and site habitat features.

For most species, standard quantitative measures of wildlife density involve total counts, sample counts or mark-and-recapture. Assumptions and formulae for estimating population densities from these techniques are presented in Wildlife Management Techniques (Schemnitz, 1980), and White et al. (1982). Density estimates are time-specific, as populations of most animals fluctuate greatly from season-to-season and year-to-year.

### 5.5.2 Collecting Specimens for Chemical Analysis

The objectives of collecting plant and animal specimen for chemical analyses are to (1) identify occurrence of elevated concentrations of potential contaminants, (2) identify gradients of contaminant concentration, and/or (3) quantitatively determine concentrations in particular target species. For the latter two objectives a statistical approach will have to be developed to determine number of samples per tissue type, species, location, etc.

Selection of species for chemical analysis will depend on the program objectives, nature of suspected contaminants, and ecosystems occurring on-site. In most instances, species selected will either be a possible component of the human food chain, or a known bioaccumulator of the contaminant(s) of concern.

In developing a sampling plan and while collecting plant specimens, a number of factors have to be considered which influence concentrations of substances in vegetation. Concentrations may vary with height above ground, distance from plant perimeter, species, and plant tissue (e.g., leaf, root, current year stem, old growth stem and fruit). Many substances are relatively immobile in plants, tending to accumulate at exterior surfaces where concentrations may be affected by rainfall washing and leaching. Soil factors can greatly influence substance availability for plant uptake and thus tissue concentrations.

After sampling design has been determined, consult with the analytical laboratory for proper containers and storage procedures. For most sampling efforts, zip-lock plastic bags will be adequate. Animal specimen should be stored in refrigerated containers and then frozen until laboratory analysis.

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## 7.0 ATTACHMENTS

Attachment A - Typical Terrestrial Ecology Field Data Sheet
Attachment B - Site Characterization

## ATTACHMENT A

## TYPICAL TERRESTRIAL ECOLOGY FIELD DATA SHEET

SITE: ______________________________

INVESTIGATOR: ____________________ DATE: ____________

SAMPLING LOCATE OR TRANSECT: ____________________

PLOT: ______________________________

REVIEWED: ______________________________

EACH QUANTITATIVE PLANT SAMPLING FORM SHOULD FEATURE ONE OF THE FOLLOWING:

- Upper Canopy (stem diameter > 10 cm): Listing at a minimum each individual by species and DBH (diameter at breast height)
- Lower Canopy (2.5 cm < stem diameter < 10 cm): Listing at a minimum each individual by species and DBH
- Middle Stratum (Height > 50 cm and stem diameter < 2.5 cm and woody vines): Listing at a minimum each species and percent cover.

Lower Stratum (all herbs; woody spp. < 50 cm tall): Listing at a minimum each species and percent cover.

NOTING:

- Terrain features
- Disturbances
- Wildlife Observations
- Wetlands
- Etcetera

## ATTACHMENT B

## SITE CHARACTERIZATION

1. **General Information:**

**Site ID Number:** ____________________
**County:** ____________________
**Section:** ____________________
**Watershed:** ____________________
**Date:** ____________________
**Observers:** ____________________ ____________________
**Air Photo Reference:** ____________________
**Photographs Taken:** ____________________

2. **Topography and Soils:**

**Elevation:** ________________ **Slope Percent:** ________________
**Slope Position:** ________________ **Aspect:** ________________
**Soils:** ________________

3. **Vegetation (Cover Classes(1)):**

| | | Tree Stratum | Shrub Stratum | Herb Stratum |
|---|---|---|---|---|
| **Cover (%):** | | | | |
| **Cover Type:** | | | | |
| **Association:** | | | | |
| **Average Height Dominants:** | | | | |
| **Average DBH Dominants:** | | | | |
| **Species Composition and Abundance:** | | | | |
| 1. | | | | |
| 2. | | | | |
| 3. | | | | |
| 4. | | | | |
| 5. | | | | |
| 6. | | | | |
| 7. | | | | |
| 8. | | | | |
| 9. | | | | |
| 10. | | | | |
| 11. | | | | |
| 12. | | | | |
| 13. | | | | |
| 14. | | | | |

## ATTACHMENT B
## SITE CHARACTERIZATION
## PAGE TWO

3. Vegetation (Cover Classes[1]) (CONTINUED):

| | | Tree Stratum | Shrub Stratum | Herb Stratum |
|---|---|---|---|---|
| Cover (%): | | | | |
| Cover Type: | | | | |
| Association: | | | | |
| Average Height Dominants: | | | | |
| Average DBH Dominants: | | | | |
| Species Composition and Abundance: | | | | |
| 15. | | | | |
| 16. | | | | |
| 17. | | | | |
| 18. | | | | |
| 19. | | | | |
| 20. | | | | |
| 21. | | | | |
| 22. | | | | |
| 23. | | | | |
| 24. | | | | |
| 25. | | | | |

(1) Cover classes (midpoints): T < 1% none; 1 = 1-5% (3.0); 2 = 6-15% (10.5); 3 = 16-25% (20.5); 4 = 26-50% (38.0); 5 = 51-75% (63.0); 6 = 76-95% (85.5); 7 = 96-100% (98.0).

4. Wildlife:

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| | | Applicability<br>EMG | |
| | | Prepared<br>Earth Sciences | |
| Subject | BIOLOGICAL SAMPLING EQUIPMENT CALIBRATION AND MAINTENANCE | Approved<br>D. Senovich | |

## TABLE OF CONTENTS

**SECTION**

## 1.0 PURPOSE

The purpose of this procedure is to describe standard methods for the calibration and maintenance (including decontamination and storage) of biological sampling equipment used at hazardous waste sites. The objectives are to minimize equipment malfunction in the field and the possibility of contamination of samples and personnel.

## 2.0 SCOPE

This procedure presents general methods for decontaminating, calibrating, maintaining and storing biological sampling equipment used at hazardous waste sites.

## 3.0 GLOSSARY

None.

## 4.0 RESPONSIBILITIES

<u>Site Manager</u> - Will be responsible for ensuring that methods and facilities employed for the decontamination and onsite storage of biological sampling equipment are in compliance with this guideline.

<u>Project Biologist</u> - Responsible for ensuring that equipment is properly calibrated prior to field use.

<u>Government Property Administrator</u> - Responsible for ensuring that equipment is properly maintained when stored offsite.

## 5.0 PROCEDURES

Proper decontamination, calibration, and maintenance and storage for biological equipment is necessary to ensure the health and safety of personnel coming in contact with the equipment, and consistent results. The following sections describe standard procedures for these functions.

### 5.1 DECONTAMINATION OF BIOLOGICAL EQUIPMENT

Selection of proper decontamination procedures for sampling equipment depends on the ability of the equipment to withstand the various cleaning processes. Decontamination of equipment capable of withstanding steam cleaning, immersion and/or solvent rinses. Equipment unable to withstand such procedures will require special techniques, unless the equipment cannot withstand any decontamination or extended reuse, a topic which is treated. Recommended decontamination procedures for specific equipment are summarized in Attachment A.

### 5.1.1 General Methods

Water sampler and biological sampling devices are decontaminated prior to, and again subsequent to sampling events. Equipment leaving the site will also be decontaminated as called for in the Health and Safety Plan.

Grab sampler (substrate and water) can be decontaminated by steam cleaning at a steam cleaning pit, the location of which should be designated in the Health and Safety Plan (HASP). After steam cleaning grab samplers (substrate and water) contaminated with certain residues may require soap scrubbing prior to final rinsing with solvents (regionally specific) and distilled deionized water.

Other types of equipment (and grab samplers, if a steam cleaner is not available onsite) should be thoroughly cleaned using the following sequence:

1. Potable water rinse
2. Alconox/Liquidnox detergent wash
3. Potable water rinse
4. 10 percent nitric acid solution rinse for suspected metals
5. Distillated deionized water rinse
6. Reagent grade rinse if analyzing for organics
7. Distilled deionized water rinse
8. Air dry
9. Wrap with aluminum foil (dull side towards equipment)

Personnel directly involved in equipment decontamination will wear proper protective clothing and respiratory equipment as specified in the Health and Safety Plan.

### 5.1.2 Equipment Requiring Special Methods

Equipment such as D.O. meters or the electronic parts of electroshockers cannot be steam cleaned or washed without damaging the units. During field use, equipment of this type should be contained in non-permeable materials (e.g., a plastic bag or sleeve) which is then removed and properly discarded. Caution must be exercised when using equipment such as gasoline-powered electroshockers, which may overheat or malfunction when operated in an enclosing non-permeable material.

Components such as D.O.probes, that must come in contact with potentially contaminated materials, may be either decontaminated under general procedures, or discarded. The field biologist and Health and Safety Officer, after consulting the equipment manufacturer's manuals, must establish isolation and decontamination procedures prior to project startup. Equipment requiring isolation is indicated in Attachment A.

### 5.1.3 Equipment Requiring Disposal or Limited Use

Some equipment cannot be decontaminated or isolated due to construction material and/or size. This includes most sampling devices constructed of or containing netting material. The decontamination procedure for such devices is site-dedication and ultimate disposal. Equipment of this type may either be disposed of after each sample or re-used onsite for the duration of the sampling program. Equipment requiring dedication, along with an acceptable duration of use, must be identified by the field biologist and Health and Safety Officer during program initiation. Types of equipment requiring dedication are indicated in Attachment A.

## 5.2 CALIBRATION

Most measuring devices require calibration to ensure accurate results. This may involve field calibration before each sampling event, as well as a periodic (annual) factory calibration by the manufacturer or certified technician.

Frequency of calibration, for both field and factory, are specific for brand and model due to variation in construction and precision. Specific field calibration procedures and recommended frequencies presented in the manufacturer's manual should be reviewed and implemented.

Typical frequencies of both field and factory calibrations are presented in Attachment A. Once a calibration schedule is established for each instrument, conformance to it should be documented by a calibration log maintained for each instrument.

## 5.3 MAINTENANCE AND STORAGE

Proper maintenance and storage of biological equipment will help to ensure consistent functioning during field sampling. All equipment returned from the field to the in-house storage facility should be thoroughly decontaminated according to the health and safety procedure for equipment used at hazardous waste sites. Specific maintenance and storage requirements for each piece of equipment are elaborated in the manufacturer's manual, and should be consulted at project startup to establish a maintenance and storage program. A log sheet should be kept to document equipment maintenance activities.

General maintenance checks should be performed on all sampling devices on a routine basis and should include, where appropriate, testing of seals on equipment suspected of leaking, and inspection for:

- Checks or deformities in seals
- Properly-functioning springs
- Cracks in cases or meter windows
- Missing screws, bolts, parts
- Broken or frayed wires
- Condensation forming inside meters
- Rust or corrosion
- Integrity of electrical components

In general, equipment storage requires:

- Thoroughly rinsing and drying all equipment prior to storing
- Storing in dry areas (except electrodes)
- Disconnecting probes and installing dust caps
- Maintaining recommended storage temperatures
- Storing in a secure location to prevent damage or discourage vandalism

Store electrodes for short-terms (1-6 months, depending on recommendations in manufacturer's manual) in beakers with appropriate solution. For long-term storage of electrodes, moisten and replace end caps, fill liquid-filled probes with electrolyte, and remove batteries.

## 6.0 REFERENCES

None.

## 7.0 ATTACHMENTS

Attachment A - General Recommended Decontamination and Calibration Procedures for Biological Sampling Equipment

## ATTACHMENT A

## GENERAL RECOMMENDED DECONTAMINATION AND CALIBRATION METHODS FOR BIOLOGICAL SAMPLING EQUIPMENT

| Sampling Device | Decontamination Method | Calibration | | |
|---|---|---|---|---|
| | | Frequency | | Method (Field) |
| | | Factory | Field | |
| Kemmerer | Steam/Decon | | | |
| Van Dorn | Steam/Decon | | | |
| Nansen | Steam/Decon | | | |
| Ponar | Steam/Decon | | | |
| Smith-McIntyre | Steam/Decon | | | |
| Shipeck | Steam/Decon | | | |
| Hand Corer | Steam/Decon | | | |
| D.O. Meter | | 6-12 months | Daily | As per manual |
| Probe Meter | Wash & Rinse<br>Isolation Bag | | | |
| pH Meter | | 6-12 months | Daily | Standard Buffer |
| Probe Meter | Wash & Rinse<br>Isolation Bag | | | |
| SCT Meter | | 6-12 months | | |
| Probe Meter | Wash & Rinse<br>Isolation Bag | | | |
| Flow Meter | Wash& Rinse | 6 months | | |
| Balance | Wash& Rinse | 6 months | | |
| Electrofisher | | | | |
| Battery type<br>Generator | Isolation Bag<br>Locate out of "Hot" Zone | 1 month<br>12 months | | |
| Seine Net | Disposal | | | |

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## ATTACHMENT A
## GENERAL RECOMMENDED DECONTAMINATION AND CALIBRATION METHODS FOR BIOLOGICAL SAMPLING EQUIPMENT
## PAGE TWO

| Sampling Device | Decontamination Method | Calibration | | |
|---|---|---|---|---|
| | | Frequency | | Method (Field) |
| | | Factory | Field | |
| Gill Net | Disposal | | | |
| Trawl | | | | |
| Net | Disposal | | | |
| Doors | Steam | | | |
| Plankton | | | | |
| Nets | Disposal | | | |
| Meters | Wash & Rinse | 6 months | | |
| Sieves | Steam | | | |
| Surlier | Disposal | | | |
| Boat | Steam | | | |

| | | | |
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| | | Applicability<br>EMG | |
| | | Prepared<br>Earth Sciences | |
| Subject<br>LAGOON SAMPLING | | Approved<br>D. Senovich | |

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**SECTION**

## 1.0 PURPOSE

The purpose of this procedure is to provide general information for sampling of surface impoundments or lagoons present at uncontrolled hazardous waste sites which are known or suspected to contain high levels of contamination.

## 2.0 SCOPE

This procedure describes requirements and methods for collecting samples of liquid, sludges, sediments and bottom soils from lagoons containing hazardous materials. Factors which affect access to appropriate sampling locations and methods of obtaining samples at these locations are discussed herein. In this guideline, however, strong emphasis is given to the stringent health and safety requirements related to lagoon sampling. Since many lagoons contain highly concentrated wastes and present direct physical hazards via inhalation or contact, extreme care must be taken with all lagoon sampling programs.

## 3.0 GLOSSARY

Lagoon - Any on-site impoundment, depression, excavation, or diked area where hazardous materials have been deposited.

Core Sample - A sediment sample from the lagoon floor taken in such a way as to preserve the horizontal and vertical integrity of the sample for subsequent physical and/or chemical characterization of specific vertical intervals.

Caisson - A large diameter circular tube or pipe from which lagoon or impoundment liquid can be removed to allow collection of a "dry" sample of bottom solids.

## 4.0 RESPONSIBILITIES

Site Manager - Responsible to assure that the need for lagoon sampling is well justified and that the sampling objectives and procedures are well defined.

Field Operations Leader - Responsible for the conduct of the lagoon sampling operation, including *potentially dangerous sampling operations performed from a flotation device.* The FOL has the authority to change sampling locations/strategies based on conditions on-site.

Site Health and Safety Officer - Responsible for the site-specific HASP and its modification as needed to ensure that sampling is performed using adequate precautions. The HSO's duties include determination and monitoring of respiratory protection levels and overall safety of the operations.

## 5.0 PROCEDURES

### 5.1 INITIAL PLANNING

Investigation of lagoon liquid, sludges and sediments will help to define the nature and concentration of contaminants in the lagoon for use in site characterization, remedial alternatives analysis, or for conducting an Expedited Response Action. Characterization of bottom soils (i.e., permeability testing and chemical analysis) will determine the likelihood and possibly the extent of migration from the lagoon. Unfortunately, no standard methods exist for lagoon characterization, and decisions as to where and how to sample must be made on a site-specific basis. The following discussion describes several methods by which lagoon characterization can be performed.

Before initiating a lagoon sample collection program, the Site Manager (SM) should review available site information to determine where samples should be taken and for what purpose. Factors affecting location and methods of sampling include:

- The presence of a bottom liner in the lagoon. (Penetration of bottom liners should be avoided unless the lagoon materials have already been removed or a caisson is used and the liner is properly resealed.)
- The history of site operations and the probably contents and distribution of solids in the lagoon.
- The variability of bottom deposit physical/chemical characteristics and thickness.
- Size of lagoon.
- Presence of surface materials which could interfere with sampling.
- The likely homogeneity and degree of stratification or mixing in the lagoon.

The SM should clearly establish the objectives of the sampling program. Sampling and analytical requirements will differ greatly depending on whether the program is seeking bathymetric (i.e., depth) information for estimating the total quantity of contaminated materials in the lagoon, a determination of the degree of contamination in various media (liquid, sludge, sediment), or the physical characteristics of the materials present (such as permeability, viscosity, etc.).

The first major decision of the lagoon sampling program is whether adequate samples can be taken from the shoreline, or whether a flotation device will be required. For health and safety reasons, shore sampling is more desirable, but this may not be acceptable if representative samples cannot be *obtained from the lagoon periphery. On the other hand, sampling from a flotation device may be* unacceptable for personnel safety reasons, such as where the lagoon contains extremely corrosive or hazardous materials. The Site Manager must determine the best method of sampling based on sample representativeness, the availability of needed equipment, budget and time constraints, and the intended use of the data. These considerations will also effect the type of samples to be taken.

Upon resolution of these concerns a plan for the lagoon sampling can be developed. This plan should include the following information:

- Sampling pattern (grid, random, or targeted toward specific areas).
- Required number of samples
- Sample size (Depending on analytical requirements).
- Sampling methods (including composite or grab samples).

The plan should be carefully reviewed by all personnel who will take part in the sampling effort. Special health and safety issues must be addressed in the site HASP.

## 5.2 METHODS OF OBTAINING ACCESS TO SAMPLING LOCATIONS

Because the collected samples must be representative of conditions throughout a lagoon, sampling directly from the shore is usually only appropriate for sampling of very small lagoons or impoundments (less than 10,000 square feet). Samples can also be collected from a platform suspended from shore-based machinery such as a "cherry picker." These platforms may extend to a maximum of 20-25 feet from the shore, depending on the available support on the lagoon bank. Platforms can be outfitted with suitable protective guardrails to provide a relatively safe working environment. However, space is limited and it is often difficult for more than two people to work effectively.

In situations where samples must be collected from the interior sections of a lagoon, a flotation device must be used. Safety is the overriding factor in such an operation and special care must be exercised to insure that a stable work platform is provided.

In many cases, commercially available vessels are not appropriate for lagoon, sampling and must be modified to increase stability, facilitate sampling operations over the side or through the hull and allow enough room for personnel, sampling equipment and personal protection equipment. Provisions must also be made to decontaminate or dispose of the vessel after use. Custom designed and built vessels and equipment may also be appropriate, depending on the situation.

A flat-bottomed boat may be used for lagoon sampling but this may still represent a dangerously unstable condition. To overcome instability, a sampling platform can be constructed from two flat-bottomed boats outfitted with a frame, guardrails, stabilizing legs at each corner and an opening in the center.

This opening can be used for caisson placement hand coring, or liquid sample collection (see Reference 2). Other designs and configurations are also possible.

Independent of final design, platforms may be moved over the lagoon by means of ropes, oars or attached outboard motors. The use of ropes is favored for all but the largest lagoons because the ropes will also keep the platform in position. Where movement of the sampling platform is hindered by viscous surface deposits or other impediments, winches or motor vehicles may be required to move the platform.

## 5.3 METHODS OF SAMPLE COLLECTION

When collecting liquid samples from the shore, the sampling container can be filled directly (as for the collection of surface water samples) or a sampling bucket can be thrown into the lagoon interior to collect samples before transfer to the sampling container. In the latter case, care must be taken to insure that the sample bucket construction materials are inert to the lagoon materials and will not cause potential interferences (contamination) with the analyses of interest. Also, the bucket should not be allowed to drag along the bottom and thus contaminate the liquid sample with sediment.

Samples of sludges and sediments can be collected directly from the shore in a manner similar to the collection of liquid samples. However, substantial mixing with overlying liquid is likely. For compacted or cemented bottom materials, samples may be collected directly from the shore using a trowel or a drive sampler (e. g., split barrel).

In collecting liquid samples from suspended or floating platforms, various surface water and tank sampling devices (such as the Bacon Bomb Sampler or the weighted bottled sampler) may be used. Direct methods used for shore-sampling may also be applied. Use of these specialized samplers is