Groundwater Investigation and Remediation

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Hydrogeologic Frameworks

Unsaturated (Vadose) Zone

- The unsaturated zone is the region that overlies the saturated zone.
- Contaminants almost always pass through this region to get to an aquifer.
- Fluid moves in response to surface tension, capillarity, and gravity.
- The unsaturated zone is inhomogeneous.
- Accurate description of the geologic makeup of the unsaturated zone is difficult and requires substantial subsurface investigation.
- Four important processes that govern flow in the unsaturated zone are:

  Hysteresis

  Macropore Flow

  Capillary Movement

  Darcian Flow

Saturated (Aquifer) Zone

- The saturated zone underlies the unsaturated zone and is completely saturated with water.
- Exist in several geologic environments.
- Igneous-Metamorphic: rocks are usually "dry" and don't yield much groundwater. Flow is primarily in fractures -- in some cases may be significant.
- Sedimentary: comprised of sediments and limestones. Groundwater more abundant than in igneous-metamorphic systems. Flow is between grains and voids, sometimes with significant fracture flow.
- Alluvial-Fluvial: shallow or deep basins filled with deposits transported by fluvial processes. Very abundant groundwater. Most systems are deposited in strata comprised of clay and sand beds. Geometry of the interbedding greatly influences flow behavior.

Groundwater Motion

- Discharge is proportional to driving energy (hydraulic gradient), cross sectional area (A), and ease of conductance (Hydraulic conductivity, K).
  $Q = -K A \text{ gradient(head)}$
- Formula is called Darcy's Law.
- Interstitial velocity can be estimated as
  $v = q/n$
  where n = porosity; q = specific discharge (Q/A)
- Transmissivity is ability of aquifer to transmit water through its entire thickness, $T=Kb$, where b is thickness.

Concepts of Environmental Investigations

- Collect data so that contamination extent is defined, and remediation can be designed.
- Site geology forms physical framework for groundwater and contaminant flow.
- Due to expenses involved the information must be as complete and accurate as possible for each borehole drilled -- depending on time, money, and site conditions.
- Sites are often small -- scale is different from traditional investigations -- looking at small areas in close detail.
- Searching for shallow water zones that are not usually used a water resources -- in general, nearly all information will be generated from the site geological study.
- Very small features are significant: strata several inches thick, animal burrows, root holes, cracks, decayed piping, foundation drains, etc.
- Field strategy is to conduct an investigation in traditional manner, but also include detailed description and quantification of very small features.

CONCEPTUAL APPROACH TO SITE INVESTIGATIONS

- SITE GEOLOGY FORMS FRAMEWORK FOR GROUNDWATER FLOW $\Rightarrow$ GEOLOGIC <u>MODEL</u> MUST DESCRIBE THE HYDROGEOLOGY ACCURATELY

- BOREHOLES ARE EXPENSIVE (1000^{00} SET-UP + 10^{00} PER FOOT)
  + ACCESS & REGULATIONS MAY LIMIT NUMBER THAT CAN BE PLACED

  $\Rightarrow$ INFORMATION MUST BE AS COMPLETE AND ACCURATE AS POSSIBLE

- SITE INVESTIGATIONS ARE <u>SMALL</u> SCALE COMPARED TO USGS "SIZE" STUDIES
  + STUDY VERY SMALL AREAS IN CLOSE DETAIL
  + SEARCHING FOR SHALLOW WATER ZONES

  $\Longrightarrow$ MOST INFORMATION WILL BE GENERATED FROM THE <u>SITE</u> STUDY

- SMALL FEATURES ARE SIGNIFICANT
  -- STRATA SEVERAL INCHES THICK
  -- CONTAMINANT PATHWAYS:
  ANIMAL BURROWS
  ROOT HOLES
  BURIED/CORRODED CONDUIT

- GENERAL APPROACH IS TO CONDUCT INVESTIGATION FOR A "USGS" SIZE STUDY, BUT ALSO CATALOG, DESCRIBE, AND QUANTIFY <u>SMALL-SCALE</u> FEATURES

- GATHER BACKGROUND DATA

  U.S.G.S.

  E.P.A.

  PREVIOUS SITE INVESTIGATIONS NEARBY

  LOCAL PLANNING OFFICES
  - SOIL ENGINEER STUDIES

  LOCAL WATER DISTRICTS
  - GROUNDWATER BASIN MANAGEMENT

  LOCAL HAZARDOUS WASTE AGENCIES

  FIRE DEPARTMENTS

Subsurface Exploration, Sampling, and Logging

Introduction

- Scope of work depends on project task: determination of presence of contamination, meeting reporting requirements, etc.
- Involves planning for work, scheduling, budgeting, and selecting appropriate equipment and personnel.

Program Approach

- Establish overall geologic setting.
- Define site hydrogeology, identify aquifer and aquitard units.
- Sample soil and groundwater at different depths and locations in both unsaturated and saturated zones for contaminant and geologic parameters.

Logistics

- Logistic problems will always occur in field work (Murphy's law)
- Project budget, site access, permits, site clearance, "surprises".
- Safety plan, worker protection based known and suspected hazards.
- Drilling contractor: experienced with method, experienced with monitoring well installation, and preferably experienced in region. -- In Texas must be a licensed monitor well or water well driller.
- Insurance or bonding -- professional liability.

- GEOLOGIC DATA COLLECTION GOALS
  (1) ESTABLISH OVERALL GEOLOGICAL SETTING
  (2) ALLOW DEFINITION OF SITE HYDROGEOLOGY, IDENTIFY AQUIFER UNITS, AQUITARD UNITS
  (3) COLLECT "SOIL" SAMPLES AT DISCRETE DEPHTS AND LOCATIONS TO BE ANALYZED FOR CONTAMINANT, GEOLOGIC, AND ENGINEERING PROPERTIES
  (4) COLLECT "SUBSURFACE" WATER SAMPLES FROM BOTH UNSATURATED AND SATURATED ZONES FOR CONTAMINANT AND GEOCHEMICAL PROPERTIES

- ESTIMATE NUMBER AND POSITION OF BORINGS AND MONITOR WELLS, AND SAMPLING PLAN TO ACHIEVE THESE GOALS WITHIN THE GIVEN BUDGET.

- DRILLING SERVICES
  - LISCENCED DRILLER
  - SITE ACCESS
  - PERMITS
  - SITE CLEARANCE
  - "SUPRISES"
  - INSURANCE
  - SAFETY PLANS
  - UTILITY LINES

Drilling and Sampling-Introduction

- Techniques chosen based on site access, data needs, formation type, and regulatory requirements.
- Field work is not easy or simple -- need experience.

Decontamination Procedures

- Purpose is to clean equipment to prevent cross contamination between boreholes.
- If neglected, data will be challenged.

Drilling Methods

- Auger (Dry) Drilling
- Common, fast, economical to 100' in alluvium.
- Solid-Stem Augers; "flights" attached to solid stem, drill string must be lifted for sample recovery.
- Hollow-Stem Augers; "flights" attached to hollow stem, samples recovered through hollow annulus in stem without removing entire drill string.
- Rotary (Wet) Drilling
- Common, effective, technique for 100' and deeper. Drilling fluid interferes with water identification, but continuous logs possible using wire-line logging tools. Cuttings can be logged by a competent exploration geologist very quickly.
- Cable (Percussion) Drilling
- Slow, but can penetrate any formation. Considered a "dry" method although some slurry is generated.

Problems

- Swelling formation.
- Caving formation.
- Flowing sand.
- Boulders.

- DECONTAMINATION IS REQUIRED FOR QUALITY ASSURANCE

  1) DECONTAMINATION AREA
     - CLOSE TO STUDY AREA
     - WEATHER
     - SECURITY

  2) UTILITIES
     - POWER
     - WATER

  3) FLUIDS & CUTTINGS
     - DISPOSAL PERMITS

  4) ALL DRILLING & WELL COMPLETION MATERIALS MUST BE CLEANED BEFORE ENTERING SITE

  5) HAND WASHING - SMALL TOOLS
     MECHANICAL WASHING - LARGE TOOLS & VEHICLES

- EXPLORATION METHODS

  AUGER DRILLING - DRY

  WET ROTARY

  PERCUSSION

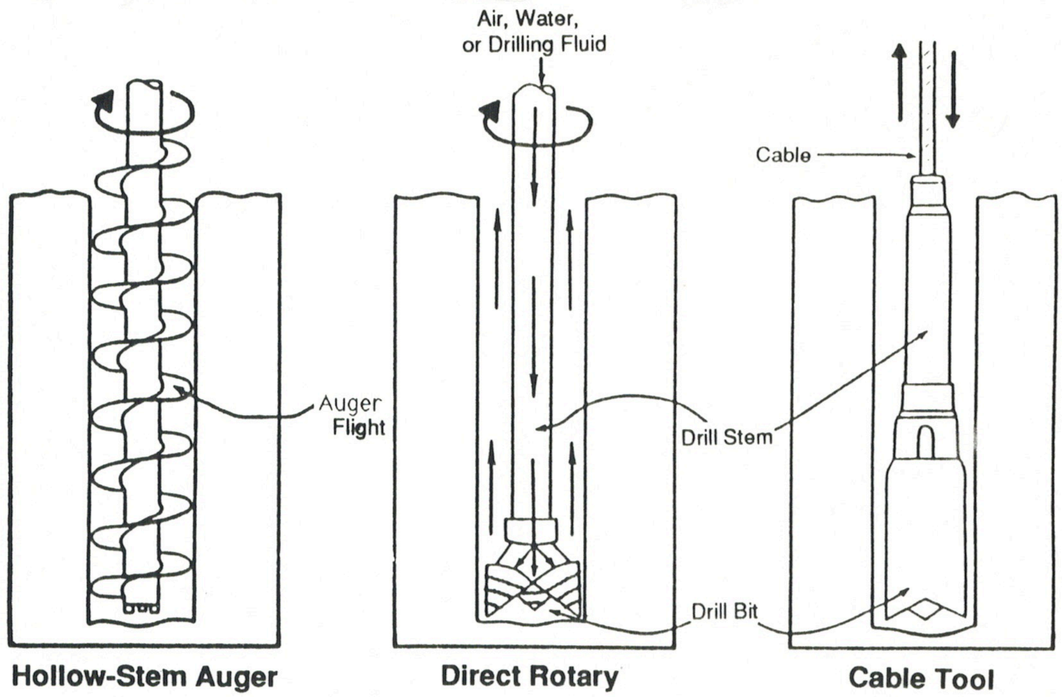
- "SOIL" SAMPLING

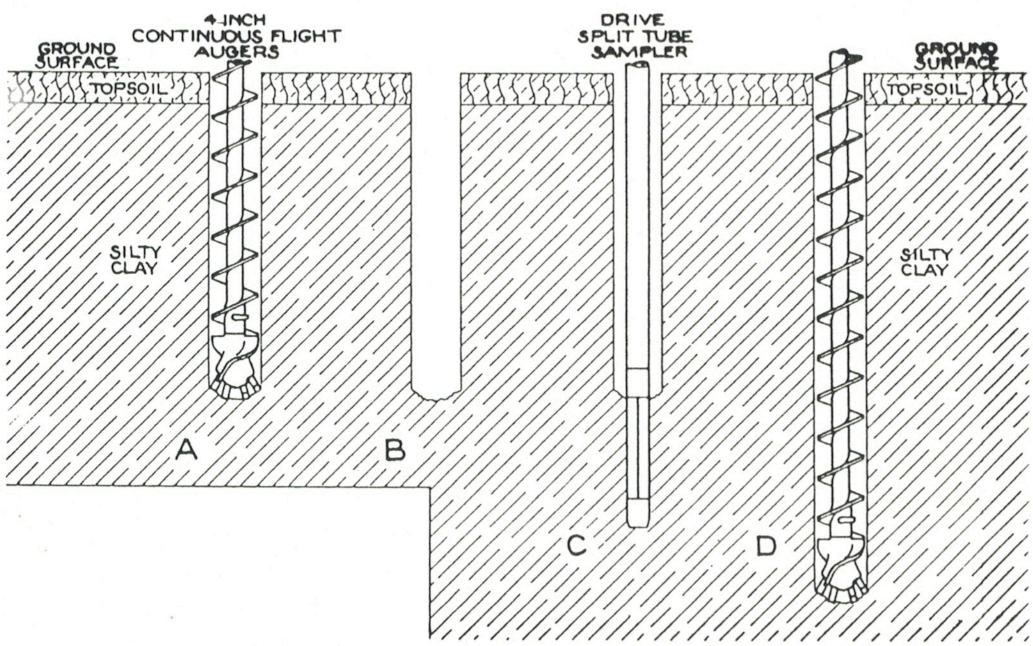
  SOIL RECOVERY PROBES

  SHELBY (THIN-TUBE)

  SPLIT-SPOON

  PISTON CORE


Air, Water,
or Drilling Fluid
Cable
Auger
Flight
Drill Stem
Drill Bit
Hollow-Stem Auger
Direct Rotary
Cable Tool


4-INCH
CONTINUOUS FLIGHT
AUGERS
GROUND
SURFACE
TOPSOIL
DRIVE
SPLIT TUBE
SAMPLER
GROUND
SURFACE
TOPSOIL
SILTY
CLAY
SILTY
CLAY
A
B
C
D

Advantages and Disadvantages of Auger, Rotary, and Cable Tool Drilling

Type	Advantages	Disadvantages
Auger	• Minimal damage to aquifer • No drilling fluids required • Auger flights act as temporary casing, stabilizing hole for well construction • Good technique for unconsolidated deposits • Continuous core can be collected by wire-line method	• Cannot be used in consolidated deposits • Limited to wells less than 150 ft in depth • May have to abandon holes if boulders are encountered
Rotary	• Quick and efficient method • Excellent for large and small diameter holes • No depth limitations • Can be used in consolidated and unconsolidated deposits • Continuous core can be collected by wire-line method	• Requires drilling fluids, which alter water chemistry • Results in a mud cake on the borehole wall, requiring additional well development, and potentially causing changes in chemistry • Loss of circulation can develop in fractured and high-permeability material • May have to abandon holes if boulders are encountered
Cable Tool	• No limitation on well depth • Limited amount of drilling fluid required • Can be used in both consolidated and unconsolidated deposits • Can be used in areas where lost circulation is a problem • Good lithologic control • Effective technique in boulder environments	• Limited rigs and experienced personnel available • Slow and inefficient • Difficult to collect core

Source: EPA (1989).

- BOREHOLE LOGGING

  ENGINEERING PROPERTIES — USCS, FIELD TESTS

  GEOLOGIC PROPERTIES — DESCRIPTIVE

  IN SITE SURVEY **BOTH** TYPES OF LOGS MUST BE INCLUDED

  SUGGESTED PROCEDURE

  1) DRIVE SAMPLER, RECORD BLOW COUNT OR PULL DOWN FORCE

  2) REMOVE SAMPLE IN CORRECT ORIENTATION, PACKAGE SAMPLES FOR CHEMICAL ANALYSIS

  3) LOG THE SAMPLE, PERFORM FIELD TESTS:

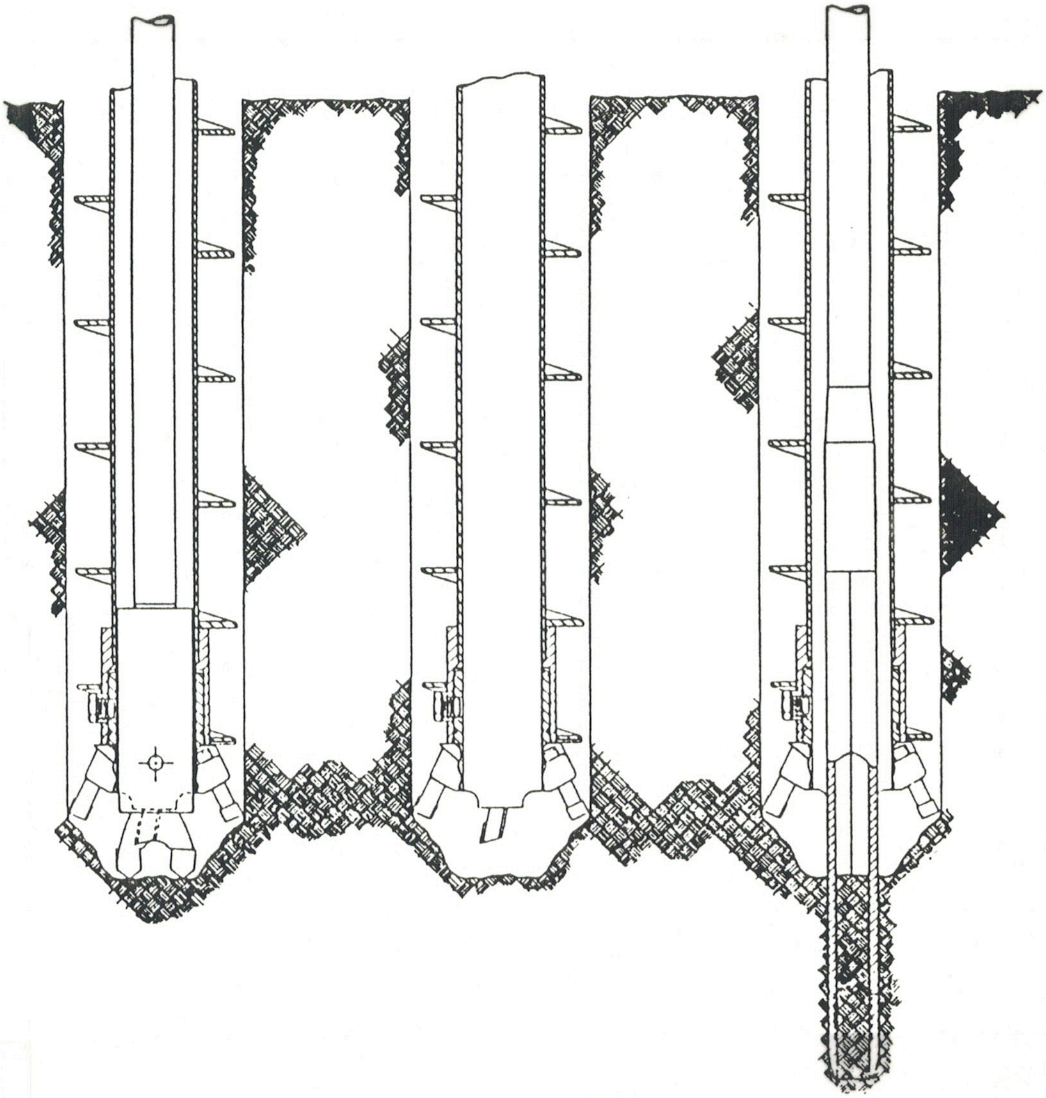
     -- TEXTURE (USCS)
     -- COLOR (MUNSELL)
     -- CONSTITUENTS (SAND/SILT/CLAY)
     -- PLASTICITY
     -- BEDDING
     -- BIOGENIC STRUCTURES
     -- CHEMICAL VAPORS
     -- STAINING
     -- CONSISTENCY } ASTM OR FIELD PENETROMETER
     -- DENSITY } AND SHEAR VANE
     -- RELATIVE MOISTURE (DAMP, MOIST ...)
     -- FRACTURING
     -- OTHER FEATURES

  - <u>ALWAYS LOG IN SAME ORDER</u>

  - SMALL TAPE RECORDERS ARE USEFUL, BUT BEWARE OF MACHINERY NOISE

- GROUNDWATER IN EXPLORATORY BORING
  - ALWAYS COLLECT SOIL SAMPLE IF WATER IS EXPECTED AT INTERVAL OF INTEREST
  - LOG RATES OF ADVANCE OR DRILLING RESISTANCE
    - RATES DECREASE WITH INCREASED MOISTURE
  - INCREASING RELATIVE MOISTURE MAY IMPLY APPROACHING AQUIFER CONTACT
  - WHEN DRILLING THROUGH SATURATED UNIT COLLECT FREQUENT SOIL SAMPLES TO LOCATE "DRY" AQUITARD BENEATH UNIT

    —— IMPORTANT TO PREVENT CROSS CONTAMINATION ——
  - COMMUNICATE WITH THE DRILLERS
  - ONCE WATER IS ENCOUNTERED, PROCEED SLOWLY.
  - MEASURE DEPTH TO WATER WHEN FIRST ENCOUNTERED – FOR LATER COMPARISION
  - PERFORM PACKER TESTS TO ISOLATE UNITS
    - ESPECIALLY IMPORTANT IN FRACTURED SYSTEMS



Monitoring Well Installation

Introduction

- Groundwater monitoring wells are data collection points for groundwater investigation.
- Are located and constructed to collect representative samples of groundwater quality and piezometeric data; design should reflect site-specific hydrogeologic environment.

Filter Pack

- Artificial filter pack is used when native materials cannot be used.
- Filter pack stabilizes the formation and allows water entry into the well.

Well Casing

- Material selection depends on budget and corrosion environment.
- Teflon, stainless steel, and PVC type 1 are common choices.

Well Screens

- Screen length depends on formation and contamination condition.
- Screen serves to increase well yield and efficiency.
- Allow for observation and capture of contaminants.
- Useful during seasonal groundwater variations.
- Used to perform aquifer tests for characterizing hydraulic properties.

Annular Seals

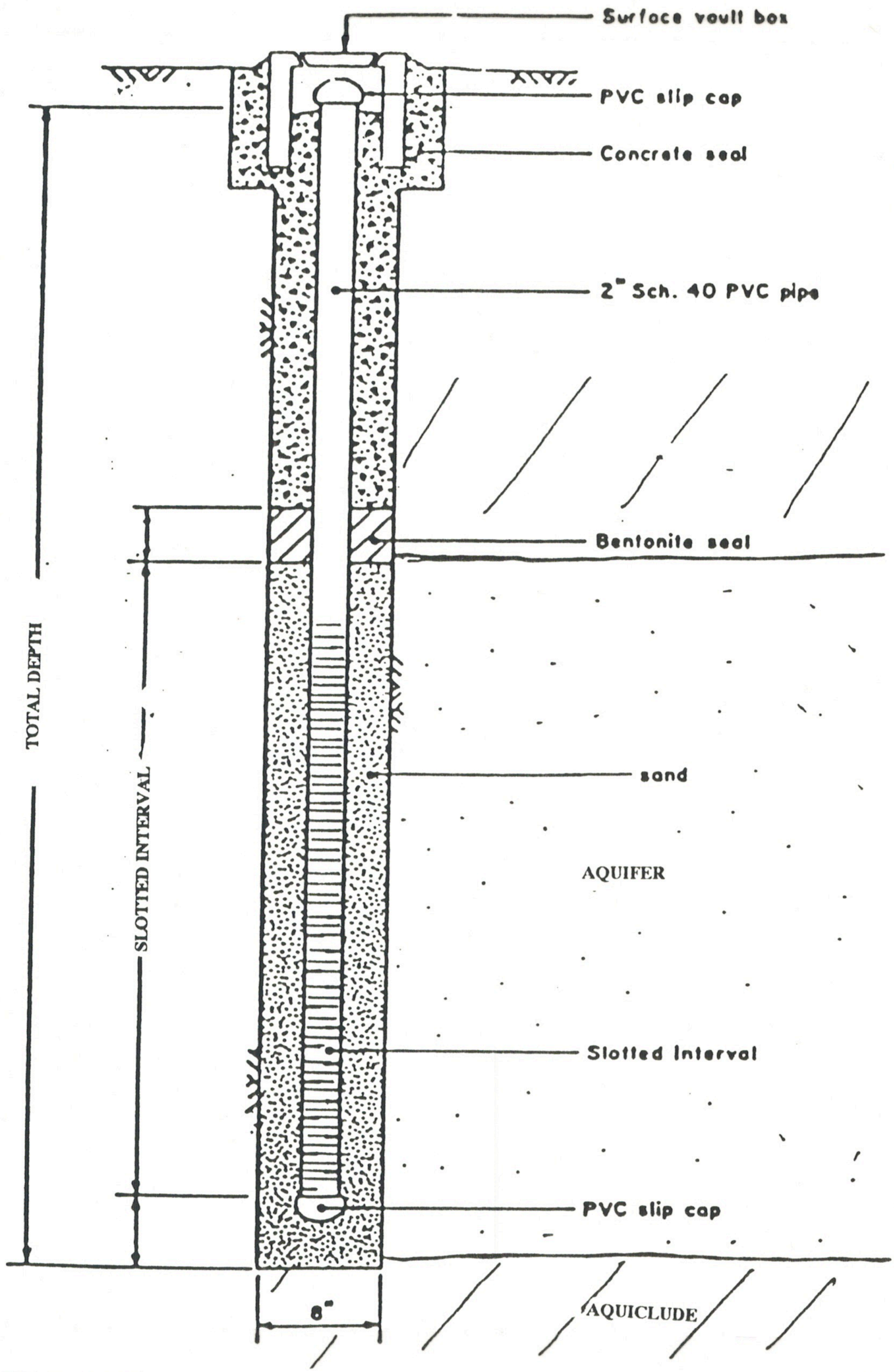
- Well annulus must be sealed to isolate the screened interval and to prevent contaminants from entering the well directly down the borehole.

Surface Completion

- Provides ground surface access and security at the wellhead.

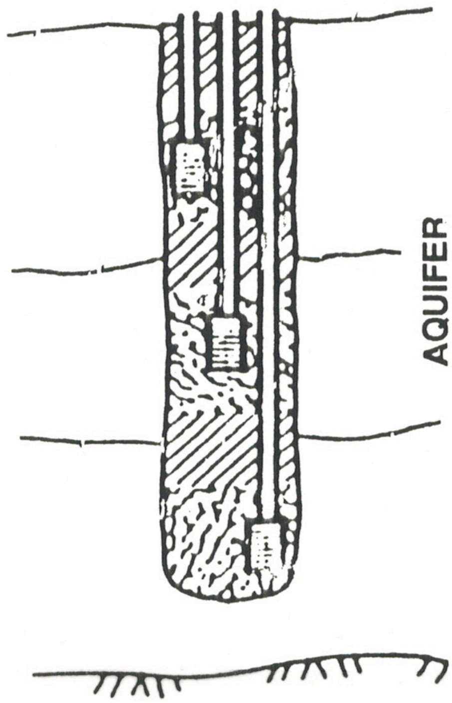
Well Development

- Clear suspended particles from the water column.
- Remove mud cake and smear from borehole walls.
- Grades the sand pack to improve contact with the aquifer.
- Provides hydraulic connection between casing and aquifer.
- Wells are developed by bailing and surging, or jetting.

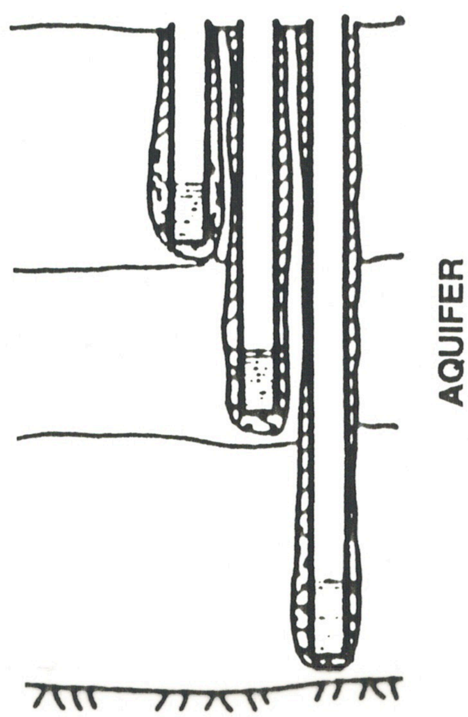


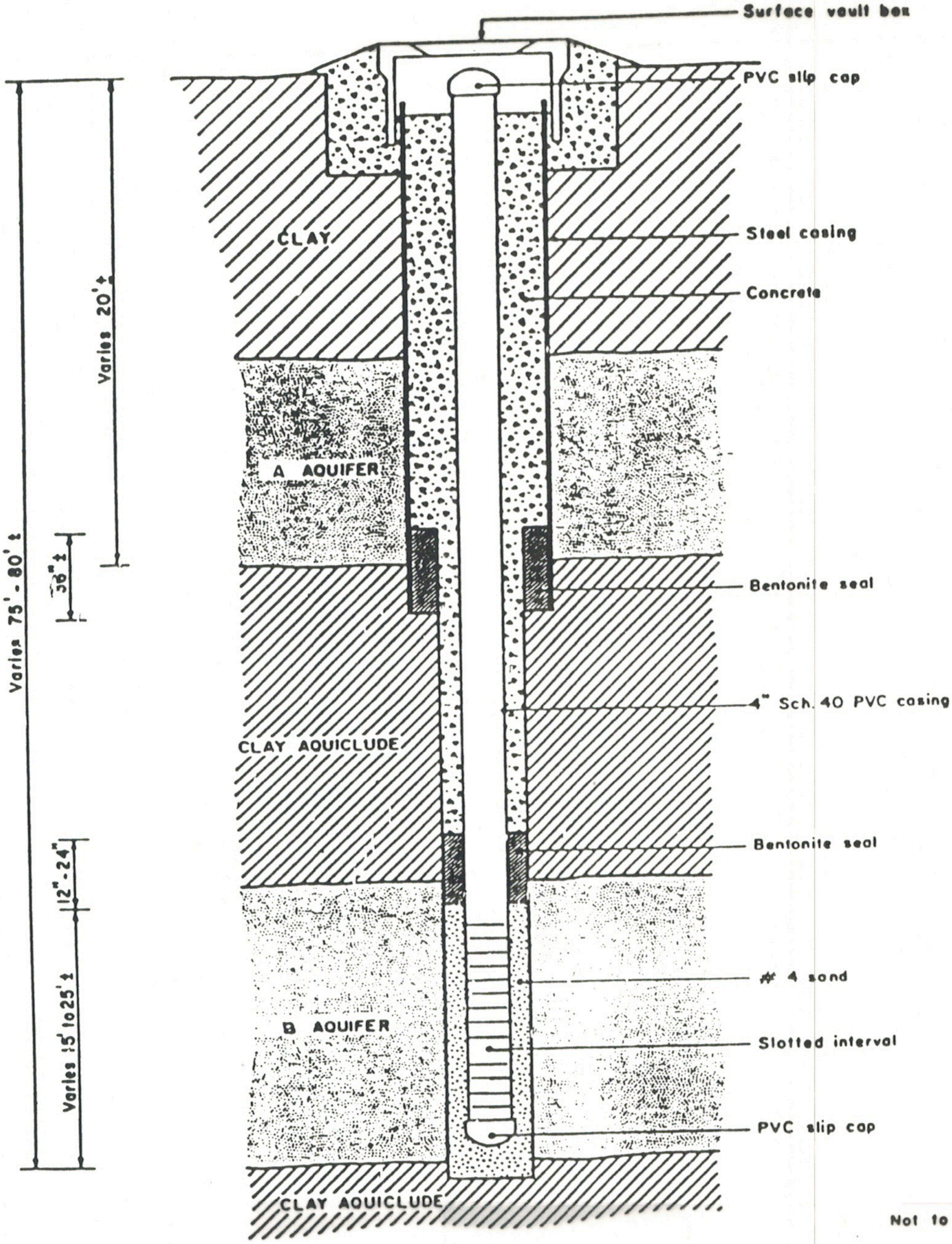
Surface vault box
PVC slip cap
Concrete seal
2" Sch. 40 PVC pipe
Bentonite seal
sand
AQUIFER
Slotted Interval
PVC slip cap
AQUICLUDE
8"
TOTAL DEPTH
SLOTTED INTERVAL

Single Borehole Well Nest



Multiple Borehole Well Nest





Surface vault box
PVC slip cap
Steel casing
Concrete
Bentonite seal
4" Sch. 40 PVC casing
Bentonite seal
4 sand
Slotted interval
PVC slip cap
CLAY
A AQUIFER
CLAY AQUICLUDE
B AQUIFER
CLAY AQUICLUDE
Varies 20'±
Varies 75'-80'±
36"±
12"-24"
Varies 15' to 25'±

Not to scale

Groundwater Sampling

Introduction

- Groundwater monitoring well sampling is one important task performed in a subsurface investigation.
- Care and quality control must be exercised during sample collection.
- Ascertain whether or not a contamination problem is present.
- Quantify magnitude of problem based on chemical data.
- Sampling must accurately define aquifer hydrogeochemistry.

Sampling Protocols

- Sampling plans and procedures are prepared prior to field work.
- A high level of care must be exercised regardless of project size.
- Subsurface data may be legally challenged -- Use industry/regulatory standards.
- Numerous guidance documents can be used.
- Basic plan provides for: collecting information related to project; define collection procedures; data management through proper paperwork; establish "chain of custody" procedures; and develop data collection forms.
- Goal is to develop a project database to monitor groundwater elevation, flow direction, and chemical evolution.

Laboratories

- Selection of analytical laboratory is as important as sampling plan.
- Use EPA methods.
- Use specialty analyses if needed.
- May need to use more than one lab.
- Rapid shipment of samples.
- Use same lab(s) for duration of project.

Quality Assurance/Quality Control (QA/QC)

- Procedures to obtain field data for water quality in an accurate, precise, and complete manner.
- Information that is accurate and representative of actual field conditions.
  - Accuracy: the degree of agreement of a measurement with respect to an accepted, referenced, or true value.
  - Precision: a measure of agreement among individual measurements under similar conditions. Expressed in terms of standard deviation.
  - Completeness: the amount of valid data obtained from a measurement system compared to the amount that was expected to meet project data goals.
  - Comparability: the confidence with which one data set can be compared to another.
  - Representativeness: a sample or group of samples that reflects the characteristics of the media or water quality at the sampling point; also how well the sampling point represents the actual parameter variations under consideration.
- Suggested procedures in government guidance documents and regulations of various federal, state, and local agencies.

Sample Bias

- Sampling bias may be difficult to detect.
- QA/QC to prevent field errors from affecting laboratory results.
- Bias from numerous sources: improper collection methods, analytical errors, "Murphy's Law".
- Sample blanks to detect bias and laboratory errors.
- Typically 5%-10% of samples in an analytical program are used.
    - <u>Trip blanks</u> are used for purgeable organic compounds only. They are sent to the project site and travel with collected samples. Trip blanks are not opened and are returned and analyzed with the project samples.
    - <u>Field blanks</u> are prepared with organic free water. These samples accompany the project samples to the laboratory and are analyzed for specific chemical parameters unique to the site at which they were prepared.

- Duplicates are collected as "second samples" from a selected well and/or project site. They are collected as either split samples (collected from the same collector tool) or as second-run samples (separate collections) from the same well.
- Equipment blanks are collected from the field equipment rinseate as a check for decontamination thoroughness.

Sample Collection

Preliminary Steps

- Prepare sampling data forms.
- Sampling plan: sample from least to most contaminated well -- to reduce possibility of cross contamination.
- On arrival, clean and decontaminate sampling equipment.
- Record time, date, site conditions, etc.
- Take bolt cutters in case access keys are lost, It is far cheaper to cut locks and replace than to return to office to find keys!

Purging the Well

- Calculate purge volume -- usually three to five borehole volumes.
- Low rate purging preferred, but takes time.
- Measure physical parameters; pH, temp., conductivity, DO. Parameters tend to stabilize when formation water is being drawn.
- When formation water is drawn, begin collecting sample.

Collecting the Sample

- Collect sample according to appropriate technique.
- Avoid agitation to prevent loss of low vapor pressure contaminants in the sample.
- Log sample into notes and on chain of custody form.
- Decontaminate equipment and sample next well -- sample from least contaminated to most contaminated well.

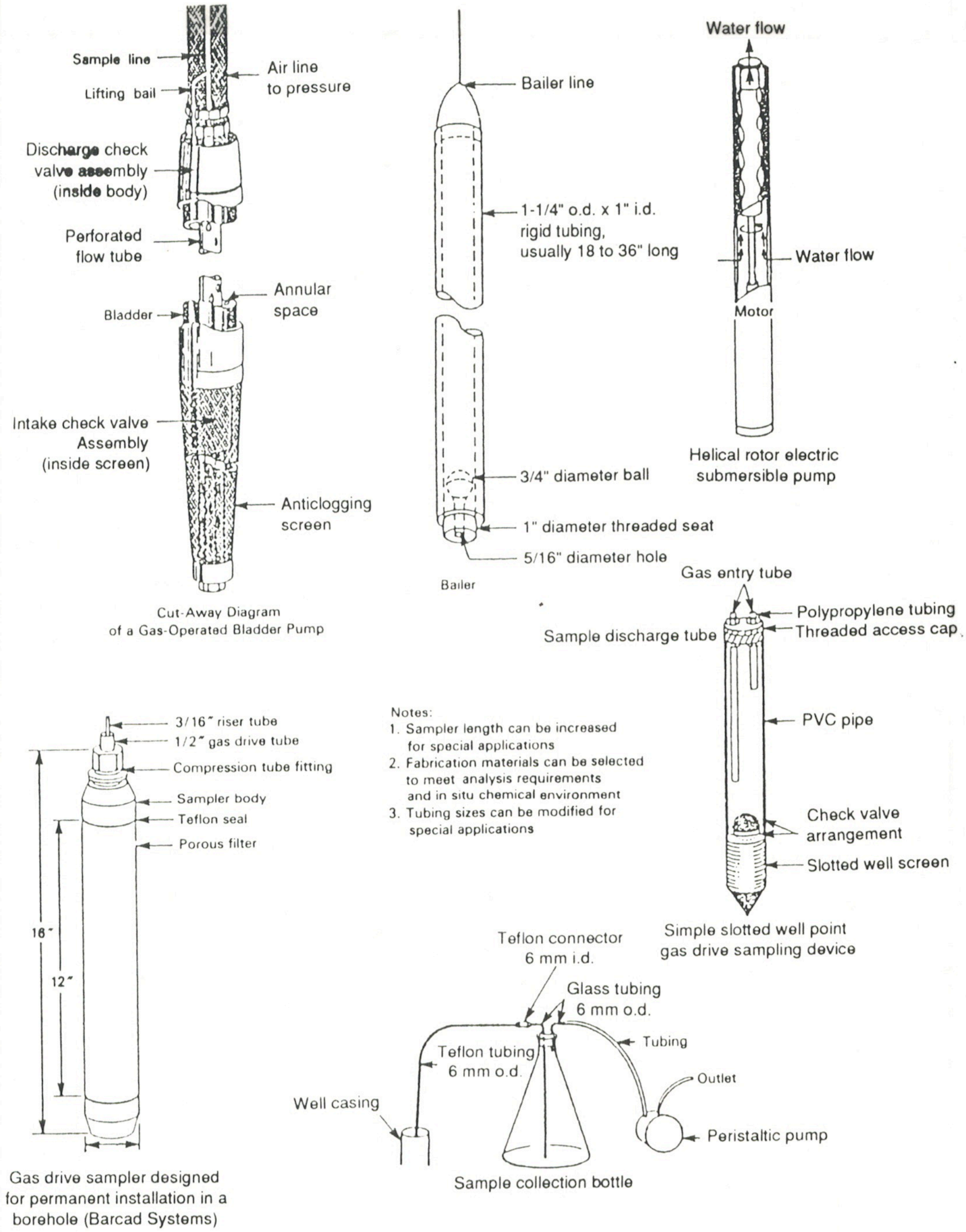


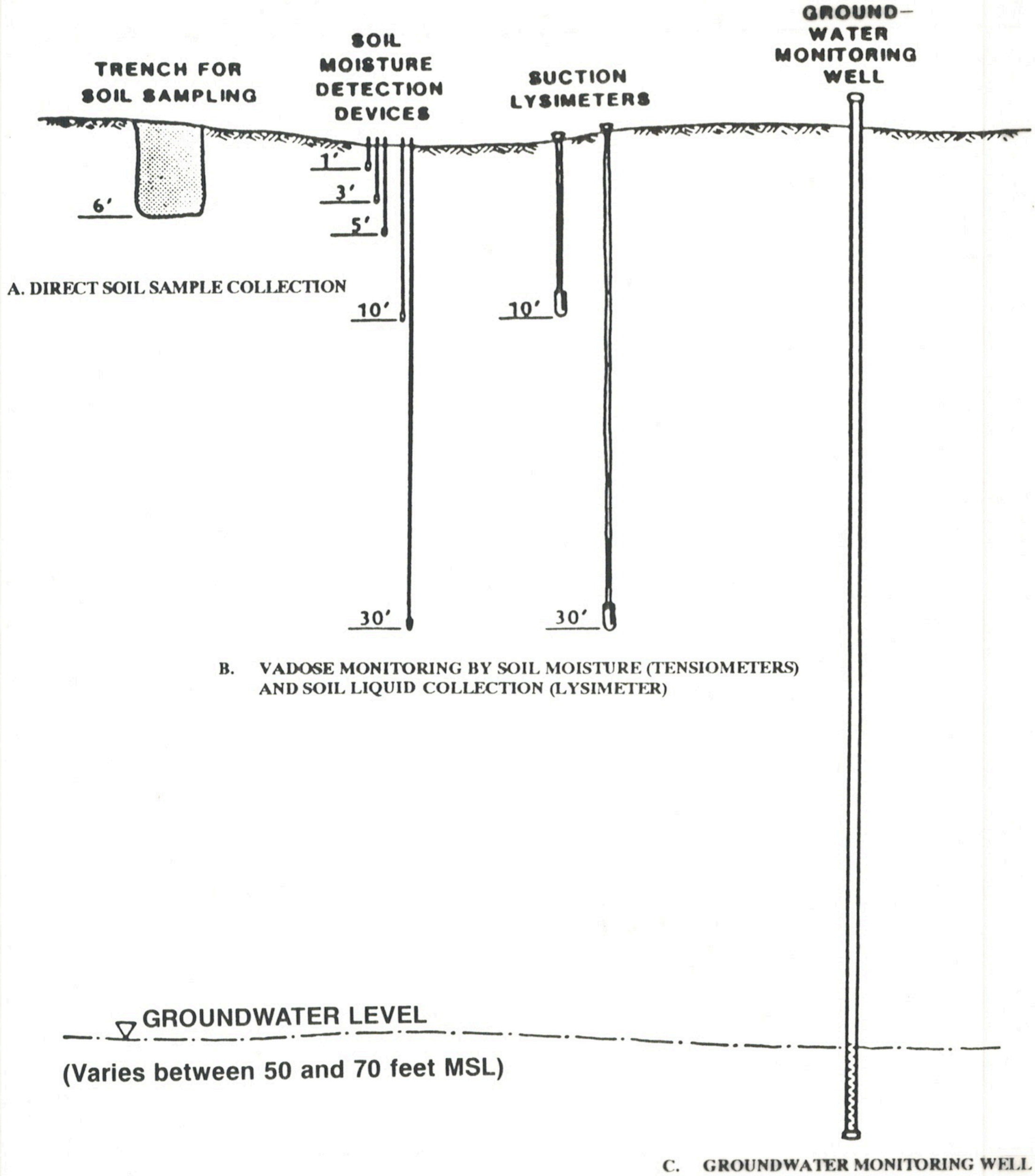
Figure 1. Schematic diagram of monitoring well sampling devices, after Neilson and Yeates (1985) in EPA (1987c).

Low-Permeability Aquifers

- Low permeability units can be sampling challenges.
- Low yield, and turbid water due to suspended fines.
- Suction sampling may work, but will be of questionable use for volatile contaminants.

Unsaturated Zone Sampling

- Suction samplers are used.
- Similar techniques as for saturated sampling.
- Samplers sometimes introduce unwanted constituents, but are generally rugged, reliable instruments.


TRENCH FOR SOIL SAMPLING
SOIL MOISTURE DETECTION DEVICES
SUCTION LYSIMETERS
GROUND-WATER MONITORING WELL
6'
1'
3'
5'
A. DIRECT SOIL SAMPLE COLLECTION
10'
10'
30'
30'
B. VADOSE MONITORING BY SOIL MOISTURE (TENSIOMETERS) AND SOIL LIQUID COLLECTION (LYSIMETER)
GROUNDWATER LEVEL
(Varies between 50 and 70 feet MSL)
C. GROUNDWATER MONITORING WELL