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Compendium of ERT Groundwater Sampling Procedures

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January 1991

COMPENDIUM OF ERT GROUNDWATER SAMPLING PROCEDURES

Sampling Equipment Decontamination

Groundwater Well Sampling

Soil Gas Sampling

Monitoring Well Installation

Water Level Measurement

Well Development

Controlled Pumping Test

Slug Test

Interim Final

Environmental Response Team
Emergency Response Division

Office of Emergency and Remedial Response
U.S. Environmental Protection Agency
Washington, DC 20460

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Questions, comments, and recommendations are welcomed regarding the Compendium of ERT Groundwater Sampling Procedures. Send remarks to:

Mr. William A. Coakley
Removal Program QA Coordinator
U.S. EPA - ERT
Raritan Depot - Building 18, MS-101
2890 Woodbridge Avenue
Edison, NJ 08837-3679

For additional copies of the Compendium of ERT Groundwater Sampling Procedures, please contact:

National Technical Information Service (NTIS)
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161
(703) 487-4600

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1.0 SAMPLING EQUIPMENT DECONTAMINATION: SOP #2006

1.1 SCOPE AND APPLICATION

This Standard Operating Procedure (SOP) describes methods used for preventing or reducing cross-contamination, and provides general guidelines for sampling equipment decontamination procedures at a hazardous waste site. Preventing or minimizing cross-contamination in sampled media and in samples is important for preventing the introduction of error into sampling results and for protecting the health and safety of site personnel.

Removing or neutralizing contaminants that have accumulated on sampling equipment ensures protection of personnel from permeating substances, reduces or eliminates transfer of contaminants to clean areas, prevents the mixing of incompatible substances, and minimizes the likelihood of sample cross-contamination.

1.2 METHOD SUMMARY

Contaminants can be physically removed from equipment, or deactivated by sterilization or disinfection. Gross contamination of equipment requires physical decontamination, including abrasive and non-abrasive methods. These include the use of brushes, air and wet blasting, and high-pressure water cleaning, followed by a wash/rinse process using appropriate cleaning solutions. Use of a solvent rinse is required when organic contamination is present.

1.3 SAMPLE PRESERVATION, CONTAINERS, HANDLING, AND STORAGE

This section is not applicable to this SOP.

1.4 INTERFERENCES AND POTENTIAL PROBLEMS

- The use of distilled/deionized water commonly available from commercial vendors may be acceptable for decontamination of sampling equipment provided that it has been verified by laboratory analysis to be analyte free.
- An untreated potable water supply is not an acceptable substitute for tap water. Tap water may be used from any municipal water treatment system for mixing of decontamination solutions.
- Acids and solvents utilized in the decontamination sequence pose the health and safety risks of inhalation or skin contact, and raise shipping concerns of permeation or degradation.
- The site work plan must address disposal of the spent decontamination solutions.
- Several procedures can be established to minimize contact with waste and the potential for contamination. For example:

  Stress work practices that minimize contact with hazardous substances.

  Use remote sampling, handling, and container-opening techniques when appropriate.

  Cover monitoring and sampling equipment with protective material to minimize contamination.

  Use disposable outer garments and disposable sampling equipment when appropriate.

1.5 EQUIPMENT/APPARATUS

- appropriate personal protective clothing
- non-phosphate detergent
- selected solvents
- long-handled brushes
- drop cloths/plastic sheeting
- trash container
- paper towels
- galvanized tubs or buckets
- tap water

- distilled/deionized water
- metal/plastic containers for storage and disposal of contaminated wash solutions
- pressurized sprayers for tap and deionized/distilled water
- sprayers for solvents
- trash bags
- aluminum foil
- safety glasses or splash shield
- emergency eyewash bottle

1.6 REAGENTS

There are no reagents used in this procedure aside from the actual decontamination solutions and solvents. In general, the following solvents are utilized for decontamination purposes:

- 10% nitric acid([1])
- acetone (pesticide grade)(*)
- hexane (pesticide grade)(*)
- methanol

([1]) Only if sample is to be analyzed for trace metals.
([2]) Only if sample is to be analyzed for organics.

1.7 PROCEDURES

As part of the health and safety plan, develop and set up a decontamination plan before any personnel or equipment enter the areas of potential exposure. The equipment decontamination plan should include:

- the number, location, and layout of decontamination stations
- which decontamination apparatus is needed
- the appropriate decontamination methods
- methods for disposal of contaminated clothing, apparatus, and solutions

1.7.1 Decontamination Methods

All personnel, samples, and equipment leaving the contaminated area of a silt must be decontaminated. Various decontamination methods will eithcr physically remove contaminants, inactivate contaminants by disinfection or sterilization, or do hot h.

In many cases, gross contamination can be removed by physical means. The physical decontamination techniques appropriate for equipment decontamination can be grouped into two categories: abrasive methods and non-abrasive methods.

Abrasive Cleaning Methods

Abrasive cleaning methods work by rubbing and wearing away the top layer of the surface containing the contaminant. The following abrasive methods arc available:

- Mechanical: Mechanical cleaning methods use brushes of metal or nylon. The amount and type of contaminants removed will vary with the hardness of bristles, length of brushing time, and degree of brush contact.

- Air Blasting: Air blasting is used for cleaning large equipment, such as bulldozers, drilling rigs or auger bits. The equipment used in air blast cleaning employs compressed air to force abrasive material through a nozzle at high velocities. The distance between the nozzle and the surface cleaned, as well as the pressure of air, the time of application, and the angle at which the abrasive strikes the surface, determines cleaning efficiency. Air blasting has several disadvantages: it is unable to control the amount of material removed, it can acrate contaminants, and it generates large amounts of waste.

- Wet Blasting: Wet blast cleaning, also used to clean large equipment, involves use of a suspended fine abrasive: delivered by compressed air to the contaminated area. The amount of materials removed can be carefully controlled by using wry line abrasives. This method generates a large amount of waste.

Non-Abrasive Cleaning Methods

Non-abrasive cleaning methods work by forcing the contaminant off of a surface with pressure. In general, less of the equipment surface is removed using non-ahrasive methods. The following non-abrasive methods arc available:

- High-Pressure Water: This method consists of a high-pressure pump, an operator-controlled directional nozzle, and a high pressure hose. Operating pressure usually ranges from 340 to 680 atmospheres (atm) which relates to flow rates of 20 to 140 liters per minute.

- Ultra-High-Pressure Water: This system produces a pressurized water jet (from 1,000 to 4,000 atm). The ultra-high-pressure spray removes tightly-adhered surface film. The water velocity ranges from 500 m/sec (l,000 atm) to 900 m/sec (4,000 atm). Additives can enhance the method. This method is not applicable for hand-held sampling equipment.

Disinfection/Rinse Methods

- Disinfection: Disinfectants are a practical means of inactivating infectious agents.

- Sterilization: Standard sterilization methods involve heating the equipment. Sterilization is impractical for large equipment.

- Rinsing: Rinsing removes contaminants through dilution, physical attraction, and solubilization.

1.7.2 Field Sampling Equipment Cleaning Procedures

Solvent rinses are not necessarily required when organics are not a contaminant of concern and may be eliminated from the sequence specified below. Similarly, an acid rinse is not required if analysis does not include inorganics.

1. Where applicable, follow physical removal procedures specified in section 1.7.1.

2. Wash equipment with a non-phosphate detergent solution.

3. Rinse with tap water.

4. Rinse with distilled/deionized water.

5. Rinse with 10% nitric acid if the sample will be analyzed for trace organics.

6. Rinse with distilled/deionized water.

7. Use a solvent rinse (pesticide grade) if the sample will be analyzed for organics.

8. Air dry the equipment completely.

9. Rinse again with distilled/deionized water.

Selection of the solvent for use in the decontamination process is based on the contaminants present at the site. Use of a solvent is required when organic contamination is present on-site. Typical solvents used for removal of organic contaminants include acetone, hexane, or water. An acid rinse step is required if metals are present on-site. If a particular contaminant fraction is not present at the site, the nine-step decontamination procedure listed above may be modified for site specificity. The decontamination solvent used should not be among the contaminants of concern at the site.

Table 1 lists solvent rinses which may be required for elimination of particular chemicals. After each solvent rinse, the equipment should be air dried and rinsed with distilled/deionized water.

Sampling equipment that requires the use of plastic tubing should be disassembled and the tubing replaced with clean tubing, before commencement of sampling and between sampling locations.

1.8 CALCULATIONS

This section is not applicable to this SOP.

1.9 QUALITY ASSURANCE/ QUALITY CONTROL

One type of quality control sample specific to the field decontamination process is the rinsate blank. The rinsate blank provides information on the effectiveness of the decontamination process employed in the field. When used in conjunction with field blanks and trip blanks, a rinsate blank can detect contamination during sample handling, storage and sample transportation to the laboratory.

Table 1: Recommended Solvent Rinse for Soluble Contaminants

SOLVENT	SOLUBLE CONTAMINANTS
Water	• Low-chain hydrocarbons • Inorganic compounds • Salts • Some organic acids and other polar compounds
Dilute Acids	• Basic (caustic) compounds • Amines • Hydrazines
Dilute Bases -- for example, detergent and soap	• Metals • Acidic compounds • Phenol • Thiols • Some nitro and sulfonic compounds
Organic Solvents([1]) - for example, alcohols, ethers, ketones, aromatics, straight-chain alkanes (e.g., hexane), and common petroleum products (e.g., fuel, oil, kerosene)	• Nonpolar compounds (e.g., some organic compounds)

([1]) - WARNING: Some organic solvents can permeate and/or degrade protective clothing.

A rinsate blank consists of a sample of analyte-free (i.e, deionized) water which is passed over and through a field decontaminated sampling device and placed in a clean sample container.

Rinsate blanks should be run for all parameters of interest at a rate of 1 per 20 for each parameter, even if samples are not shipped that day. Rinsate blanks are not required if dedicated sampling equipment is used.

1.10 DATA VALIDATION

This section is not applicable to this SOP.

1.11 HEALTH AND SAFETY

When working with potentially hazardous materials, follow U.S. EPA, OSHA and specific health and safety procedures.

Decontamination can pose hazards under certain circumstances even though performed to protect health and safety. Hazardous substances may be incompatible with decontamination methods. For example, the decontamination solution or solvent may react with contaminants to produce heat, explosion, or toxic products. Decontamination methods may be incompatible with clothing or equipment; some solvents can permeate or degrade protective clothing. Also, decontamination solutions and solvents may pose a direct health hazard to workers through inhalation or skin contact, or if they combust.

The decontamination solutions and solvents must be determined to be compatible before use. Any method that permeates, degrades, or damages personal protective equipment should not be used. If decontamination methods pose a direct health hazard, measures should be taken to protect personnel or the methods should be modified to eliminate the hazard.

2.0 GROUNDWATER WELL SAMPLING: SOP #2007

2.1 SCOPE AND APPLICATION

The objective of this Standard Operating Procedure (SOP) is to provide general reference information on sampling of groundwater wells. This guideline is primarily concerned with the collection of water samples from the saturated zone of the subsurface. Every effort must be made to ensure that the sample is representative of the particular zone of water being sampled. These procedures are designed to be used in conjunction with analyses for the most common types of groundwater contaminants (e.g., volatile and semi-volatile organic compounds, pesticides, metals, biological parameters).

2.2 METHOD SUMMARY

Prior to sampling a monitoring well, the well must be purged. This may be done with a number of instruments. The most common of these are the bailer, submersible pump, non-gas contact bladder pump and inertia pump. At a minimum, three well volumes should be purged, if possible. Equipment must be decontaminated prior to use and between wells. Once purging is completed and the correct laboratory-cleaned sample containers have been prepared, sampling may proceed. Sampling may be conducted with any of the above instruments, and need not be the same as the device used for purging. Care should be taken when choosing the sampling device as some will affect the integrity of the sample. Sampling equipment must also be decontaminated. Sampling should occur in a progression from the least to most contaminated we11, if this information is known.

2.3 SAMPLE PRESERVATION, CONTAINERS, HANDLING, AND STORAGE

The type of analysis for which a sample is being collected determines the type of bottle, preservative, holding time, and filtering requirements. Samples should be collected directly from the sampling device into appropriate laboratory-cleaned containers. Check that a Teflon liner is present in the cap, if required. Attach a sample identification label. Complete a field data sheet, a chain of custody form and record all pertinent data in the site logbook.

Samples shall be appropriately preserved, labelled, logged, and placed in a cooler to be maintained at 4°C. Samples must be shipped well before the holding time is over and ideally should be shipped within 24 hours of sample collection. It is imperative that these samples be shipped or delivered daily to the analytical laboratory in order to maximize the time available for the laboratory to perform the analysis. The bottles should be shipped with adequate packing and cooling to ensure that they arrive intact.

Certain conditions may require special handling techniques. For example, treatment of a sample for volatile organic (WA) analysis with sodium thiosulfate preservative is required if there is residual chlorine in the water (such as public water supply) that could cause free radical chlorination and change the identity of the original contaminants. However, sodium thiosulfate should not be used if chlorine is not present in the water. Special requirements must be determined prior to conducting fieldwork.

2.4 INTERFERENCES AND POTENTIAL PROBLEMS

2.4.1 General

The primary goal of groundwater sampling is to obtain a representative sample of the groundwater body. Analysis can be compromised by field personnel in two primary ways: (1) taking an unrepresentative sample, or (2) by incorrect handling of the sample. There are numerous ways of introducing foreign contaminants into a sample, and these must be avoided by following strict sampling procedures and only utilizing trained field personnel.

2.4.2 Purging

In a non-pumping well, there will be little or no vertical mixing of the water, 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, become stagnant and lack the VOAs representative of the groundwater. Sampling personnel should realize that stagnant water may contain foreign material inadvertently or deliberately introduced from the surface, resulting in an unrepresentative sample. To safeguard against collecting nonrepresentative stagnant water, follow these guidelines during sampling:

- As a general rule, all monitoring wells should be pumped or bailed prior to sampling. Purge water should be containerized on site or handled as specified in the site-specific project plan. Evacuation of a minimum of one volume of water in the well casing, and preferably three to five volumes, is recommended for a representative sample. In a high-yielding ground water formation and where there is no stagnant water in the well above the screened section, evacuation prior to sample withdrawal is not as critical. However, in all cases where the monitoring data is to be used for enforcement actions, evacuation is recommended.

- For wells that can be pumped or bailed to dryness with the equipment being used, the well should be evacuated and allowed to recover prior to sample withdrawal. If the recovery rate is fairly rapid and the schedule allows, evacuation of more than one volume of water is preferred. If recovery is slow, sample the well upon recovery after one evacuation.

- A nonrepresentative sample can also result from excessive pre-pumping of the monitoring well. Stratification of the leachate concentration in the groundwater formation may occur, or heavier-than-water compounds may sink to the lower portions of the aquifer. Excessive pumping can dilute or increase the contaminant concentrations from what is representative of the sampling point of interest.

2.4.3 Materials

Samplers and evacuation equipment (bladders, pumps, bailers, tubing, etc.) should be limited to those made with stainless steel, Teflon, and glass in areas where concentrations are expected to be at or near the detection limit. The tendency of organics to leach into and out of many materials make the selection of materials critical for trace analyses. The use of plastics, such as PVC or polyethylene, should be avoided when analyzing for organics. However, PVC may be used for evacuation equipment as it will not come in contact with the sample.

Table 2 on page 7 discusses the advantages and disadvantages of certain equipment.

2.5 EQUIPMENT/APPARATUS

2.5.1 General

- water level indicator
  - electric sounder
  - steel tape
  - transducer
  - reflection sounder
  - airline
- depth sounder
- appropriate keys for well cap locks
- steel brush
- HNU or OVA (whichever is most appropriate)
- logbook
- calculator
- field data sheets
- chain of custody forms
- forms and seals
- sample containers
- Engineer's rule
- sharp knife (locking blade)
- tool box (to include at least: screwdrivers, pliers, hacksaw, hammer, flashlight, adjustable wrench)
- leather work gloves
- appropriate health and safety gear
- 5-gallon pail
- plastic sheeting
- shipping containers
- packing materials
- bolt cutters
- Ziploc plastic bags
- containers for evacuation of liquids
- decontamination solutions
- tap water
- non-phosphate soap
- several brushes

Table 2: Advantages and Disadvantages
of Various Groundwater Sampling Devices

Device	Advantages	Disadvantages
Bailer	✍ The only practical limitations are size and materials ✍ No power source needed ✍ Portable ✍ Inexpensive; it can be dedicated and hung in a well reducing the chances of cross-contamination ✍ Minimal outgassing of volatile organics while sample is in bailer ✍ Readily available ✍ Removes stagnant water first ✍ Rapid, simple method for removing small volumes of purge water	✍ Time consuming, especially for large wells ✍ Transfer of sample may cause aeration
Submersible Pump	✍ Portable; can be used on an unlimited number of wells ✍ Relatively high pumping rate (dependent on depth and size of pump) ✍ Generally very reliable; does not require priming	✍ Potential for effects on analysis of trace organics ✍ Heavy and cumbersome, particularly in deeper wells ✍ Expensive ✍ Power source needed ✍ Susceptible to damage from silt or sediment ✍ Impractical in low yielding or shallow wells
Non-Gas Contact Bladder Pump	✍ Maintains integrity of sample ✍ Easy to use	✍ Difficult to clean although dedicated tubing and bladder may be used ✍ Only useful to approximately 100 feet in depth ✍ Supply of gas for operation (bottled gas and/or compressor) is difficult to obtain and is cumbersome
Suction Pump	✍ Portable, inexpensive, and readily available	✍ Only useful to approximately 25 feet or less in depth ✍ Vacuum can cause loss of dissolved gases and volatile organics ✍ Pump must be primed and vacuum is often difficult to maintain ✍ May cause pH modification
Inertia Pump	✍ Portable, inexpensive, and readily available ✍ Rapid method for purging relatively shallow wells	✍ Only useful to approximately 70 feet or less in depth ✍ May be time consuming to use ✍ Labor intensive ✍ WaTerra pump is only effective in 2-inch diameter wells

- pails or tubs
- aluminum foil
- garden sprayer
- preservatives
- distilled or deionized water

2.5.2 Bailer

- clean, decontaminated bailer(s) of appropriate size and construction material
- nylon line, enough to dedicate to each well
- Teflon-coated bailer wire
- sharp knife
- aluminum foil (to wrap clean bailers)
- 5-gallon bucket

2.5.3 Submersible Pump

- pump(s)
- generator (110, 120, or 240 volt) or 12-volt battery if inaccessible to field vehicle
- l-inch black PVC coil pipe -- enough to dedicate to each well
- hose clamps
- safety cable
- tool box supplement
  - pipe wrenches, 2
  - wire strippers
  - electrical tape
  - heat shrink
  - hose connectors
  - Teflon tape
- winch or pulley
- gasoline for generator
- flow meter with gate valve
- l-inch nipples and various plumbing (i.e., pipe connectors)

2.5.4 Non-Gas Contact Bladder Pump

- non-gas contact bladder pump
- compressor or nitrogen gas tank
- batteries and charger
- Teflon tubing -- enough to dedicate to each well
- Swagelock fitting
- toolbox supplements -- same as submersible pump

2.5.5 Suction Pump

- pump
- black coil tubing -- enough to dedicate to each well
- gasoline -- if required
- toolbox
- plumbing fittings
- flow meter with gate valve

2.5.6 Inertia Pump

- pump assembly (WaTerra pump, piston Pump)
- 5-gallon bucket

2.6 REAGENTS

Reagents will be utilized for preservation of samples and for decontamination of sampling equipment. The preservation required is specified by the analysis to be performed. Decontamination solutions are specified in ERT SOP #2006, Sampling Equipment Decontamination.

2.7 PROCEDURES

2.7.1 Preparation

1. Determine the extent of the sampling effort, the sampling methods to be employed, and which equipment and supplies are needed.

2. Obtain necessary sampling and monitoring equipment.

3. Decontaminate or preclean equipment, and ensure that it is in working order.

4. Prepare scheduling and coordinate with staff, clients, and regulatory agency, if appropriate.

5. Perform a general site survey prior to site entry in accordance with the site-specific health and safety plan.

6. Identify and mark all sampling locations.

2.7.2 Field Preparation

1. Start at the least contaminated well, if known.

2. Lay plastic sheeting around the well to minimize likelihood of contamination of equipment from soil adjacent to the well.

3. Remove locking well cap, note location, time of day, and date in field notebook or an appropriate log form.

4. Remove well casing cap.

5. Screen headspace of well with an appropriate monitoring instrument to determine the presence of volatile organic compounds and record in site logbook.

6. Lower water level measuring device or equivalent (i.e., permanently installed transducers or airline) into well until water surface is encountered.

7. Measure distance from water surface to reference measuring point on well casing or protective barrier post and record in site logbook. Alternatively, if there is no reference point, note that water level measurement is from top of steel casing, top of PVC riser pipe, from ground surface, or some other position on the well head.

8. Measure total depth of well (do this at least twice to confirm measurement) and record in site logbook or on log form.

9. Calculate the volume of water in the well and the volume to be purged using the calculations in Section 2.8.

10. Select the appropriate purging and sampling equipment.

2.7.3 Evacuation of Static Water (Purging)

The amount of flushing a well receives prior to sample collection depends on the intent of the monitoring program as well as the hydrogeologic conditions. Programs where overall quality determination of water resources are involved may require long pumping periods to obtain a sample that is representative of a large volume of that aquifer. The pumped volume can be determined prior to sampling so that the sample is a composite of known volume of the aquifer, or the well can be pumped until the stabilization of parameters such as temperature, electrical conductance, or pH has occurred. However, monitoring for defining a contaminant plume requires a representative sample of a small volume of the aquifer. These circumstances require that the well be pumped enough to remove the stagnant water but not enough to induce flow from other areas. Generally, three well volumes are considered effective, or calculations can be made to determine, on the basis of the aquifer parameters and well dimensions, the appropriate volume to remove prior to sampling.

During purging, water level measurements may be taken regularly at 15- to 30-second intervals. This data may be used to compute aquifer transmissivity and other hydraulic characteristics.

The following well evacuation devices are most commonly used. Other evacuation devices are available, but have been omitted in this discussion due to their limited use.

Bailer

Bailers are the simplest purging device used and have many advantages. They generally consist of a rigid length of tube, usually with a ball check-valve at the bottom. A line is used to lower the bailer into the well and retrieve a volume of water. The three most common types of bailer are PVC, Teflon, and stainless steel.

This manual method of purging is best suited to shallow or narrow diameter wells. For deep, larger diameter wells which require evacuation of large volumes of water, other mechanical devices may be more appropriate.

Bailing equipment includes a clean decontaminated bailer, Teflon or nylon line, a sharp knife, and plastic sheeting.

1. Determine the volume of water to be purged as described in Section 2.7.2, Field Preparation.

2. Lay plastic sheeting around the well to prevent contamination of the bailer line with foreign materials.

3. Attach the line to the bailer and lower until the bailer is completely submerged.

4. Pull bailer out ensuring that the line either falls onto a clean area of plastic sheeting or never touches the ground.

5. Empty the bailer into a pail until full to determine the number of bails necessary to achieve the required purge volume.

6. Thereafter, pour the water into a container and dispose of purge waters as specified in the site-specific project plan.

Submersible Pump

Submersible pumps are generally constructed of plastic, rubber, and metal parts which may affect the analysis of samples for certain trace organics and inorganics. As a consequence, submersible pumps may not be appropriate for investigations requiring analyses of samples for trace contaminants. However, they are still useful for pre-sample purging. However, the pump must have a check valve to prevent water in the pump and the pipe from rushing back into the well.

Submersible pumps generally use one of two types of power supplies, either electric or compressed gas. Electric pumps can be powered by a 12-volt DC rechargeable battery, or a 110- or 220-volt AC power supply. Those units powered by compressed gas normally use a small electric compressor which also needs 12-volt DC or 110-volt AC power. They may also utilize compressed gas from bottles. Pumps differ according to the depth and diameter of the monitoring wells.

1. Determine the volume of water to be purged as described in section 2.7.2, Field Preparation.

2. Lay plastic sheeting around the well to prevent contamination of pumps, hoses or lines with foreign materials.

3. Assemble pump, hoses and safety cable, and lower the pump into the well. Make sure the pump is deep enough so that purging does not evacuate all the water. (Running the pump without water may cause damage.)

4. Attach flow meter to the outlet hose to measure the volume of water purged.

5. Attach power supply, and purge well until specified volume of water has been evacuated (or until field parameters, such as temperature, pH, conductivity, etc. have stabilized). Do not allow the pump to run dry. If the pumping rate exceeds the well recharge rate, lower the pump further into the well, and continue pumping.

6. Collect and dispose of purge waters as specified in the site-specific project plan.

Non-Contact Gas Bladder Pump

For this procedure, an all stainless-steel and Teflon Middleburg-squeeze bladder pump (e.g., IEA, TIMCO, Well Wizard, Geoguard, and others) is used to provide the least amount of material interference to the sample (Barcelona, 1985). Water comes into contact with the inside of the bladder (Teflon) and the sample tubing, also Teflon, that may be dedicated to each well. Some wells may have permanently installed bladder pumps (i.e., Well Wizard, Geoguard), that will be used to sample for all parameters.

1. Assemble Teflon tubing, pump and charged control box.

2. Use the same procedure for purging with a bladder pump as for a submersible pump.

3. Be sure to adjust flow rate to prevent violent jolting of the hose as sample is drawn in.

Suction Pump

There are many different types of suction pumps. They include: centrifugal, peristaltic and diaphragm. Diaphragm pumps can be used for well evacuation at a fast pumping rate and sampling at a low pumping rate. The peristaltic pump is a low-volume pump that uses rollers to squeeze the flexible tubing, thereby creating suction. This tubing can be dedicated to a well to prevent cross-contamination. Peristaltic pumps, however, require a power source.

1. Assemble the pump, tubing, and power source if necessary.

2. To purge with a suction pump, follow the exact procedures outlined for the submersible pump.

Inertia Pump

Inertia pumps, such as the WaTerra pump and piston pump, are manually operated. They are appropriate to use when wells are too deep to bail by hand, but are not inaccessible enough to warrant an automatic (submersible, etc.) pump. These pumps are made of plastic and may be either decontaminated or discarded, after use.

1. Determine the volume of water to be purged as described in Section 2.7.2, Field Preparation.

2. Lay plastic sheeting around the well to prevent contamination of pumps or hoses with foreign materials.

3. Assemble pump, and lower to the appropriate depth in the well.

4. Begin pumping manually, discharging water into a 5-gallon bucket (or other graduated vessel). Purge until specified volume of water has been evacuated (or until field parameters such as temperature, pH, conductivity, etc. have stabilized).

5. Collect and dispose of purge waters as specified in the site-specific project plan.

2.7.4 Sampling

Sample withdrawal methods require the use of pumps, compressed air, bailers, and samplers. Ideally, purging and sample withdrawal equipment should be completely inert, economical to use, easily cleaned, sterilized, reusable, able to operate at remote sites in the absence of power resources, and capable of delivering variable rates for sample collection.

There are several factors to take into consideration when choosing a sampling device. Care should be taken when reviewing the advantages or disadvantages of any one device. It may be appropriate to use a different device to sample than that which was used to purge. The most common example of this is the use of a submersible pump to purge and a bailer to sample.

Bailer

The positive-displacement volatile sampling bailer (by GPI) is perhaps the most appropriate for collection of water samples for volatile analysis. Other bailer types (messenger, bottom fill, etc.) are less desirable, but may be mandated by cost and site conditions. Generally, bailers can provide an acceptable sample, providing that sampling personnel use extra care in the collection process.

1. Surround the monitoring well with clean plastic sheeting.

2. Attach a line to the bailer. If a bailer was used for purging, the same bailer and line may be used for sampling.

3. Lower the bailer slowly and gently into the well, taking care not to shake the casing sides or to splash the bailer into the water. Stop lowering at a point adjacent to the screen.

4. Allow bailer to fill and then slowly and gently retrieve the bailer from the well, avoiding contact with the casing, so as not to knock flakes of rust or other foreign materials into the bailer.

5. Remove the cap from the sample container and place it on the plastic sheet or in a location where it will not become contaminated. See Section 2.7.7 for special considerations on VOA samples.

6. Begin pouring slowly from the bailer.

7. Filter and preserve samples as required by sampling plan.

8. Cap the sample container tightly and place pre-labeled sample container in a carrier.

9. Replace the well cap.

10. Log all samples in the site logbook and on field data sheets and label all samples.

11. Package samples and complete necessary paperwork.

12. Transport sample to decontamination zone to prepare it for transport to analytical laboratory.

Submersible Pump

Although it is recommended that samples not be collected with a submersible pump due to the reasons stated in Section 2.4, there are some situations where they may be used.

1. Allow the monitoring well to recharge after purging, keeping the pump just above the screened section,

2. Attach gate valve to hose (if not already fitted), and reduce flow of water to a manageable sampling rate.

3. Assemble the appropriate bottles.

4. If no gate valve is available, run the water down the side of a clean jar and fill the sample bottles from the jar.

5. Cap the sample container tightly and place pre-labeled sample container in a carrier.

6. Replace the we11 cap.

7. Log all samples in the site logbook and on the field data sheets and label all samples.

8. Package samples and complete necessary paperwork.

9. Transport sample to decontamination zone for preparation for transport to analytical laboratory.

10. Upon completion, remove pump and assembly and fully decontaminate prior to setting into the next sample well. Dedicate the tubing to the hole.

Non-Gas Contact Bladder Pump

The use of a non-gas contact positive displacement bladder pump is often mandated by the use of dedicated pumps installed in wells. These pumps are also suitable for shallow (less than 100 feet) wells. They are somewhat difficult to clean, but may be used with dedicated sample tubing to avoid cleaning. These pumps require a power supply and a compressed gas supply (or compressor). They may be operated at variable flow and pressure rates making them ideal for both purging and sampling.

Barcelona (1984) and Nielsen (1985) report that the non-gas contact positive displacement pumps cause the least amount of alteration in sample integrity as compared to other sample retrieval methods.

1. Allow well to recharge after purging.

2. Assemble the appropriate bottles.

3. Turn pump on, increase the cycle time and reduce the pressure to the minimum that will allow the sample to come to the surface.

4. Cap the sample container tightly and place pre-labeled sample container in a carrier.

5. Replace the well cap.

6. Log all samples in the site logbook and on field data sheets and label all samples.

7. Package samples and complete necessary paperwork.

8. Transport sample to decontamination zone for preparation for transport to analytical laboratory.

9. On completion, remove the tubing from the well and either replace the Teflon tubing and bladder with new dedicated tubing and bladder or rigorously decontaminate the existing materials.

10. Collect non-filtered samples directly from the outlet tubing into the sample bottle.

11. For filtered samples, connect the pump outlet tubing directly to the filter unit. The pump pressure should remain decreased so that the pressure build-up on the filter does not blow out the pump bladder or displace the filter. For the Geotech barrel filter, no actual connections are necessary so this is not a concern.

Suction Pump

In view of the limitations of suction pumps, they are not recommended for sampling purposes.

Inertia Pump

Inertia pumps may be used to collect samples. It is more common, however, to purge with these pumps and sample with a bailer.

1. Following well evacuation, allow the well to recharge.

2. Assemble the appropriate bottles.

3. Since these pumps are manually operated, the flow rate may be regulated by the sampler. The sample may be discharged from the pump outlet directly into the appropriate sample container.

4. Cap the sample container tightly and place pre-labeled sample container in a carrier.

5. Replace the well cap.

6. Log all samples in the site logbook and on field data sheets and label all samples.

7. Package samples and complete necessary paperwork.

8. Transport sample to decontamination zone for preparation for transport to analytical laboratory.

9. Upon completion, remove pump and decontaminate or discard, as appropriate.

2.7.5 Filtering

For samples that require filtering, such as samples which will be analyzed for total metals, the filter must be decontaminated prior to use and between uses. Filters work by two methods. A barrel filter such as the "Geotech" filter works with a bicycle pump, which is used to build up positive pressure in the chamber containing the sample. The sample is then forced through the filter paper (minimum size 0.45µ) into a jar placed underneath. The barrel itself is filled manually from the bailer or directly via the hose of the sampling pump. The pressure must be maintained up to 30 psi by periodic pumping.

A vacuum type filter involves two chambers, the upper chamber contains the sample and a filter (minimum size 0.45µ) divides the chambers. Using a hand pump or a Gilian type pump, air is withdrawn from the lower chamber, creating a vacuum and thus causing the sample to move through the filter into the lower chamber where it is drained into a sample jar, repeated pumping may be required to drain all the sample into the lower chamber. If preservation of the sample is necessary, this should be done after filtering.

2.7.6 Post Operation

After all samples are collected and preserved, the sampling equipment should be decontaminated prior to sampling another well. This will prevent cross-contamination of equipment and monitoring wells between locations.

1. Decontaminate all equipment.

2. Replace sampling equipment in storage containers.

3. Prepare and transport water samples to the laboratory. Check sample documentation and make sure samples are properly packed for shipment.

2.7.7 Special Considerations for VOA Sampling

The proper collection of a sample for volatile organics requires minimal disturbance of the sample to limit volatilization and therefore a loss of volatiles from the sample.

Sample retrieval systems suitable for the valid collection of volatile organic samples are: positive displacement bladder pumps, gear driven submersible pumps, syringe samplers and bailers (Barcelona, 1984; Nielsen, 1985). Field conditions and other constraints will limit the choice of appropriate systems. The focus of concern must be to provide a valid sample for analysis, one which has been subjected to the least amount of turbulence possible.

The following procedures should be followed:

1. Open the vial, set cap in a clean place, and collect the sample during the middle of the cycle. When collecting duplicates, collect both samples at the same time.

2. Fill the vial to just overflowing. Do not rinse the vial, nor excessively overfill it. There should be a convex meniscus on the top of the vial.

3. Check that the cap has not been contaminated (splashed) and carefully cap the vial. Place the cap directly over the top and screw down firmly. Do not overtighten and break the cap.

4 Invert the vial and tap gently. Observe vial for at least 10 seconds. If an air bubble appears, discard the sample and begin again. It is imperative that no entrapped air is in the sample vial.

5. Immediately place the vial in the protective foam sleeve and place into the cooler, oriented so that it is lying on its side, not straight up.

6. The holding time for VOAs is 7 days. Samples should be shipped or delivered to the laboratory daily so as not to exceed the holding time. Ensure that the samples remain at 4°C, but do not allow them to freeze.

2.8 CALCULATIONS

There are no calculations necessary to implement this procedure. However, if it is necessary to calculate the volume of the well, utilize the following equation:

Well volume = nr^2h (cf) [Equation l]

where:

n =

r = radius of monitoring well (feet)

height of the water column (feet) [This may be determined by subtracting the depth to water from the total depth of the well as measured from the same reference point.]

cf = conversion factor (gal/ft^3) = 7.48 gal/ft^3 [In this equation, 7.48 gal/ft^3 is the necessary conversion factor.]

Monitoring wells are typically 2, 3, 4, or 6 inches in diameter. If you know the diameter of the monitoring well, there are a number of standard conversion factors which can be used to simplify the equation above.

The volume, in gallons per linear foot, for various standard monitoring well diameters can be calculated as follows:

v = nr^2 (cf) [Equation 2)

where:

v = volume in gallons per linear foot

n = pi

= radius of monitoring well (feet)

cf = conversion factor (7.48 gal/ft^3)

For a 2-inch diameter well, the volume in gallons per linear foot can be calculated as follows:

v = nr^2 (cf) [Equation 2)

= 3.14 (l/12 ft)^2 7.48 gal/ft^3

= 0.1632 gal/ft

Remember that if you have a 2-inch diameter, well you must convert this to the radius in feet to be able to use the equation.

The volume in gallons per linear foot for the common size monitoring wells are as follows:

Well Diameter	v (volume in gal/ft.)
2 inches	0.1632
3 inches	0.3672
4 inches	0.6528
6 inches	1.4688

If you utilize the conversion factors above, Equation 1 should be modified as follows:

Well volume = (h)(v) [Equation 3)

where:

h = height of water column (feet)

v = volume in gallons per linear foot as calculated from Equation 2

2.9 QUALITY ASSURANCE/ QUALITY CONTROL

There are no specific quality assurance activities which apply to the implementation of these procedures. However, the following general QA procedures apply:

- All data must be documented on field data sheets or within site logbooks.

- All instrumentation must be operated in accordance with operating instructions as supplied by the manufacturer, unless otherwise specified in the work plan. Equipment checkout and calibration activities must occur prior to sampling/operation and they must be documented.

2.10 DATA VALIDATION

This section is not applicable to this SOP.

2.11 HEALTH AND SAFETY

When working with potentially hazardous materials, follow U.S. EPA, OSHA and specific health and safety procedures. More specifically, depending upon the site-specific contaminants, various protective programs must be implemented prior to sampling the first well. The site health and safety plan should be reviewed with specific emphasis placed on the protection program planned for the well sampling tasks. Standard safe operating practices should be followed such as minimizing contact with potential contaminants in both the vapor phase and liquid matrix through the use of respirators and disposable clothing.

For volatile organic contaminants:

- Avoid breathing constituents venting from the well.
- Pre-survey the well head-space with an FID/PID prior to sampling.
- If monitoring results indicate organic constituents, sampling activities may be conducted in Level C protection. At a minimum, skin protection will be afforded by disposable protective clothing.

Physical hazards associated with well sampling are:

- Lifting injuries associated with pump and bailer retrieval; moving equipment.
- Use of pocket knives for cutting discharge hose.
- Heat/cold stress as a result of exposure to extreme temperatures (may be heightened by protective clothing).
- Slip, trip, fall conditions as a result of pump discharge.
- Restricted mobility due to the wearing of protective clothing.

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3.0 SOIL GAS SAMPLING: SOP #2149

3.1 SCOPE AND APPLICATION

Soil gas monitoring provides a quick means of waste site evaluation. Using this method, underground contamination can be identified, and the source, extent, and movement of the pollutants can be traced.

This Standard Operating Procedure (SOP) outlines the methods used by EPA/ERT in installing soil gas wells; measuring organic levels in the soil gas using an HNU PI 101 Portable Photoionization Analyzer and/or other air monitoring devices; and sampling the soil gas using Tedlar bags, Tenax sorbent tubes, and SUMMA canisters.

3.2 METHOD SUMMARY

A 3/8-inch diameter hole is driven into the ground to a depth of 4 to 5 feet using a commercially available "slam bar". (Soil gas can also be sampled at other depths by the use of a longer bar or bar attachments.) A l/Cinch O.D. stainless steel probe is inserted into the hole. The hole is then sealed at the top around the probe using modeling clay. The gas contained in the interstitial spaces of the soil is sampled by pulling the sample through the probe using an air sampling pump. The sample may be stored in Tedlar bags, drawn through sorbent cartridges, or analyzed directly using a direct reading instrument.

The air sampling pump is not used for SUMMA canister sampling of soil gas. Sampling is achieved by soil gas equilibration with the evacuated SUMMA canister. Other field air monitoring devices, such as the combustible gas indicator (MSA CGI/02 Meter, Model 260) and the organic vapor analyzer (Foxboro OVA, Model 128), can also be used depending on specific site conditions. Measurement of soil temperature using a temperature probe may also be desirable. Bagged samples are usually analyzed in a field laboratory using a portable Photovac GC.

Power driven sampling probes may be utilized when soil conditions make sampling by hand unfeasible (i.e., frozen ground, very dense clays, pavement, etc.). Commercially available soil gas sampling probes (hollow, l/2inch O.D. steel probes) can be driven to the desired depth using a power hammer (e.g., Bosch Demolition Hammer). Samples can be drawn through the probe itself, or through Teflon tubing inserted through the probe and attached to the probe point. Samples are collected and analyzed as described above.

3.3 SAMPLE PRESERVATION, CONTAINERS, HANDLING, AND STORAGE

3.3.1 Tedlar Bag

Soil gas samples are generally contained in 1-L Tedlar bags. Bagged samples are best stored in coolers to protect the bags from any damage that may occur in the field or in transit. In addition, coolers ensure the integrity of the samples by keeping them at a cool temperature and out of direct sunlight. Samples should be analyzed as soon as possible, preferably within 24 to 48 hours.

3.3.2 Tenax Tube

Bagged samples can also be drawn into Tenax or other sorbent tubes to undergo lab GC/MS analysis. If Tenax tubes are to be utilized, special care must be taken to avoid contamination. Handling of the tubes should be kept to a minimum, and samplers must wear nylon or other lint-free gloves. After sampling, each tube should be stored in a clean, sealed culture tube; the ends packed with clean glass wool to protect the sorbent tube from breakage. The culture tubes should be kept cool and wrapped in aluminum foil to prevent any photodegradation of samples (see Section 3.7.4.).

3.3.3 SUMMA Canister

The SUMMA canisters used for soil gas sampling have a 6-L sample capacity and are certified clean by GC/MS analysis before being utilized in the field. After sampling is completed, they are stored and shipped in travel cases.

3.4 INTERFERENCES AND POTENTIAL PROBLEMS

3.4.1 HNU Measurements

A number of factors can affect the response of the HNU PI 101. High humidity can cause lamp fogging and decreased sensitivity. This can be significant when soil moisture levels are high, or when a soil gas well is actually in groundwater. High concentrations of methane can cause a downscale deflection of the meter. High and low temperature, electrical fields, FM radio transmission, and naturally occurring compounds, such as terpenes in wooded areas, will also affect instrument response.

Other field screening instruments can be affected by interferences. Consult the manufacturers' manuals.

3.4.2 Factors Affecting Organic Concentrations in Soil Gas

Concentrations in soil gas are affected by dissolution, adsorption, and partitioning. Partitioning refers to the ratio of component found in a saturated vapor above an aqueous solution to the amount in the solution; this can, in theory, be calculated using the Henry's Law constants. Contaminants can also be adsorbed onto inorganic soil components or "dissolved" in organic components. These factors can result in a lowering of the partitioning coefficient.

Soil "tightness" or amount of void space in the soil matrix, will affect the rate of recharging of gas into the soil gas well.

Existence of a high, or perched, water table, or of an impermeable underlying layer (such as a clay lens or layer of buried slag) may interfere with sampling of the soil gas. Knowledge of site geology is useful in such situations, and can prevent inaccurate sampling.

3.4.3 Soil Probe Clogging

A common problem with this sampling method is soil probe clogging. A clogged probe can be identified by using an in-line vacuum gauge or by listening for the sound of the pump laboring. This problem can usually be eliminated by using a wire cable to clear the probe (see procedure #3 in Section 3.7.1).

3.4.4 Underground Utilities

Prior to selecting sample locations, an underground utility search is recommended. The local utility companies can be contacted and requested to mark the locations of their underground lines. Sampling plans can then be drawn up accordingly. Each sample location should also be screened with a metal detector or magnetometer to verify that no underground pipes or drums exist.

3.5 EQUIPMENT/APPARATUS

3.5.1 Slam Bar Method

- slam bar (one per sampling team)
- soil gas probes, stainless steel tubing, 1/4-inch O.D., 5 foot length
- flexible wire or cable used for clearing the tubing during insertion into the well
- "quick connect" fittings to connect sampling probe tubing, monitoring instruments, and Gilian pumps to appropriate fittings on vacuum box
- modeling clay
- vacuum box for drawing a vacuum around Tedlar bag for sample collection (one per sampling team)
- Gilian pump Model HFS113A adjusted to approximately 3.0 L/min (one to two per sampling team)
- l/4-inch Teflon tubing, 2 to 3 foot lengths, for replacement of contaminated sample line
- Tedlar bags, 1 liter, at least one bag per sample point
- soil gas sampling labels, field data sheets, logbook, etc.
- HNU Model PI 101, or other field air monitoring devices, (one per sampling team)
- ice chest, for carrying equipment and for protection of samples (two per sampling team)
- metal detector or magnetometer, for detecting underground utilities/ pipes/drums (one per sampling team)
- Photovac GC, for field-lab analysis of bagged samples
- SUMMA canisters (plus their shipping cases) for sample, storage and transportation

3.5.2 Power Hammer Method

- Bosch demolition hammer
- l/2inch O.D. steel probes, extensions, and points
- dedicated aluminum sampling points
- Teflon tubing, l/Cinch O.D.
- "quick connect" fittings to connect sampling probe tubing, monitoring instruments, and Gilian pumps to appropriate fittings on vacuum box
- modeling clay
- vacuum box for drawing a vacuum around Tedlar bag for sample collection (one per sampling team)
- Gilian pump Model HFS113A adjusted to approximately 3.0 L/min (one to two per sampling team)
- l/4-inch Teflon tubing, 2 to 3 foot lengths, for replacement of contaminated sample line
- Tedlar bags, 1 liter, at least one bag per sample point
- soil gas sampling labels, field data sheets, logbook, etc.
- HNU Model PI 101, or other field air monitoring devices, (one per sampling team)
- ice chest, for carrying equipment and for protection of samples (two per sampling team)
- metal detector or magnetometer, for detecting underground utilities/ pipes/drums (one per sampling team)
- Photovac GC, for field-lab analysis of bagged samples
- SUMMA canisters (plus their shipping cases) for sample, storage and transportation
- generator with extension cords
- high lift jack assembly for removing probes

3.6 REAGENTS

- HNU Systems Inc. Calibration Gas for HNU Model PI 101, and/or calibration gas for other field air monitoring devices
- deionized organic-free water, for decontamination
- methanol, HPLC grade, for decontamination
- ultra-zero grade compressed air, for field blanks
- standard gas preparations for Photovac GC calibration and Tedlar bag spikes

3.7 PROCEDURES

3.7.1 Soil Gas Well Installation

1. Initially, make a hole slightly deeper than the desired depth. For sampling up to 5 feet, use a 5-foot single piston slam bar. For deeper depths, use a piston slam bar with threaded 4-foot-long extensions. Other techniques can be used, so long as holes are of narrow diameter and no contamination is introduced.

2. After the hole is made, carefully withdraw the slam bar to prevent collapse of the walls of the hole. Then insert the soil gas probe.

3. It is necessary to prevent plugging of the probe, especially for deeper holes. Place a metal wire or cable, slightly longer than the probe, into the probe prior to inserting into the hole. Insert the probe to full depth, then pull it up 3 to 6 inches, then clear it by moving the cable up and down. The cable is removed before sampling.

4. Seal the top of the sample hole at the surface against ambient air infiltration by using modeling clay molded around the probe at the surface of the hole.

5. If conditions preclude hand installation of the soil gas wells, the power driven system may be employed. Use the generator-powered demolition hammer to drive the probe to the desired depth (up to 12 feet may be attained with extensions). Pull the probe up 1 to 3 inches if the retractable point is used. No clay is needed to seal the hole. After sampling, retrieve the probe using the high lift jack assembly.

6. If semi-permanent soil gas wells are required, use the dedicated aluminum probe points. Insert these points into the bottom of the power-driven probe and attach it to the Teflon tubing. Insert the probe as in step 5. When the probe is removed, the point and Teflon tube remain in the hole, which may be scaled by backfilling with sand, bentonite, or soil.

3.7.2 Screening with Field Instruments

1. The **well** volume **must** be evacuated prior to sampling. Connect the Gilian pump, adjusted to 3.0 L/min, to the sample probe using a section of Teflon tubing as a connector. Turn the pump on, and a vacuum is pulled through the probe for approximately 15 seconds. A longer time is required for sample wells of greater depths.

2. After evacuation, connect the monitoring instrument(s) to the probe using a Teflon connector. When the reading is stable, or peaks, record the reading. For detailed procedures on HNU field protocol, see appendix B, and refer to the manufacturer's instructions.

3. Some readings may be above or below the range set on the field instruments. The range may be reset, or the response recorded as a figure greater than or less than the range. Consider the recharge rate of the well with soil gas when sampling at a different range setting.

3.7.3 Tedlar Bag Sampling

1. Follow step 1 in section 3.7.2 to evacuate well volume. If air monitoring instrument screening was performed prior to sampling, evacuation is not necessary.

2. Use the vacuum box and sampling train (Figure 3 in Appendix A) to take the sample. The sampling train is designed to minimize the introduction of contaminants and losses due to adsorption. All wetted parts are either Teflon or stainless steel. The vacuum is drawn indirectly to avoid contamination from sample pumps.

3. Place the Tedlar bag inside the vacuum box, and attach it to the sampling port. Attach the sample probe to the sampling port via Teflon tubing and a "quick connect" fitting.

4. Draw a vacuum around the outside of the bag, using a Gilian pump connected to the vacuum box evacuation port, via Tygon tubing and a "quick connect" fitting. The vacuum causes the bag to inflate, drawing the sample.

5. Break the vacuum by removing the Tygon line from the pump. Remove the bagged sample from the box and close valve. Label bag, record data on data sheets or in logbooks. Record the date, time, sample location ID, and the HNU, or other instrument reading(s) on sample bag label.

CAUTION: Labels should not be pasted directly onto the bags, nor should bags be labeled directly using a marker or pen. Inks and adhesive may diffuse through the bag material, contaminating the sample. Place labels on the edge of the bags, or tie the labels to the metal eyelets provided on the bags. Markers with inks containing volatile organics (i.e., permanent ink markers) should not be used.

3.7.4 Tenax Tube Sampling

Samples collected in Tedlar bags may be sorbed onto Tenax tubes for further analysis by GC/MS.

Additional Apparatus

- Syringe with a luer-lock tip capable of drawing a soil gas or air sample from a Tedlar bag onto a Tenax/CMS sorbent tube. The syringe capacity is dependent upon the volume of sample being drawn onto the sorbent tube.

- Adapters for fitting the sorbent tube between the Tedlar bag and the sampling syringe. The adapter attaching the Tedlar bag to the sorbent tube consists of a reducing union (l/Cinch to l/16-inch O.D. -- Swagelok cat. # SS-400-6-ILV or equivalent) with a length of l/4 inch O.D. Teflon tubing replacing the nut on the 1/6-inch (Tedlar bag) side. A l/Cinch I.D. silicone O-ring replaces the ferrules in the nut on the l/Cinch (sorbent tube) side of the union.

  The adapter attaching the sampling syringe to the sorbent tube consists of a reducing union (l/Cinch to l/16-inch O.D. -- Swagelok Cat. # SS-4OO-6-ILV or equivalent) with a l/Cinch I.D. silicone O-ring replacing the ferrules in the nut on the l/4 inch (sorbent tube) side and the needle of a luer-lock syringe needle inserted into the l/16-inch side (held in place with a l/16-inch ferrule). The luer-lock end of the needle can be attached to the sampling syringe. It is useful to have a luer-lock on/off valve situated between the syringe and the needle.

- Two-stage glass sampling cartridge (1/4-inch O.D. x l/&inch I.D. x 5 1/8 inch) contained in a flame-sealed tube (manufactured by Supelco Custom Tenax/Spherocarb Tubes or equivalent) containing two sorbent sections retained by glass wool:

  Front section: 150 mg of Tenax-GC
  Back section: 150 mg of CMS
  (Carbonized Molecular Sieve)

  Sorbent tubes may also be prepared in the lab and stored in either Teflon-capped culture tubes or stainless steel tube containers. Sorbent tubes stored in this manner should not be kept more than 2 weeks without reconditioning. (See SOP #2052 for Tenax/CMS sorbent tube preparation).

- Teflon-capped culture tubes or stainless steel tube containers for sorbent tube storage. These containers should be conditioned by baking at 120°C for at least 2 hours. The culture tubes should contain a glass wool plug to prevent sorbent tube breakage during transport. Reconditioning of the containers should occur between usage or after extended periods of disuse (i.e., 2 weeks or more).

- Nylon gloves or lint-free cloth. (Hewlett Packard Part # 8650-0030 or equivalent.)

Sample Collection

1. Handle sorbent tubes with care, using nylon gloves (or other lint-free material) to avoid contamination.

2. Immediately before sampling, break one end of the sealed tube and remove the Tenax cartridge. For in-house prepared tubes, remove cartridge from its container.

3. Connect the valve on the Tedlar bag to the sorbent tube adapter. Connect the sorbent tube to the sorbent tube adapter with the Tenax (white granular) side of the tube facing the Tedlar bag.

4. Connect the sampling syringe assembly to the CMS (black) side of the sorbent tube. Fittings on the adapters should be very tight.

5. Open the valve on the Tedlar bag.

6. Open the on/off valve of the sampling syringe.

7. Draw **a** predetermined volume of sample onto the sorbent tube. (This may require closing the syringe valve, emptying the syringe and then repeating the procedure, depending upon the syringe capacity and volume of sample required.)

8. After sampling, remove the tube from the sampling train with gloves or a clean cloth. **Do not label or write on the Tenax/CMS tube.**

9. Place the sorbent tube in a conditioned stainless steel tube holder or culture tube. Culture tube caps should be sealed with Teflon tape.

Sample Labeling

Each sample tube container (not tube) must be labeled with the site name, sample station number, sample date, and sample volume.

Chain of custody forms must accompany all samples to the laboratory.

Quality Assurance

Before field use, a QA check should be performed on each batch of sorbent tubes by analyzing a tube with thermal desorption/cryogenic trapping GC/MS.

At least one blank sample must be submitted with each set of samples collected at a site. This trip blank must be treated the same as the sample tubes except no sample will be drawn through the tube.

Sample tubes should be stored out of UV light (i.e., sunlight) and kept on ice until analysis.

Samples should be taken in duplicate, when possible.

3.7.5 SUMMA Canister Sampling

1. Follow item 1 in step 3.7.2 to evacuate well volume. If HNU analysis was performed prior to taking a sample, evacuation is not necessary.

2. Attach a certified clean, evacuated 6-L SUMMA canister via the l/4-inch Teflon tubing.

3. Open the valve on SUMMA canister. The soil gas sample is drawn into the canister by pressure equilibration. The approximate sampling time for a 6-L canister is 20 minutes.

4. Site name, sample location, number, and date must be recorded on a chain of custody form and on a blank tag attached to the canister.

3.8 CALCULATIONS

3.8.1 Field Screening Instruments

Instrument readings are usually read directly from the meter. In some cases, the background level at the soil gas station may be subtracted:

Final Reading = Sample Reading - Background

3.8.2 Photovac GC Analysis

Calculations used to determine concentrations of individual components by Photovac GC analysis are beyond the scope of this SOP and are covered in ERT SOP #2109, Photovac GC Analysis for Soil, Water and Air/Soil Gas.

3.9 QUALITY ASSURANCE/ QUALITY CONTROL

3.9.1 Field Instrument Calibration

Consult the manufacturers' manuals for correct use and calibration of all instrumentation. The HNU should be calibrated at least once a day.

3.9.2 Gilian Model HFS113A Air Sampling Pump Calibration

Flow should be set at approximately 3.0 L/min; accurate flow adjustment is not necessary. Pumps should be calibrated prior to bringing into the field.

3.9.3 Sample Probe Contamination

Sample probe contamination is checked between each sample by drawing ambient air through the probe via a Gilian pump and checking the response of the HNU PI 101. If HNU readings are higher than background, replacement or decontamination is necessary.

Sample probes may be decontaminated simply by drawing ambient air through the probe until the HNU reading is at background. More persistent contamination can be washed out using methanol and water, then air drying. Having more than one probe per sample team will reduce lag times between sample stations while probes are decontaminated.

3.9.4 Sample Train Contamination

The Teflon line forming the sample train from the probe to the Tedlar bag should be changed on a daily basis. If visible contamination (soil or water) is drawn into the sampling train, it should be changed immediately. When sampling in highly contaminated areas, the sampling train should be purged with ambient air, via a Gilian pump, for approximately 30 seconds between each sample. After purging, the sampling train can be checked using an HNU, or other field monitoring device, to establish the cleanliness of the Teflon line.

3.9.5 Field Blank

Each cooler containing samples should also contain one Tedlar bag of ultra-zero grade air, acting as a field blank. The field blank should accompany the samples in the field (while being collected) and when they are delivered for analysis. A fresh blank must be provided to be placed in the empty cooler pending additional sample collection. One new field blank per cooler of samples is required. A chain of custody form must accompany each cooler of samples and should include the blank that is dedicated to that group of samples.

3.9.6 Trip Standard

Each cooler containing samples should contain a Tedlar bag of standard gas to calibrate the analytical instruments (Photovac GC, etc.). This trip standard will be used to determine any changes in concentrations of the target compounds during the course of the sampling day (e.g., migration through the sample bag, degradation, or adsorption). A fresh trip standard must be provided and placed in each cooler pending additional sample collection. A chain of custody form should accompany each cooler of samples and should include the trip standard that is dedicated to that group of samples.

3.9.7 Tedlar Bag Check

Prior to use, one bag should be removed from each lot (case of 100) of Tedlar bags to be used for sampling and checked for possible contamination as follows: the test bag should be tilled with ultra-zero grade air; a sample should be drawn from the bag and analyzed via Photovac GC or whatever method is to be used for sample analysis. This procedure will ensure sample container cleanliness prior to the start of the sampling effort.

3.9.8 SUMMA Canister Check

From each lot of four cleaned SUMMA canisters, one is to be removed for a GC/MS certification check. If the canister passes certification, then it is re-evacuated and all four canisters from that lot are available for sampling.

If the chosen canister is contaminated, then the entire lot of four SUMMA canisters must be recleaned, and a single canister is re-analyzed by GC/MS for certification.

3.9.9 Options

Duplicate Samples

A minimum of 5% of all samples should be collected in duplicate (i.e., if a total of 100 samples arc to be collected, five samples should be duplicated). In choosing which samples to duplicate, the following criterion applies: if, after filling the first Tedlar bag, and, evacuating the well for 15 seconds, the second HNU (or other field monitoring device being used) reading matches or is close to (within 50%) the first reading, a duplicate sample may be taken.

Spikes

A Tedlar bag spike and Tenax tube spike may be desirable in situations where high concentrations of contaminants other than the target compounds are found to exist (landfills, etc.). The additional level of QA/QC attained by this practice can be useful in determining the effects of interferences caused by these non-target compounds. SUMMA canisters containing samples are not spiked.

3.10 DATA VALIDATION

For each target compound, the level of concentration found in the sample must be greater than three times the level (for that compound) found in the field blank which accompanied that sample to be considered valid. The same criteria apply to target compounds detected in the Tedlar bag pre-sampling contamination check.

3.11 HEALTH AND SAFETY

Because the sample is being drawn from underground, and no contamination is introduced into the breathing zone, soil gas sampling usually occurs in Level D, unless the sampling location is within the hot zone of a site, which requires Level B or Level C protection. However, to ensure that the proper level of protection is utilized, constantly monitor the ambient air using the HNU PI 101 to obtain background readings during the sampling procedure. As long as the levels in ambient air do not rise above background, no upgrade of the level of protection is needed.

Also, perform an underground utility search prior to sampling (see section 3.4.4). When working with potentially hazardous materials, follow U.S. EPA, OSHA, and specific health and safety procedures.

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4.0 MONITORING WELL INSTALLATION: SOP #2150

4.1 SCOPE AND APPLICATION

The purpose of this Standard Operating Procedure (SOP) is to provide an overview of the methods used for monitoring well installation. Monitoring well installation creates a permanent access for the collection of samples to determine groundwater quality and the hydrogeologic properties of the aquifer in which the contaminants exist. Such wells should not alter the medium which is being monitored.

The most commonly used drilling methods are: (1) hollow-stem augers, (2) cable tool drills, and (3) rotary drills. Rotary drilling can be divided into a mud rotary or air rotary method.

4.2 METHOD SUMMARY

There is no ideal monitoring well installation method for all conditions; therefore, hydrogeologic conditions at the site and project objectives must be considered before deciding which drilling method to use.

4.2.1 Hollow-Stem Augering

Hollow-stem augering is fast and relatively less expensive than cable tool or rotary drilling methods. It is possible to drill several hundred feet of borehole per day in unconsolidated formations.

4.2.2 Cable Tool Drilling

Cable tool drilling method involves lifting and dropping a heavy, solid chisel-shaped bit, suspended on a steel cable. This bit pounds a hole through soil and rock. Temporary steel casing is used while drilling to keep the hole open and to isolate strata. The temporary casing is equipped with a drive shoe, which is attached to the lower end, and which aids the advancement of the casing by drilling out a slightly larger diameter borehole than the hole made by the drill bit alone.

Water is sometimes used when drilling above the saturated zone to reduce dust and to form a slurry with the loosened material. This facilitates removal of cuttings using a bailer or a sand pump. Potable water or distilled/deionized water should be used to prevent the introduction of contamination into the borehole.

4.2.3 Rotary Drilling

Mud Rotary Method

In the mud rotary method, the borehole is advanced by rapid rotation of the drill bit, which cuts and breaks the material at the bottom of the hole into smaller pieces. Cuttings are removed by pumping drilling fluid (water, or water mixed with bentonite) down through the drill rods and bit, and up the armulus between the borehole and the drill rods. The drilling fluid also serves to cool the drill bit and prevent the borehole from collapsing in unconsolidated formations.

Air Rotary Method

The air rotary method is the same as the mud rotary except that compressed air is pumped down the drill rods and returns with the drill cuttings up through the annulus. Air rotary method is generally limited to consolidated and semi-consolidated formations. Casing is sometimes used to prevent cavings in semi-consolidated formations. The air must be filtered to prevent introduction of contamination into the borehole.

4.3 SAMPLE PRESERVATION, CONTAINERS, HANDLING, AND STORAGE

Often, a primary object of the drilling program is to obtain representative lithologic or environmental samples. Lithologic samples are taken in order to determine the geologic or hydrogeologic regime at a site. The most common techniques for retrieving lithologic samples in unconsolidated formations are described below.

- Split spoon sampling, carried out continuously or at discrete intervals during drilling, is used to make a field description of the sample and create a log of each boring.

- Shelby tube sampling, is used when an undisturbed sample is required from clayey or silty soils, especially for geotechnical evaluation or chemical analysis.

- Cuttings description is used when a general lithologic description and approximate depths are sufficient.

The most common techniques for retrieving lithologic sampling in consolidated formations are described below.

- Rock coring is carried out continuously or at discrete intervals during drilling and enables the geologist to write a field description of the sample, create a log of each boring, and map occurrences and orientation of fractures.

- Cuttings description is used when a general lithologic description and approximate depths are sufficient.

4.4 INTERFERENCES AND POTENTIAL PROBLEMS

Table 3 on page 27 displays the advantages and disadvantages of the various drilling techniques.

4.5 EQUIPMENT/APPARATUS

The drilling contractor will provide all operational equipment for the drilling program which is outlined. The geologist should bring:

- well log sheets
- metal case (container for well logs)
- ruler
- depth sounder
- water level indicator
- all required health and safety gear
- sample collection jars
- trowels
- description aids (Munsell, grain size charts, etc.)

4.6 REAGENTS

No chemical reagents are used in this procedure. Decontamination of drilling equipment should follow ERT SOP #2006, Sampling Equipment Decontamination and the site-specific work plan.

4.7 PROCEDURES

4.7.1 Preparation

The planning, selection and implementation of any monitoring well installation program should include the following steps.

1. Review existing data on site geology and hydrogeology including publications, air photos, water quality data, and existing maps. These may be obtained from local, state, or federal agencies.

2. Visit the site to observe field geology and potential access problems for drill rig, to establish water supply, and drill equipment and materials storage area.

3. Prepare site safety plan.

4. Define project objectives; select drilling, well development, and sampling methods.

5. Select well construction materials including well construction specifications (i.e., casing and screen materials, casing and screen diameter, screen length and screen interval, filter pack and screen size).

6. Determine need for containing drill cuttings/fluids and their disposal.

7. Prepare work plan including all of the above.

8. Prepare and execute the drilling contract.

9. Implement the drilling program.

10. Prepare the final report, including background data, project objective, field procedure, well construction data including well logs and well construction.

All drilling and well installation programs must be planned and supervised by a professional geologist/hydrogeologist.

4.7.2 Field Preparation

1. Prior to the mobilization of the drill rig,

Table 3: Advantages and Disadvantages of Various Drilling Techniques

Drilling Type	Advantages	Disadvantages
Auger	• Allows sampling from different strata during drilling. • Less potential for cross-contamination between strata than in other techniques. • Large diameter borehole may be drilled for multiple-well completion. • Less well development is generally needed than in mud rotary because of the relatively large diameter borehole, the ability to emplace a large and effective gravel pack, and because no drilling fluids are introduced into the borehole.	• Very slow or impossible in coarse materials such as cobbles and boulders. • Cannot drill hard rock formations and is generally not suited for wells deeper than 100 feet. • Not good in caving formations. • Potential for disturbing large volume of subsurface materials around the borehole; therefore affecting local permeabilities and creating annular channels for contaminant movement between different strata.
Cable Tool	• Allows for easy and accurate detection of the water table. • Driven casing seals off formation, minimizing the threat of cross-contamination in pollution investigation. • Especially successful for drilling in glacial till.	• Extremely slow rate of drilling. • Can lose casing in deep wells.
Mud Rotary	• Quite fast, more than 100 feet of borehole advancement per day is possible. • Geophysical logs such as resistivity (which must be run in an uncased borehole) can be run before well construction.	• Potential cross-contamination of strata exposed to the circulating drilling fluid during drilling. • Difficulty in removing mud residues during well development. • Drilling mud may alter the groundwater chemistry by binding metals, sorbing organic compounds and by altering pH, cation exchange capacity and chemical oxidation demand of native fluids. • Drilling mud may change local permeability of the formation.
Air Rotary	• Like mud rotary method, more than 100 feet of borehole advancement a day is possible. • Sampling different strata during drilling is possible if temporary casing is advanced.	• In contaminated formations, the use of high pressure air may pose a significant hazard to the drill crew due to rapid transport of contaminated material up the borehole during drilling. • Introduction of air to ground water could reduce concentration of volatile organic compounds locally.

thoroughly decontaminate the rig and all associated equipment to remove all oil, grease, mud, etc.

2. Before drilling each boring, steam-clean and rinse all the "down-the-hole" drill equipment with potable water to minimize cross-contamination. Special attention should be given to the thread section of the casings, and to the drill rods. All drilling equipment should be steam-cleaned at completion of the project to ensure that no contamination is transported to or from the sampling site.

3. Record lithologic descriptions and all field measurements and comments on the well log form (Appendix C). Include well construction diagrams on the well log form for each well installed. At a minimum, the well construction information should show depth from surface grade, the bottom of the boring, the screened interval, casing material, casing diameter, gravel pack location, grout seal and height of riser pipe above the ground. Also record the actual compositions of the grout and seal on the well log form.

4.7.3 Well Construction

The most commonly used casing materials include stainless steel, polyvinyl chloride (PVC) and Teflon. Monitoring wells are constructed with casings and materials that are resistant to the subsurface environment. The selection of well construction material is based on the material's long-term interaction with the contaminated groundwater. Construction materials should not cause an analytical bias in the interpretation of the chemical analysis of the water samples.

Well casing material should also be judged from a structural standpoint. Material should be rigid and nonporous, with a low surface-area-to-water ratio in the wellbore relative to the formation materials (U.S. EPA, 1987).

1. Fill the annular space between the well screen and the boring with a uniform gravel/sand pack to serve as a filter media. For wells deeper than approximately 50 feet, or when recommended by the site geologist, emplace the sand pack using a tremie pipe (normally consisting of a 1.25inch PVC or steel pipe). Pump sand slurry composed of sand and potable water through the tremie pipe into the annulus throughout the entire screened interval, and over the top of the screen. It is necessary to pump sufficient sand/gravel slurry to cover the screen after the sand/gravel pack has settled and become dense.

2. Determine the depth of the top of the sand using the tremie pipe, thus verifying the thickness of the sand pack. Add more sand to bring the top of the sand pack to approximately 2-3 feet above the top of the well screen. Under no circumstances should the sand pack extend into any aquifer other than the one to be monitored. In most cases, the well design can be modified to allow for a sufficient sand pack without threat of crossflow between producing zones through the sand pack.

3. In materials that will not maintain an open hole, withdraw the temporary or outer casing gradually during placement of sand pack/grout to the extent practical.

   For example, after filling 2 feet with sand pack, the outer casing should be withdrawn 2 feet. This step of placing more gravel and withdrawing the outer casing should be repeated until the level of the sand pack is approximately 3 feet above the top of the well screen. This ensures that there is no locking of the permanent (inner) casing in the outer casing.

4. Emplace a bentonite seal, composed of pellets, between the sand pack and grout to prevent infiltration of cement into the filter pack and the well screen.

   These pellets should have a minimum purity of 90% montmorillonite clay, and a minimum dry bulk density of 75 lb/ft^3 for ½ inch pellets, as provided by American Colloid, or equivalent. Bentonite pellets shall be poured directly down the annulus.

   Care must be taken to avoid introducing pellets into the well bore. A cap placed over the top of the well casing before pouring the bentonite pellets from the bucket will prevent this. To ensure even application, pour the pellets from different points around the casing. To avoid bridging of pellets, they should not be introduced at a rate faster than they can settle. A tremie pipe may be used to redistribute and level out the top of the seal,

5. If using a slurry of bentonite as an annular seal, prepare it by mixing powdered or granular bentonite with potable water. The slurry must be of sufficiently high specific gravity and viscosity to prevent its displacement by the grout to be emplaced above it. As a precaution, regardless of depth, and depending on fluid viscosity, add a few handfuls of bentonite pellets to solidify the bentonite slurry surface.

6. Place a mixture of cement and bentonite grout from the top of the bentonite seal to the ground surface.

   Only Type I or II cement without accelerator additives may be used. An approved source of potable water must be used for mixing grouting materials. The following mixes are acceptable:

   - Neat cement, a maximum of 6 gallons of water per 94-pound bag of cement
   - Granular bentonite, 1.5 pounds of bentonite per 1 gallon of water
   - Cement-bentonite, 5 pounds of pure bentonite per 94-pound bag of cement with 7-8 gallons of water; 13-14 pounds weight, if dry mixed
   - Cement-bentonite, 6 to 8 pounds of pure bentonite per 94-pound bag of cement with 8-10 gallons of water, if water mixed
   - Non-expandable cement, mixed at 7.5 gallons of water to l/2 teaspoon of aluminum hydroxide, 94 pounds of neat cement (Type I) and 4 pounds of bentonite
   - Non-expandable cement, mixed at 7 gallons of water to l/2 teaspoon of aluminum hydroxide, 94 pounds of neat cement (Type I and Type II)

7. Pump grout through a tremie pipe to the bottom of the open annulus until undiluted grout flows from the annulus at the ground surface.

8. In materials that will not maintain an open hole, the temporary steel casing should be withdrawn in a manner that prevents the level of grout from dropping below the bottom of the casing.

9. Additional grout may be added to compensate for the removal of the temporary casing and the tremie pipe to ensure that the top of the grout is at or above ground surface.

10. Place the protective casing. Protective casings should be installed around all monitoring wells. Exceptions are on a case-by-case basis. The minimum elements in the protection design include:

    - A protective steel cap to keep precipitation out of the protective casing, secured to the casing by padlocks.
    - A 5-foot-minimum length of black iron or galvanized pipe, extending about 1.5 to 3 feet above the ground surface, and set in cement grout. The pipe diameter should be 8 inches for 4-inch wells, and 6 inches for 2-inch wells (depending on approved borehole size). A 0.5-inch drain hole near ground level is permitted.
    - The installation of guard posts in addition to the protective casing, in areas where vehicular traffic may pose a hazard. These guard posts consist of 3-inch diameter steel posts or tee-bar driven steel posts. Groups of three are radially located 4 feet around each well 2 feet below and 4 feet above ground surface, with flagging in areas of high vegetation. Each post is cemented in-place.
    - A flush mount of protective casing may also be used in areas of high traffic or where access to other areas would be limited by a well with stickup.

After the grout sets (about 48 hours), fill any depression due to settlement with a grout mix similar to that described above.

4.0 CALCULATIONS

To maintain an open borehole using sand or water rotary drilling, the drilling fluid must exert a pressure greater than the formation pore pressure. Typical pore pressure for an unconfined aquifer is

0.433 psi/ft and for a confined aquifer is 0.465 psi/ft.

The calculation for determining the hydrostatic pressure of the drilling fluid is:

Hydrostatic Pressure (psi) = Fluid Density (lb/gal) x Height of Fluid Column (ft) x 0.052

The minimum grout volume necessary to grout a well can be calculated using:

$$\text{Grout Vol (ft}^3) = \text{Vol of Borehole (f}^3) - \text{Vol of Casing (ft}^3)$$

$$= L\ (r_b^2 - r_c^2)$$

where:

r_B = radius of boring (ft)
r_C = radius of casing (ft)
L = length of borehole to be grouted (ft)

4.9 QUALITY ASSURANCE/ QUALITY CONTROL

There are no specific quality assurance activities which apply to the implementation of these procedures.

However, the following general QA procedures apply:

- All data must be documented on standard well completion forms, field data sheets or within field/site logbooks.

- All instrumentation must be operated in accordance with operating instructions as supplied by the manufacturer, unless otherwise specified in the work plan. Equipment checkout and calibration activities must occur prior to sampling/operation and they must be documented.

4.10 DATA VALIDATION

This section is not applicable to this SOP.

4.11 HEALTH AND SAFETY

When working with potentially hazardous materials, follow U.S. EPA, OSHA, and specific health and safety procedures.

5.0 WATER LEVEL MEASUREMENT: SOP #2151

5.1 SCOPE AND APPLICATION

The purpose of this Standard Operating Procedure (SOP) is to set guidelines for the determination of the depth to water in an open borehole, cased borehole, monitoring well or piezometer.

Generally, water level measurements from boreholes, piezometers, or monitoring wells are used to construct water table or potentiometric surface maps. Therefore, all water level measurements at a given site should be collected within a 24-hour period. Certain situations may necessitate that all water level measurements be taken within a shorter time interval. These situations may include:

- the magnitude of the observed changes between wells appears too large
- atmospheric pressure changes
- aquifers which are tidally influenced
- aquifers affected by river stage, impoundments, and/or unlined ditches
- aquifers stressed by intermittent pumping of production wells
- aquifers being actively recharged due to precipitation events

5.2 METHOD SUMMARY

A survey mark should be placed on the casing for use as a reference point for measurement. Many times the lip of the riser pipe is not flat. Another measuring reference should be located on the grout apron. The measuring point should be documented in the site logbook and on the groundwater level data form (see Appendix C).

Water levels in piezometers and monitoring wells should be allowed to stabilize for a minimum of 24 hours after well construction and development, prior to measurement. In low yield situations, recovery may take longer.

Working with decontaminated equipment, proceed from the least to the most contaminated wells. Open the well and monitor headspace with the appropriate monitoring instrument to determine the presence of volatile organic compounds. Lower the water level measurement device into the well until water surface or bottom of casing is encountered. Measure distance from water surface to the reference point on the well casing and record in the site logbook and/or groundwater level data form. Remove all downhole equipment, decontaminate as necessary, and replace well casing cap.

5.3 SAMPLE PRESERVATION, CONTAINERS, HANDLING AND STORAGE

This section is not applicable to this SOP.

5.4 INTERFERENCES AND POTENTIAL PROBLEMS

- The chalk used on steel tape may contaminate the well.
- Cascading water may obscure the water mark or cause it to be inaccurate.
- Many types of electric sounders use metal indicators at 5-foot intervals around a conducting wire. These intervals should be checked with a surveyor's tape to ensure accuracy.
- If there is oil present on the water, it can insulate the contacts of the probe on an electric sounder or give false readings due to thickness of the oil. Determining the thickness and density of the oil layer may be warranted, in order to determine the correct water level.
- Turbulence in the well and/or cascading water can make water level determination difficult with either an electric sounder or steel tape.

- An airline measures drawdown during pumping. It is only accurate to 0.5 foot unless it is calibrated for various "drawdowns".

5.5 EQUIPMENT/APPARATUS

There are a number of devices which can be used to measure water levels, such as steel tape or airlines. The device should be adequate to attain an accuracy of 0.01 feet.

The following equipment is needed to measure water levels:

- air monitoring equipment
- water level measurement device
- electronic water level indicator
- metal tape measure
- airline
- steel tape
- chalk
- ruler
- notebook
- paper towels
- decontamination solution and equipment
- groundwater level data forms

5.6 REAGENTS

No chemical reagents are used in this procedure, with the exception of decontamination solutions. Where decontamination of equipment is required, refer to ERT SOP #2006, Sampling Equipment Decontamination and the site-specific work plan.

5.7 PROCEDURES

57.1 Preparation

1. Determine the extent of the sampling effort, the sampling methods to be employed, and which equipment and supplies are needed.

2. Obtain necessary sampling and monitoring equipment.

3. Decontaminate or preclean equipment, and ensure that it is in working order.

4. Prepare scheduling and coordinate with staff, clients, and regulatory agency, if appropriate.

5. Perform a general site survey prior to site entry in accordance with the site-specific health and safety plan.

6. Identify and mark all sampling locations.

5.7.2 Procedures

1. Make sure water level measuring equipment is in good operating condition.

2. If possible and where applicable, start at those wells that are least contaminated and proceed to those wells that are most contaminated.

3. Clean all equipment entering the well by the following decontamination procedure:

   - Triple rinse equipment with deionized water.

   - Wash equipment with an Alconox solution followed by a deionized water rinse.

   - Rinse with an approved solvent (e.g., methanol, isopropyl alcohol, acetone) as per the work plan, if organic contamination is suspected.

   - Place equipment on clean surface such as a Teflon or polyethylene sheet.

4. Remove locking well cap, note location, time of day, and date in site notebook or an appropriate groundwater level data form.

5. Remove well casing cap.

6. If required by site-specific condition, monitor headspace of well with PID or PID to determine presence of volatile organic compounds and record in site logbook.

7. Lower electric water level measuring device or equivalent (i.e., permanently installed tranducers or airline) into the well until water surface is encountered.

8. Measure the distance from the water surface to the reference measuring point on the well casing or protective barrier post and record in the field logbook. In addition, note that the

water level measurement was from the top of the steel casing, top of the PVC riser pipe, from the ground surface, or from some other position on the well head.

9. The groundwater level data form in Appendix C should be completed as follows:

- site name
- logger name: person taking field notes
- date: the date when the water levels are being measured
- location: monitor well number and physical location
- time: the military time at which the water level measurement was recorded
- depth to water: the water level measurement in feet, or in tenths or hundreds of feet, depending on the equipment used
- comments: any information the field personnel feels to be applicable
- measuring point: marked measuring point on PVC riser pipe, protective steel casing or concrete pad surrounding well casing from which all water level measurements for individual wells should be measured. This provides consistency in future water level measurements.

10. Measure total depth of well (at least twice to confirm measurement) and record in site notebook or on log form.

11. Remove all downhole equipment, replace well casing cap and lock steel caps.

12. Rinse all downhole equipment and store for transport to next well.

13. Note any physical changes such as erosion or cracks in protective concrete pad or variation in total depth of well in field notebook and on field data sheets.

14. Decontaminate all equipment as outlined in Step 3 above.

5.8 CALCULATIONS

To determine groundwater elevation above mean sea level, use the following equation:

$$E_w = E - D$$

where:

E_w = Elevation of water above mean sea level
E = Elevation above sea level at point of measurement
D = Depth to water

5.9 QUALITY ASSURANCE/ QUALITY CONTROL

The following general quality assurance procedures apply:

- All data must be documented on standard chain of custody forms, field data sheets or within personal/site logbooks.
- All instrumentation must be operated in accordance with operating instructions as supplied by the manufacturer, unless otherwise specified in the work plan. Equipment checkout and calibration activities must occur prior to sampling/operation, and they must be documented.
- Each well should be tested at least twice in order to compare results.

5.10 DATA VALIDATION

This section is not applicable to this SOP.

5.11 HEALTH AND SAFETY

When working with potentially hazardous materials, follow U.S. EPA, OSHA, and specific health and safety procedures.

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6.0 WELL DEVELOPMENT: SOP #2156

6.1 SCOPE AND APPLICATION

The purpose of monitoring well development is to ensure removal of fines from the vicinity of the well screen. This allows free flow of water from the formation into the well and also reduces the turbidity of the water during sampling events. The most common well development methods are: surging, jetting, and overpumping.

Surging involves raising and lowering a surge block or surge plunger inside the well. The resulting motion surges water into the formation and loosens sediment to be pulled from the formation into the well. Occasionally, sediment must be removed from the well with a sand bailer to prevent sand locking of the surge block. This method may cause the sand pack around the screen to be displaced to a degree that damages its value as a filtering medium. For example, channels or voids may form near the screen if the filter pack sloughs away during surging (Keely and Boateng, 1987).

Jetting involves lowering a small diameter pipe into the well to a few feet above the well screen, and injecting water or air through the pipe under pressure so that sediments at the bottom are geysered out the top of the well. It is important not to jet air or water directly across the screen. This may cause fines in the well to be driven into the entrance of the screen openings thereby causing blockages.

Overpumping involves pumping at a rate rapid enough to draw the water level in the well as low as possible, and allowing it to recharge. This process is repeated until sediment-free water is produced. Overpumping is not as vigorous as surging and jetting and is probably the most desirable for monitoring well development.

6.2 METHOD SUMMARY

Development of a well should occur as soon as practical after installation, but not sooner than 48 hours after grouting is completed, if a rigorous well development is being used. If a less rigorous method, such as bailing, is used for development, it may be initiated shortly after installation. The main concern is that the method being used for development does not interfere with allowing the grout to set.

Open the monitoring well, take initial measurements (e.g. head space air monitoring readings, water level, well depth, pH, temperature, and specific conductivity) and record results in the site logbook. Develop the well by the appropriate method (i.e., overpumping jetting, or surging) to accommodate site conditions and project requirements. Continue until the developed water is clear and free of sediment. Containerize all discharge water from known or suspected contaminated areas. Record final measurements in the logbook. Decontaminate equipment as appropriate prior to use in the next well.

6.3 SAMPLE PRESERVATION, CONTAINERS, HANDLING, AND STORAGE

This section is not applicable to this Standard Operating Procedure (SOP).

6.4 INTERFERENCES AND POTENTIAL PROBLEMS

The following interferences or problems may occur during well development:

- The possibility of disturbing the filter pack increases with surging and jetting well development methods.

- The introduction of external water or air by jetting may alter the hydrochemistry of the aquifer.

6.5 EQUIPMENT/APPARATUS

The type of equipment used for well development is dependent on the diameter of the well. For example, submersible pumps cannot be used for well development unless the wells are 4 inches or greater in diameter, because the smallest submersible pump has a 3 l/4 inch O.D.

In general, the well should be developed shortly after it is drilled. Most drilling rigs have air compressors or pumps that may be used for the development process.

6.6 REAGENTS

No chemical reagents are used in this procedure except for decontamination solutions. For guidelines on equipment decontamination, refer to ERT SOP #2006, Sampling Equipment Decontamination and the site-specific work plan.

6.7 PROCEDURES

6.7.1 Preparation

1. Coordinate site access and obtain keys to the monitoring well security cap locks.

2. Obtain information on each well to be developed (i.e., drilling, method, well diameter, depth, screened interval, anticipated contaminants, etc.).

3. Obtain a water level meter, air monitoring equipment, materials for decontamination, pH and electrical conductivity meters, a thermometer, and a stopwatch.

4. Assemble containers for temporary storage of water produced during well development. Containers must be structurally sound, compatible with anticipated contaminants, and easy to manage in the field. The use of truck-mounted tanks may be necessary in some cases; alternately, a portable water treatment unit (e.g. activated carbon) may be used to decontaminate the purge water.

6.7.2 Operation

The development should be performed as soon as practical after the well is installed, but no sooner than 48 hours after grouting is completed. Dispersing agents, acids, or disinfectants should not be used to enhance development of the well.

1. Assemble necessary equipment on a plastic sheet around the well.

2. Record pertinent information in field logbook (personnel, time, location ID, etc.).

3. Open monitoring well, and take air monitoring readings at the top of casing and in the breathing zone as appropriate.

4. Measure depth to water and the total depth of the monitoring well from the same datum point.

5. Measure the initial pH, temperature, and specific conductivity of the water and record in the logbook.

6. Develop the well until the water is clear and appears to be free of sediment. Note the initial color, clarity and odor of the water.

7. All water produced by development in contaminated or suspected contaminated areas must be containerized or treated. Clearly label each container with the location ID. Determination of the appropriate disposal method will be based on the fast round of analytical results from each well.

8. No water should be added to the well to assist development without prior approval by the site geologist. If a well cannot be cleaned of mud to produce formation water because the aquifer yields insufficient water, small amounts of potable water may be injected to clean up this poorly yielding well. This may be done by dumping in buckets of water. When most of the mud is out, continue development with formation water only. It is essential that at least live times the amount of water injected must be produced back from the well in order to ensure that all injected water is removed from the formation.

9. Note the final color, clarity and odor of the water.

10. Measure the final pH, temperature and specific conductance of the water and record in the field logbook.

11. Record the following data in the field logbook:

    - well designation (location ID)
    - date(s) of well installation
    - date(s) and time of well development
    - static water level before and after

development
- quantity of water removed and time of removal
- type and size/capacity of pump and/or bailer used
- description of well development techniques used

6.7.3 Post Operation

1. Decontaminate all equipment.

2. Store containers of purge water produced during development in a safe and secure area.

3. After the first round of analytical results have been received, determine and implement the appropriate purge water disposal method.

6.8 CALCULATIONS

There are no calculations necessary to implement this procedure. However, if it is necessary to calculate the volume of the well, utilize the following equation:

Well volume = $nr^2h(cf)$ [Equation 1]

where:

n	=	pi
r	=	radius of monitoring well (feet)
h	=	height of the water column (feet) [This may be determined by subtracting the depth to water from the total depth of the well as measured from the same reference point.]
cf	=	conversion factor (gal/ft^3) = 7.48 gal/ft^3 [In this equation, 7.48 gal/ft^3 is the necessary conversion factor, because 7.48 gallons of water occupy 1 ft^3]

Monitoring wells are typically 2 inches, 3 inches, 4 inches, or 6 inches in diameter. If the diameter of the monitoring well is known, a number of standard conversion factors can be used to simplify the equation above.

The volume, in gallons per linear foot, for various standard monitoring well diameters can be calculated as follows:

v = $nr^2(cf)$ [Equation 2]

where:

v	=	volume in gallons per linear foot
n	=	pi
r	=	radius of monitoring well (feet)
cf	=	conversion factor (7.48 gal/ft^3)

For a 2-inch diameter well, the volume per linear foot can be calculated as follows:

v = $nr^2(cf)$ [Equation 21
= 3.14 $(l/12 \ ft)^2$ 7.48 gal/f?
= 0.1632 gal/ft

Remember that if you have a 2-inch diameter well, you must convert this to the radius in feet to be able to use the equation.

The volume per linear foot for monitoring wells of common size are as follows:

Well diameter	v (volume in gal/ft.)
2-inch	0.1632
3-inch	0.3672
4-inch	0.6528
6-inch	1.4688

If you utilize the factors above, Equation 1 should be modified as follows:

Well volume = h(v) [Equation 3]

where:

h	=	height of water column (feet)
v	=	volume in gallons per linear foot from Equation 2

6.9 QUALITY ASSURANCE/ QUALITY CONTROL

There are no specific quality assurance activities which apply to the implementation of these procedures. However, the following general QA procedures apply:

- All data must be documented on standard chain of custody forms, field data sheets or personal/site logbooks.

- All instrumentation must be operated in accordance with operating instructions as supplied by the manufacturer, unless otherwise specified in the work plan. Equipment checkout and calibration activities must occur prior to sampling/operation and they must be documented.

6.10 DATA VALIDATION

This section is not applicable to this SOP

6.11 HEALTH AND SAFETY

When working with potentially hazardous materials, follow U.S. EPA, OSHA, and specific health and safety procedures.

7.0 CONTROLLED PUMPING TEST: SOP #2157

7.1 SCOPE AND APPLICATION

The most reliable and commonly used method of determining aquifer characteristics is by controlled aquifer pumping tests. Groundwater flow varies in space and time and depends on the hydraulic properties of the rocks and the boundary conditions imposed on the groundwater system. Pumping tests provide results that are more representative of aquifer characteristics than those predicted by slug or bailer tests. Pumping tests require a greater degree of activity and expense, however, and are not always justified for all levels of investigation. For example, slug tests may be acceptable at the reconnaissance level whereas pumping tests are usually performed as part of a feasibility study in support of designs for aquifer remediation.

Aquifer characteristics which may be learned using pumping tests include hydraulic conductivity (K), transmissivity (T), specific yield (Sy) for unconfined aquifers, and storage coefficient (S) for confined aquifers. These parameters can be determined by graphical solutions and computerized programs. This Standard Operating Procedure (SOP) outlines the protocol for conducting controlled pumping tests.

7.2 METHOD SUMMARY

It is desirable to monitor pre-test water levels at the test site for about 1 week prior to performance of the pump test. This information allows for the determination of the barometric efficiency of the aquifer, as well as noting changes in head, due to recharging or pumping in the area adjacent to the well. Prior to initiating the long term pump test, a step test is conducted to estimate the greatest flow rate that may be sustained by the pump well.

After the pumping well has recovered from the step test, the long term pumping test begins. At the beginning of the test, the discharge rate is set as quickly and accurately as possible. The water levels in the pumping well and observation wells are recorded accordingly with a set schedule. Data is entered on the Pump/Recovery Test Data Sheet (Appendix C). The duration of the test is determinated by project needs and aquifer properties, but rarely goes beyond 3 days or until water levels become constant.

7.3 SAMPLE PRESERVATION, CONTAINERS, HANDLING, AND STORAGE

This section is not applicable to this SOP.

7.4 INTERFERENCES AND POTENTIAL PROBLEMS

Interferences and potential problems include:

- atmospheric conditions
- impact of local potable wells
- compression of the aquifer due to trains, heavy traffic, etc.

7.5 EQUIPMENT/APPARATUS

- tape measure (subdivided into tenths of feet)
- submersible pump
- water pressure transducer
- electric water level indicator
- weighted tapes
- steel tape (subdivided into tenths of feet)
- generator
- electronic data-logger (if transducer method is used)
- watch or stopwatch with second hand
- semilogarithmic graph paper (if required)
- water proof ink pen and logbook
- thermometer
- appropriate references and calculator
- a barometer or recording barograph (for tests conducted in confined aquifers)
- heat shrinks
- electrical tape
- flashlights and lanterns
- pH meter
- conductivity meter
- discharge pipe
- flow meter

7.6 REAGENTS

No chemical reagents are used for this procedure; however, decontamination solutions may be necessary. If decontamination of equipment is required, refer to ERT SOP #2006, Sampling Equipment Decontamination and the site-specific work plan.

7.7 PROCEDURES

7.7.1 Preparation

1. Determine the extent of the sampling effort, the sampling methods to be employed, and which equipment and supplies are needed.

2. Obtain necessary sampling and monitoring equipment.

3. Decontaminate or preclean equipment, and ensure that it is in working order.

4. Prepare scheduling and coordinate with staff, clients, and regulatory agency, if appropriate.

5. Perform a general site survey prior to site entry in accordance with the site-specific health and safety plan.

6. Identify and mark all sampling locations.

7.7.2 Field Preparation

1. Review the site work plan and become familiar with information on the wells to be tested.

2. Check and ensure the proper operation of all field equipment. Ensure that the electronic data-logger is fully charged, if appropriate. Test the electronic data-logger using a container of water. Always bring additional transducers in case of malfunctions.

3. Assemble a sufficient number of field data forms to complete the field assignment.

4. Develop the pumping well prior to testing, per ERT SOP #2156, Well Development.

5. Provide an orifice, weir, flow meter, container or other type of water measuring device to accurately measure and monitor the discharge from the pumping well.

6. Provide sufficient pipe to transport the discharge from the pumping well to an area beyond the expected cone of depression. Conducting a pumping test in contaminated groundwater may require treatment, special handling, or a discharge permit before the water can be discharged.

7. The discharge pipe must have a gate valve to control the pumping rate.

8. Determine if there is an outlet near the well head for water quality determination and sampling.

7.7.3 Pre-Test Monitoring

It is desirable to monitor pretest water levels at the test site for about 1 week prior to performance of the test. This can be accomplished by using a continuous-recording device such as a Stevens recorder. This information allows the determination of the barometric efficiency of the aquifer when barometric records are available. It also helps determine if the aquifer is experiencing an increase or decrease in head with time due to recharge or pumping in the nearby area, or diurnal effects of evapotranspiration. Changes in barometric pressure are recorded during the test (preferably with an on-site barograph) in order to correct water levels for any possible fluctuations which may occur due to changing atmospheric conditions. Pretest water level trends are projected for the duration of the test. These trends and/or barometric changes are used to “correct” water levels during the test so they are representative of the hydraulic response of the aquifer due to pumping of the test well.

7.7.4 Step Test

Conduct a step test prior to initiating a long term pumping test. The purpose of a step test is to estimate the greatest flow rate that may be sustained during a long term test. The test is performed by progressively increasing the flow rate at 1 hour intervals. The generated drawdown versus time data is plotted on semilogarithmic graph paper, and the discharge rate is determined from this graph.

7.7.5 Pump Test

Time Intervals

After the pumping well has fully recovered from the step test, the long term pumping test may start. At the beginning of the test, the discharge rate should be set as quickly and accurately as possible. The water levels in the pumping well and observation wells will be recorded according to Tables 4 and 5 below.

Water Level Measurements

Water levels will be measured as specified in ERT SOP #2151, Well Level Measurement. During the early part of the test, sufficient personnel should be available to have at least one person at each observation well and at the pumping well. After the first 2 hours, two people are usually sufficient to continue the test. It is not necessary that readings at the wells be taken simultaneously. It is very important that depth to water readings be measured accurately and readings recorded at the exact time measured. Alternately, individual pressure transducers and electronic data-loggers may be used to reduce the number of field personnel hours required to complete the pumping test. A typical aquifer pump test form is shown in Appendix C.

During a pumping test, the following data must be recorded accurately on the aquifer test data form.

1. Site ID -- A number assigned to identity a specific site.

Table 4: Time Intervals for Measuring Drawdown in the Pumped Well

Elapsed Time From Start of Test (Minutes)	Interval Between Measurements (Minutes)
0 - 10	0.5 - 1
10 - 15	1
15 - 60	5
60-300	30
300-1440	60
1440 - termination	480

Table 5: Time Intervals for Measuring Drawdown in an Observation Well

Elapsed Time From Start of Test (Minutes)	Interval Between Measurements (Minutes)
O-60	2
60 - 120	5
120 - 240	10
240 - 360	30
360-1440	60
1440 - termination	480

2. Location -- The location of the well in which water level measurements are being taken.

3. Distance from Pumped Well -- Distance between the observation well and the pumping well in feet.

4. Logging Company -- The company conducting the pumping test.

5. Test Start Date -- The date when the pumping test began.

6. Test Start Time -- Start time, using a 24hour clock.

7. Static Water Level (Test Start) -- Depth to water, in feet and tenths of feet, in the observation well at the beginning of the pumping test.

8. Test End Date -- The date when the pumping test was completed.

9. Test End Time -- End time, using a 24hour clock.

10. Static Water Level (Test End) -- Depth to water, in feet and tenths of feet, in the observation well at the end of the pumping test.

11. Average Pumping Rate -- Summation of all entries recorded in the Pumping Rate (gal/min) column divided by the total number of Pumping Rate (gal/min) readings.

12. Measurement Methods -- Type of instrument used to measure depth-to-water (this may include steel tape, electric sounding probes, Stevens recorders, or pressure transducers).

13. Comments -- Appropriate observations or information which have not been recorded elsewhere, including notes on sampling.

14. Elapsed Time (min) -- Time of measurement recorded continuously from start of test (time 00.00).

15. Depth to Water (ft) -- Depth to water, in feet and tenths of feet, in the observation well at the time of the water level measurement.

16. Pumping Rate (gal/min) -- Plow rate of pump measured from an orifice, weir, flow meter, container or other type of water-measuring device.

Test Duration

The duration of the test is determined by the needs of the project and properties of the aquifer. One simple test for determining adequacy of data is when the log-time versus drawdown for the most distant observation well begins to plot as a straight line on the semilogarithmic graph paper. There are several exceptions to this simple rule of thumb, therefore, it should be considered a minimum criterion. Different hydrogeologic conditions can produce straight line trends on log-time versus drawdown plots. In general, longer tests produce more definitive results. A duration of 1 to 3 days is desirable, followed by a similar period of monitoring the recovery of the water level. Unconfined aquifers and partially penetrating wells may have shorter test durations. Knowledge of the local hydrogeology, combined with a clear understanding of the overall project objectives, is necessary in interpreting just how long the test should be conducted. There is no need to continue the test if the water level becomes constant with time. This normally indicates that a hydrogeologic source has been intercepted and that additional useful information will not be collected by continued pumping.

7.7.6 Post Operation

1. After completion of water level recovery measurements, decontaminate and/or dispose of equipment as per ERT SOP #2006, Sampling Equipment Decontamination.

2. When using an electronic data-logger, use the following procedures.

   - Stop logging sequence.
   - Print data, or save memory and disconnect battery at the end of the day's activities.

3. Replace testing equipment in storage containers.

4. Check sampling equipment and supplies. Repair or replace all broken or damaged equipment.

5. Review field forms for completeness.

6. Interpret pumping/recovery test field results.

7.8 CALCULATIONS

There are several accepted methods for determining aquifer properties such as transmissivity, storativity, and conductivity. However, the method to use is dependent on the characteristics of the aquifer being tested (confined, unconfined, leaky confining layer, etc.). When reviewing pump test data, texts by Fetter, or Driscoll or Freeze and Cherry may be used to determine the method most appropriate to your case. See the reference section on page 69.

7.9 QUALITY ASSURANCE/ QUALITY CONTROL

Calibrate all gauges, transducers, flow meters, and other equipment used in conducting pumping tests before use at the site.

Obtain records of the instrument calibration and file with the test data records. The calibration records will consist of laboratory measurements. If necessary, perform any on-site zero adjustment and/or calibration. Where possible, check all flow and measurement meters on-site using a container of measured volume and stopwatch; the accuracy of the meters must be verified before testing proceeds.

7.10 DATA VALIDATION

This section is not applicable to this SOP.

7.11 HEALTH AND SAFETY

When working with potentially hazardous materials, follow U.S. EPA, OSHA, and specific health and safety procedures.

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8.0 SLUG TEST: SOP #2158

8.1 SCOPE AND APPLICATION

This procedure can determine the horizontal hydraulic conductivity of distinct geologic horizons under in situ conditions. The hydraulic conductivity (K) is an important parameter for modeling the flow of groundwater in an aquifer.

8.2 METHOD SUMMARY

A slug test involves the instantaneous injection of a slug (a solid cylinder of known volume) or withdrawal of a volume of water. A slug displaces a known volume of water from a well and measures the artificial fluctuation of the groundwater level.

There are several advantages to using slug tests to estimate hydraulic conductivities. First, estimates can be made in situ, thereby avoiding errors incurred in laboratory testing of disturbed soil samples. Second, compared with pump tests, slug tests can be performed quickly and at relatively low cost, because pumping and observation wells are not required. And last, the hydraulic conductivity of small discrete portions of an aquifer can be estimated (e.g., sand layers in a clay).

8.3 SAMPLE PRESERVATION, CONTAINERS, HANDLING, AND STORAGE

This section is not applicable to this Standard Operating Procedure (SOP).

8.4 INTERFERENCES AND POTENTIAL PROBLEMS

- Only the hydraulic conductivity of the area immediately surrounding the well is estimated, which may not be representative of the average hydraulic conductivity of the area.
- The storage coefficient, S, usually cannot be determined by this method.

8.5 EQUIPMENT/APPARATUS

The following equipment is needed to perform slug tests. All equipment which comes in contact with the well should be decontaminated and tested prior to commencing field activities.

- tape measure (subdivided into tenths of feet)
- water pressure transducer
- electric water level indicator
- weighted tapes
- steel tape (subdivided into tenths of feet)
- electronic data-logger (if transducer method is used)
- stainless steel slug of a known volume
- watch or stopwatch with second hand
- semilogarithmic graph paper (if required)
- waterproof ink pen and logbook
- thermometer
- appropriate references and calculator
- electrical tape
- 21X micrologger
- Compaq portable computer or equivalent with Grapher installed on the hard disk

8.6 REAGENTS

No chemical reagents are used in this procedure; however, decontamination solvents may be necessary. When decontaminating the slug or equipment, refer to ERT SOP #2006, Sampling Equipment Decontamination, and the site-specific work plan.

8.7 PROCEDURES

8.7.1 Field Procedures

When the slug test is performed using an electronic data-logger and pressure transducer, all data will be stored internally or on computer diskettes or tape. The information will be transferred directly to the main computer and analyzed. Keep a computer printout of the data in the files as documentation.

If the slug test data is collected and recorded manually, the slug test data form (Appendix C) will be used to record observations. The slug test data form should include the following information:

- site ID -- identification number assigned to the site
- location ID -- identification of location being tested
- date -- the date when the test data were collected in this order: year, month, day (e.g., 900131 for January 31, 1990)
- slug volume (ft^3) = manufacturer's specification for the known volume or displacement of the slug device
- logger -- identifies the company or person responsible for performing the field measurements
- test method -- the slug device either is injected or lowered into the well, or is withdrawn or pulled-out from the monitor well. Check the method that is applicable to the test situation being run.
- comments -- appropriate observations or information for which no other blanks are provided.
- elapsed time (minutes) -- cumulative time readings from beginning of test to end of test, in minutes
- depth to water (feet) -- depth to water recorded in tenths of feet

The following general procedures may be used to collect and report slug test data. These procedures may be modified to reflect site-specific conditions:

1. Decontaminate the transducer and cable.

2. Make initial water level measurements on monitoring **wells** in an upgradient-to-downgradient sequence, if possible, to minimize the potential for cross-contamination.

3. Before beginning the slug test, record information into the electronic data-logger. The type of information may vary depending on the model used. When using different model, consult the operator's manual for the proper data entry sequence to be used.

4. Test wells from least contaminated to most contaminated, if possible.

5. Determine the static water level in the well by measuring the depth to water periodically for several minutes and taking the averagc of the readings, (see SOP #2151, Water Level Measurement).

6. Cover sharp edges of the well casing with duct tape to protect the transducer cables.

7. Install the transducer and cable in the well to a depth below the target drawdown estimated for the test but at least 2 feet from the bottom of the well. Be sure the depth of submergence is within the design range stamped on the transducer. Temporarily tape the transducer cable to the well to keep the transducer at a constant depth.

8. Connect the transducer cable to the electronic data-logger.

9. Enter the initial water level and transducer design range into the recording device according to the manufacturer's instructions. The transducer design range will be stamped on the side of the transducer. Record the initial water level on the recording device.

10. "Instantaneously" introduce or remove a known volume or slug of water to the well. Another method is to introduce a solid cylinder of known volume to displace and raise the water level, allow the water level to restabilize and remove the cylinder. It is important to remove or add the volumes as quickly as possible because the analysis assumes an "instantaneous" change in volume is created in the well.

11. Consider the moment of volume addition or removal as time zero. Measure and record the depth to water and the time at each reading. Depths should be measured to the nearest 0.01 foot. The number of depth-time measurements necessary to complete the test is variable. It is critical to make as many measurements as possible in the early part of the test. The number and intervals between measurements will be determined from previous aquifer tests or evaluations.

12. Continue measuring and recording depth-time measurements until the water level returns to equilibrium conditions or a sufficient number of readings have been made to clearly show a trend on a semilogarithmic plot of time versus depth.

13. Retrieve slug (if applicable).

Note: The time required for a slug test to be completed is a function of the volume of the slug, the hydraulic conductivity of the formation and the type of well completion. The slug volume should be large enough that a sufficient number of water level measurements can be made before the water level returns to equilibrium conditions. The length of the test may range from less than a minute to several hours. If the well is to be used as a monitoring well, precautions against contaminating it should be taken. If water is added to the monitoring well, it should be from an uncontaminated source and transported in a clean container. Bailers or measuring devices should be decontaminated prior to the test. If tests are performed on more than one monitoring well, care must be taken to avoid cross-contamination of the wells.

Slug tests should be conducted on relatively undisturbed wells. If a test is conducted on a well that has recently been pumped for water sampling purposes, the measured water level must be within 0.1 foot of the static water level prior to sampling. At least 1 week should elapse between the drilling of a well and the performance of a slug test.

8.7.2 Post Operation

When using an electronic data-logger, use the following procedure:

1. Stop logging sequence.
2. Print data.
3. Send data to computer by telephone.
4. Save memory and disconnect battery at the end of the day's activities.
5. Review field forms for completeness.

8.8 CALCULATIONS

The simplest interpretation of piezometer recovery is that of Hvorslev (1951). The analysis assumes a homogenous, isotropic medium in which soil and water are incompressible. Hvorslev's expression for hydraulic conductivity (K) is:

$$K = \frac{r^2 \ln(L/R)}{2 L T_\circ}$$

for $L/R > 8$

where:

K = hydraulic conductivity [feet/second]
= casing radius [feet]
r = length of open screen (or open borehole) [feet]
R = filter pack (borehole) radius [feet]
$T_\circ$ = Basic Time Lag [seconds]; value of t on semilogarithmic plot of $(H-h)/(H-H_\circ)$ vs. t, when $(H-h)/(H-H_\circ) = 0.37$

where:

H = initial water level prior to removal of slug
$H_\circ$ = water level at $t = 0$
h = recorded water level at $t > 0$

(Hvorslev, 1951; Freeze and Cherry, 1979)

The Bower and Rice method is also commonly used for K calculations. However, it is much more time consuming than the Hvorslev method. Refer to Freeze and Cherry or Fetter for a discussion of these methods.

8.9 QUALITY ASSURANCE/ QUALITY CONTROL

The following general quality assurance procedures apply:

- All data must be documented on standard chain of custody forms, field data sheets, or within personal/site logbooks.
- All instrumentation must be operated in accordance with operating instructions as supplied by the manufacturer, unless otherwise specified in the work plan. Equipment checkout and calibration activities must occur prior to sampling/operation, and they must be documented.

The following specific quality assurance activity will apply:

- Each well should be tested at least twice in order to compare results.

8.10 DATA VALIDATION

This section is not applicable to this SOP.

8.11 HEALTH AND SAFETY

When working with potentially hazardous materials, follow U.S. EPA, OSHA, and specific health and safety procedures.

APPENDIX A

Sampling Train Schematic

Figure 1: Sampling Train Schematic

SOP #2149

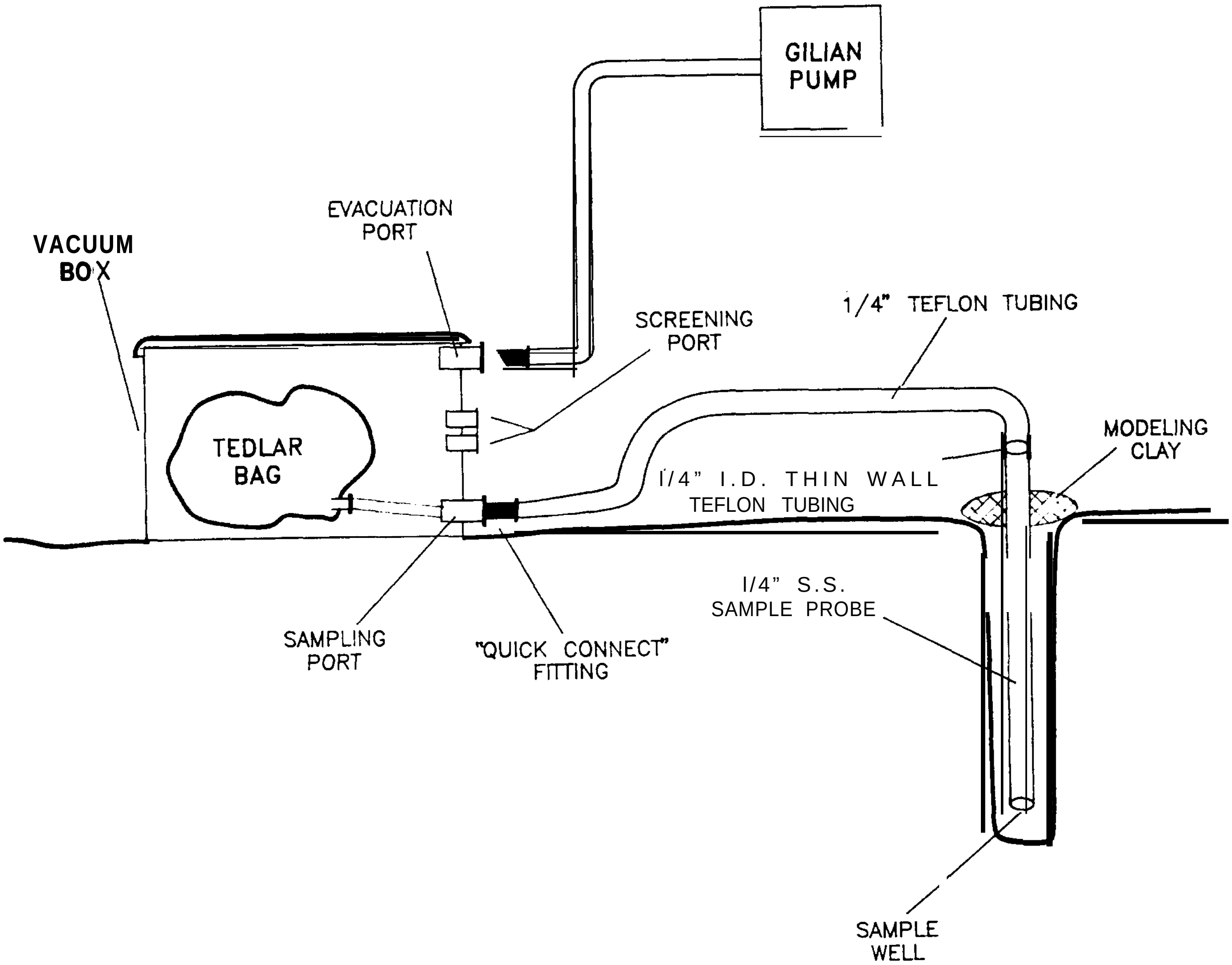
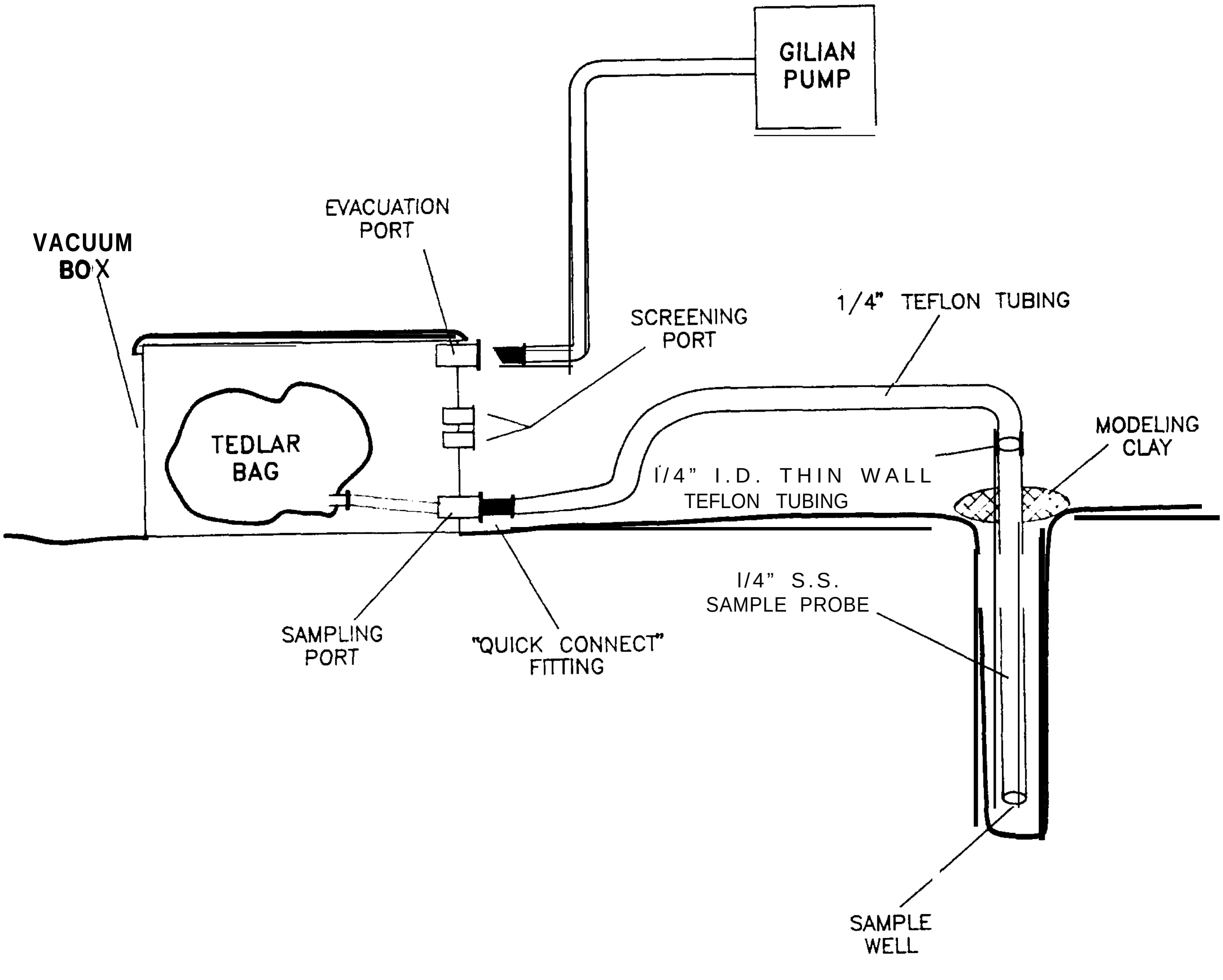


Figure 1: Sampling Train Schematic

SOP #2149



APPENDIX A

Sampling Train Schematic

8.10 DATA VALIDATION

This section is not applicable to this SOP.

8.11 HEALTH AND SAFETY

When working with potentially hazardous materials, follow U.S. EPA, OSHA, and specific health and safety procedures.

8.10 DATA VALIDATION

This section is not applicable to this SOP.

8.11 HEALTH AND SAFETY

When working with potentially hazardous materials, follow U.S. EPA, OSHA, and specific health and safety procedures.

Note: The time required for a slug test to be completed is a function of the volume of the slug, the hydraulic conductivity of the formation and the type of well completion. The slug volume should be large enough that a sufficient number of water level measurements can be made before the water level returns to equilibrium conditions. The length of the test may range from less than a minute to several hours. If the well is to be used as a monitoring well, precautions against contaminating it should be taken. If water is added to the monitoring well, it should be from an uncontaminated source and transported in a clean container. Bailers or measuring devices should be decontaminated prior to the test. If tests are performed on more than one monitoring well, care must be taken to avoid cross-contamination of the wells.

Slug tests should be conducted on relatively undisturbed wells. If a test is conducted on a well that has recently been pumped for water sampling purposes, the measured water level must be within 0.1 foot of the static water level prior to sampling. At least 1 week should elapse between the drilling of a well and the performance of a slug test.

8.7.2 Post Operation

When using an electronic data-logger, use the following procedure:

1. Stop logging sequence.
2. Print data.
3. Send data to computer by telephone.
4. Save memory and disconnect battery at the end of the day's activities.
5. Review field forms for completeness.

8.8 CALCULATIONS

The simplest interpretation of piezometer recovery is that of Hvorslev (1951). The analysis assumes a homogenous, isotropic medium in which soil and water are incompressible. Hvorslev's expression for hydraulic conductivity (K) is:

$$K = \frac{r^2 \ln(L/R)}{2LT_o}$$

for L/R > 8

where:

K = hydraulic conductivity [feet/second]
r = casing radius [feet]
L = length of open screen (or open borehole) [feet]
R = filter pack (borehole) radius [feet]
T_o = Basic Time Lag [seconds]; value of t on semilogarithmic plot of $(H-h)/(H-H_o)$ vs. t, when $(H-h)/(H-H_o) = 0.37$

where:

H = initial water level prior to removal of slug
H_o = water level at t = 0
h = recorded water level at t> 0

(Hvorslev, 1951; Freeze and Cherry, 1979)

The Bower and Rice method is also commonly used for K calculations. However, it is much more time consuming than the Hvorslev method. Refer to Freeze and Cherry or Fetter for a discussion of these methods.

8.9 QUALITY ASSURANCE/ QUALITY CONTROL

The following general quality assurance procedures apply:

- All data must be documented on standard chain of custody forms, field data sheets, or within personal/site logbooks.
- All instrumentation must be operated in accordance with operating instructions as supplied by the manufacturer, unless otherwise specified in the work plan. Equipment checkout and calibration activities must occur prior to sampling/operation, and they must be documented.

The following specific quality assurance activity will apply:

- Each well should be tested at least twice in order to compare results.

be used to record observations. The slug test data form should include the following information:

- site ID -- identification number assigned to the site
- location ID -- identification of location being tested
- date -- the date when the test data were collected in this order: year, month, day (e.g., 900131 for January 31, 1990)
- slug volume (ft^3) = manufacturer's specification for the known volume or displacement of the slug device
- logger -- identifies the company or person responsible for performing the field measurements
- test method -- the slug device either is injected or lowered into the well, or is withdrawn or pulled-out from the monitor well. Check the method that is applicable to the test situation being run.
- comments -- appropriate observations or information for which no other blanks are provided.
- elapsed time (minutes) -- cumulative time readings from beginning of test to end of test, in minutes
- depth to water (feet) -- depth to water recorded in tenths of feet

The following general procedures may be used to collect and report slug test data. These procedures may be modified to reflect site-specific conditions:

1. Decontaminate the transducer and cable.

2. Make initial water level measurements on monitoring **wells** in an upgradient-to-downgradient sequence, if possible, to minimize the potential for cross-contamination.

3. Before beginning the slug test, record information into the electronic data-logger. The type of information may vary depending on the model used. When using different model, consult the operator's manual for the proper data entry sequence to be used.

4. Test wells from least contaminated to most contaminated, if possible.

5. Determine the static water level in the well by measuring the depth to water periodically for several minutes and taking the averagc of the readings, (see SOP #2151, Water Level Measurement).

6. Cover sharp edges of the well casing with duct tape to protect the transducer cables.

7. Install the transducer and cable in the well to a depth below the target drawdown estimated for the test but at least 2 feet from the bottom of the well. Be sure the depth of submergence is within the design range stamped on the transducer. Temporarily tape the transducer cable to the well to keep the transducer at a constant depth.

8. Connect the transducer cable to the electronic data-logger.

9. Enter the initial water level and transducer design range into the recording device according to the manufacturer's instructions. The transducer design range will be stamped on the side of the transducer. Record the initial water level on the recording device.

10. "Instantaneously" introduce or remove a known volume or slug of water to the well. Another method is to introduce a solid cylinder of known volume to displace and raise the water level, allow the water level to restabilize and remove the cylinder. It is important to remove or add the volumes as quickly as possible because the analysis assumes an "instantaneous" change in volume is created in the well.

11. Consider the moment of volume addition or removal as time zero. Measure and record the depth to water and the time at each reading. Depths should be measured to the nearest 0.01 foot. The number of depth-time measurements necessary to complete the test is variable. It is critical to make as many measurements as possible in the early part of the test. The number and intervals between measurements will be determined from previous aquifer tests or evaluations.

12. Continue measuring and recording depth-time measurements until the water level returns to equilibrium conditions or a sufficient number of readings have been made to clearly show a trend on a semilogarithmic plot of time versus depth.

13. Retrieve slug (if applicable).

8.0 SLUG TEST: SOP #2158

8.1 SCOPE AND APPLICATION

This procedure can determine the horizontal hydraulic conductivity of distinct geologic horizons under in situ conditions. The hydraulic conductivity (K) is an important parameter for modeling the flow of groundwater in an aquifer.

8.2 METHOD SUMMARY

A slug test involves the instantaneous injection of a slug (a solid cylinder of known volume) or withdrawal of a volume of water. A slug displaces a known volume of water from a well and measures the artificial fluctuation of the groundwater level.

There are several advantages to using slug tests to estimate hydraulic conductivities. First, estimates can be made in situ, thereby avoiding errors incurred in laboratory testing of disturbed soil samples. Second, compared with pump tests, slug tests can be performed quickly and at relatively low cost, because pumping and observation wells are not required. And last, the hydraulic conductivity of small discrete portions of an aquifer can be estimated (e.g., sand layers in a clay).

8.3 SAMPLE PRESERVATION, CONTAINERS, HANDLING, AND STORAGE

This section is not applicable to this Standard Operating Procedure (SOP).

8.4 INTERFERENCES AND POTENTIAL PROBLEMS

- Only the hydraulic conductivity of the area immediately surrounding the well is estimated, which may not be representative of the average hydraulic conductivity of the area.
- The storage coefficient, S, usually cannot be determined by this method.

8.5 EQUIPMENT/APPARATUS

The following equipment is needed to perform slug tests. All equipment which comes in contact with the well should be decontaminated and tested prior to commencing field activities.

- tape measure (subdivided into tenths of feet)
- water pressure transducer
- electric water level indicator
- weighted tapes
- steel tape (subdivided into tenths of feet)
- electronic data-logger (if transducer method is used)
- stainless steel slug of a known volume
- watch or stopwatch with second hand
- semilogarithmic graph paper (if required)
- waterproof ink pen and logbook
- thermometer
- appropriate references and calculator
- electrical tape
- 21X micrologger
- Compaq portable computer or equivalent with Grapher installed on the hard disk

8.6 REAGENTS

No chemical reagents are used in this procedure; however, decontamination solvents may be necessary. When decontaminating the slug or equipment, refer to ERT SOP #2006, Sampling Equipment Decontamination, and the site-specific work plan.

8.7 PROCEDURES

8.7.1 Field Procedures

When the slug test is performed using an electronic data-logger and pressure transducer, all data will be stored internally or on computer diskettes or tape. The information will be transferred directly to the main computer and analyzed. Keep a computer printout of the data in the files as documentation.

If the slug test data is collected and recorded manually, the slug test data form (Appendix C) will

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6. Interpret pumping/recovery test field results.

7.8 CALCULATIONS

There are several accepted methods for determining aquifer properties such as transmissivity, storativity, and conductivity. However, the method to use is dependent on the characteristics of the aquifer being tested (confined, unconfined, leaky confining layer, etc.). When reviewing pump test data, texts by Fetter, or Driscoll or Freeze and Cherry may be used to determine the method most appropriate to your case. See the reference section on page 69.

7.9 QUALITY ASSURANCE/ QUALITY CONTROL

Calibrate all gauges, transducers, flow meters, and other equipment used in conducting pumping tests before use at the site.

Obtain records of the instrument calibration and file with the test data records. The calibration records will consist of laboratory measurements. If necessary, perform any on-site zero adjustment and/or calibration. Where possible, check all flow and measurement meters on-site using a container of measured volume and stopwatch; the accuracy of the meters must be verified before testing proceeds.

7.10 DATA VALIDATION

This section is not applicable to this SOP.

7.11 HEALTH AND SAFETY

When working with potentially hazardous materials, follow U.S. EPA, OSHA, and specific health and safety procedures.

2. Location -- The location of the well in which water level measurements are being taken.

3. Distance from Pumped Well -- Distance between the observation well and the pumping well in feet.

4. Logging Company -- The company conducting the pumping test.

5. Test Start Date -- The date when the pumping test began.

6. Test Start Time -- Start time, using a 24hour clock.

7. Static Water Level (Test Start) -- Depth to water, in feet and tenths of feet, in the observation well at the beginning of the pumping test.

8. Test End Date -- The date when the pumping test was completed.

9. Test End Time -- End time, using a 24hour clock.

10. Static Water Level (Test End) -- Depth to water, in feet and tenths of feet, in the observation well at the end of the pumping test.

11. Average Pumping Rate -- Summation of all entries recorded in the Pumping Rate (gal/min) column divided by the total number of Pumping Rate (gal/min) readings.

12. Measurement Methods -- Type of instrument used to measure depth-to-water (this may include steel tape, electric sounding probes, Stevens recorders, or pressure transducers).

13. Comments -- Appropriate observations or information which have not been recorded elsewhere, including notes on sampling.

14. Elapsed Time (min) -- Time of measurement recorded continuously from start of test (time 00.00).

15. Depth to Water (ft) -- Depth to water, in feet and tenths of feet, in the observation well at the time of the water level measurement.

16. Pumping Rate (gal/min) -- Plow rate of pump measured from an orifice, weir, flow meter, container or other type of water-measuring device.

Test Duration

The duration of the test is determined by the needs of the project and properties of the aquifer. One simple test for determining adequacy of data is when the log-time versus drawdown for the most distant observation well begins to plot as a straight line on the semilogarithmic graph paper. There are several exceptions to this simple rule of thumb, therefore, it should be considered a minimum criterion. Different hydrogeologic conditions can produce straight line trends on log-time versus drawdown plots. In general, longer tests produce more definitive results. A duration of 1 to 3 days is desirable, followed by a similar period of monitoring the recovery of the water level. Unconfined aquifers and partially penetrating wells may have shorter test durations. Knowledge of the local hydrogeology, combined with a clear understanding of the overall project objectives, is necessary in interpreting just how long the test should be conducted. There is no need to continue the test if the water level becomes constant with time. This normally indicates that a hydrogeologic source has been intercepted and that additional useful information will not be collected by continued pumping.

7.7.6 Post Operation

1. After completion of water level recovery measurements, decontaminate and/or dispose of equipment as per ERT SOP #2006, Sampling Equipment Decontamination.

2. When using an electronic data-logger, use the following procedures.

   - Stop logging sequence.
   - Print data, or save memory and disconnect battery at the end of the day's activities.

3. Replace testing equipment in storage containers.

4. Check sampling equipment and supplies. Repair or replace all broken or damaged equipment.

5. Review field forms for completeness.

APPENDIX B

HNU Field Protocol

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HNU Field Protocol
SOP #2149

Startup Procedure

1. Before attaching the probe, check the function switch on the control panel to ensure that it is in the 'off position. Attach the probe by plugging it into the interface on the top of the readout module. Use care in aligning the prongs in the probe cord with the plug in; do not force.

2. Turn the function switch to the battery check position. The needle on the meter should read within or above the green area on the scale. If not, recharge the battery. If the red indicator light comes on, the battery needs recharging.

3. Turn the function switch to any range setting. For no more than 2 to 3 seconds look into the end of the probe to see if the lamp is on. If it is on, you will see a purple glow. Do not stare into the probe any longer than three seconds. Long term exposure to UV light can damage eyes. Also, listen for the hum of the fan motor.

4. To zero the instrument, turn the function switch to the standby position and rotate the zero adjustment until the meter reads zero. A calibration gas is not needed since this is an electronic zero adjustment. If the span adjustment setting is changed after the zero is set, the zero should be rechecked and adjusted, if necessary. Wait 15 to 20 seconds to ensure that the zero reading is stable. If necessary, readjust the zero.

Operational Check

1. Follow the startup procedure.

2. With the instrument set on the 0-20 range, hold a solvent-based Magic Marker near the probe tip. If the meter deflects upscale, the instrument is working.

Field Calibration Procedure

1. Follow the startup procedure and the operational check.

2. Set the function switch to the range setting for the concentration of the calibration gas.

3. Attach a regulator (HNU 101-351) to a disposable cylinder of isobutylene gas. Connect the regulator to the probe of the HNU with a piece of clean Tygon tubing. Turn the valve on the regulator to the 'on' position.

4. After 15 seconds, adjust the span dial until the meter reading equals the concentration of the calibration gas used. The calibration gas is usually 100 ppm of isobutylene in zero air. The cylinders are marked in benzene equivalents for the 10.2 eV probe (approximately 55 ppm benzene equivalent) and for the 11.7 eV probe (approximately 65 ppm benzene equivalent). Be careful to unlock the span dial before adjusting it. If the span has to be set below 3.0 calibration, the lamp and ion chamber should be inspected and cleaned as appropriate. For cleaning of the 11.7 eV probe, only use an electronic-grade, oil-free freon or similar water-free, grease-free solvent.

5. Record in the field log: the instrument ID # (EPA decal or serial number if the instrument is a rental); the initial and final span settings; the date and time; concentration and type of calibration used; and the name of the person who calibrated the instrument.

Operation

1. Follow the startup procedure, operational check, and calibration check.

2. Set the function switch to the appropriate range. If the concentration of gases or vapors is unknown, set the function switch to the 0-20 ppm range. Adjust it if necessary.

3. While taking care not to permit the HNU to be exposed to excessive moisture, dirt, or contamination, monitor the work activity as specified in the site health and safety plan.

4. When the activity is completed or at the end of the day, carefully clean the outside of the HNU with a damp disposable towel to remove any

visible dirt. Return the HNU to a secure area and place on charge.

5. With the exception of the probe's inlet and exhaust, the HNU can be wrapped in clear plastic to prevent it from becoming contaminated and to prevent water from getting inside in the event of precipitation.

APPENDIX C

Forms

Well Completion Form

SOP #2150

MONITOR WELL INSTALLATION

Client: ______ Job No.: ______ Date Drilled: ______ Well No.: ______

Site: ______ Elevation Pad ______ Top of Steel Casing: ______

Total Depth: ______ Casing Size & Type: ______ Screen Size: ______

Comments: ______

Depth	Symbol Stratigraphy	Sample Description	Completion Data

Groundwater Level Data Form

SOP #2151 PAGE-OF-

SITE NAME:	
LOG DATE:	LOGGER NAME:
MEASUREMENT REFERENCE POINT: -TOP OF GROUND -TOP OF CASING	

LOCATION	TIME	DEPTH TO WATER (FT)	COMMENTS

Pump/Recovery Test Data Sheet

SOP #2157 PAGE-OF-

SITE ID:	DISTANCE FROM PUMPED WELL (FT):
LOCATION:	LOGGER:
TEST START	TEST END
DATE:	DATE:
TIME:	TIME:
STATIC WATER LEVEL (FT):	STATIC WATER LEVEL (FT):
AVERAGE PUMPING RATE (GAL/MIN):	
MEASUREMENT METHODS:	
COMMENTS:	

ELAPSED TIME (MIN)	PUMP TEST DEPTH TO WATER (FT)	PUMPING RATE (GAL/MIN)	RECOVERY TEST ELAPSED TIME (MIN)	DEPTH TO WATER (FT)
0.00			0.00	

Pump/Recovery Test Data Sheet (Continued)

SOP #2157 PAGE-OF-

SITE ID:		DATE:		
LOCATION:		LOGGER:		
ELAPSED TIME (MIN)	PUMP TEST DEPTH TO WATER (FT)	PUMPING RATE (GAL/MIN)	RECOVERY TEST ELAPSED TIME (MIN)	DEPTH TO WATER (FT)

Slug Test Data Form

SOP #2158 PAGE-OF-

DATE:	
SITE ID:	SLUG VOLUME (FT^3):
LOCATION ID:	LOGGER:
TEST METHOD: _ SLUG INJECTION _ SLUG WITHDRAWAL	
COMMENTS:	

TIME (Begin Test #1):		TIME (Begin Test #2):	
TIME (End Test #1):		TIME (End Test #2):	
ELAPSED TIME (MIN)	DEPTH TO WATER (FT)	ELAPSED TIME (MIN)	DEPTH TO WATER (FT)

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