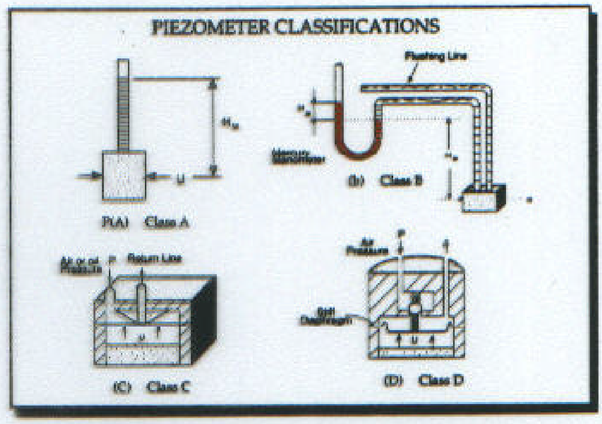

Figure 4-39 Piezometer Classifications

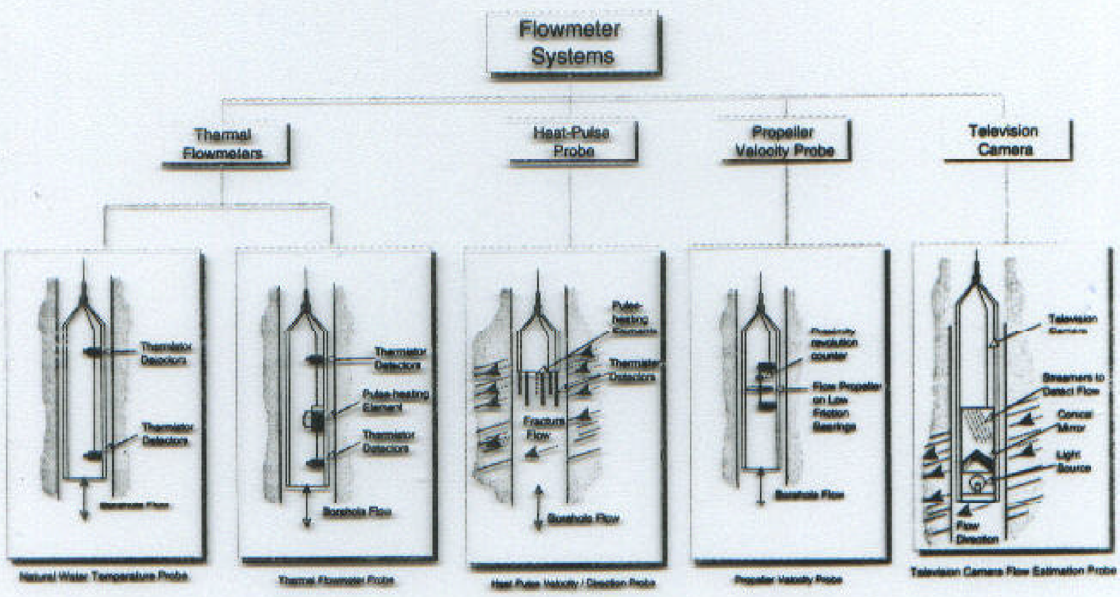

Figure 4-47 Flowmeter Systems

Piezometer Evaluations

Gauge Pressure	Piezometer Type	Pressure Range	Response Time	De-aring Capabiliy	Remote Reading Capability	Long-Term Reliability	Other: Advantages	Other: Disadvantages	Recommendations
Positive	Open-hydraulic (Casagrande)	Atmospheric to top of standpipe	Slow	Self de-airing	Not normally, but possible with bubbler system	Very good	Cheap, simple to read & maintain; Insitu permeability measurement possible.	Vandal damage often irreparable.	First choice for measurement within positive pressure range unless rapid response or remote readingd required; response peaks can be detected by use of Halcrow buckets system.
	Closed-Hydraulic (Low air entry pressure)	Any positive pressure	Moderate	Can be de-aired	Yes	Depends on pressure measuring system 1) Mercury manometer- very good 2) Bourdon gauge - poor in humid atmosphere 3) Pressure Transducer- moderate but easily replaced.	Fairly cheap; Insitu permeability measurement possible; can be made vandal proof if required.	Gauge house usually required; regular de-airing necessary; uncovered tubing liable to rodent damage if left exposed.	Usefull when remote reading, and for artesian pressure.
	Closed-Hydraulic (High air entry pressure)	-1 atmosphere to any positive pressure	Moderate	Can be de-aired	Yes	As above	Fairly cheap; Insitu permeability measurements in low permeability soil are possible	As above; very regular de-airing required when measuring suctions.	Useful for measuring small suctions
	Pneumatic	Any positive pressure	Rapid	Cannot be de-aired; only partially self de-airing	Yes some head loss over long distances	Moderate to poor, but very little long term experence available	Fairly cheap; no gauge house required	No method of checking if pore water or pore air pressure is measured	Only suitable when tip almost always below ground water level and no large suction occur.
	Electric vibrating wire type	Any positive pressure	Rapid	As above	Yes but special cable required	Signal quality degenerates with time; instrument life about ten years, but reliability of instrument that cannot be checked is always a question.	-	As above; expensive zero reading liable to drift and cannot be checked.	Not generally recommended
	Electric resistance type	Any positive pressure	Rapid	As above	Yes, but with care because of transmission losses	Poor	-	As above	Not recommended
Negative (suction)	Tensiometer	-1 Atmosphere to positive pressure	Moderate to rapid	Can be de-aired	Yes	Good	Cheap, simple to read and maintain.	Vandal damage often irreparable; regular de-airing required.	First choice for measuring pore suction.
	Psychrometer	Below -1 atmosphere	Variable	Not relevant	Short distances only	Instrument life one to two years; little long term experence available.	-	Not accurate between 0 and -1 atmospheres.	Research stage.

Table 4-11 Piezometer Selection Matrix

Table 9-8. Comparison of measured LNAPL thicknesses using water-detection paste, a clear bottom-loading bailer, and an interface probe (from Sanders, 1984).

Measurement Method	3 Inches Gasoline		1 Inch Gasoline		3 Inches Kerosene		1 Inch Kerosene	
	Ave. (inches)	Standard Deviation	Ave. (inches)	Standard Deviation	Ave. (inches)	Standard Deviation	Ave. (inches)	Standard Deviation
Water Detection paste on a stick*	3.60	0.21	1.38	0.13	3.36	0.27	1.12	0.75
Clear bottom-loading bailer**	2.58	0.16	0.82	0.13	2.46	0.18	0.80	0.12
Interface probe***	3.18	0.11	1.14	0.11	3.12	0.08	1.10	0.12

Notes: Ave. means average. Five tests were conducted with each method and fluid thickness.
*Gauging stick – 8-ft Bagby Stick Co.; McCabe, Inc. water-detection paste.
**Surface sampler – 1¾-inch OD, 12-inches long, bottom-loading bailer.
***ORS interface probe (manufacture date circa 1984).

Table 9-10. Summary of Test Results (Note: A = NAPL presence apparent based on visual examination; B = NAPL presence suspected based on visual examination; and C = no visual evidence of NAPL presence).

Method	Sample categories are based upon estimated NAPL saturations as a percent. The volume of NAPL mixed with 172 g of soil and sufficient mL of water to constitute a total fluid content of 35 mL is also given.							Notes and Conclusions
	Blank Samples (No NAPL)	Dissolved Samples (No NAPL)	1% (0.35 mL)	2.86% (1 mL)	5.71% (2 mL)	11.43% (4 mL)	22.86% (8 mL)	
OVA Headspace Analysis using an FID	1.4 - 4.8 ppm (see notes)	1.4-30 ppm	120- >1000 ppm	50- >1000 ppm	60- >1000 ppm	100- >1000 ppm	65- >1000 ppm	1. An effective screening method which may be used, in some cases, to infer NAPL presence. 2. Organic vapor concentration depends on contaminant volatility: measured concentrations were much higher in chlorobenzene and PCE samples than kerosene samples. 3. Two blank samples had OVA concentrations of <10 and <20 ppm due to residual vapors from prior samples.
Unaided Visual Exam	0 A 0 B 11 C	0 A 0 B 11 C	0 A 0 B 11 C	0 A 1 B 11 C	0 A 3 B 8 C	0 A 6 B 5 C	0 A 7 B 4 C	1. Unable to identify presence of colorless NAPL. 2. NAPL presence was suspected in some samples with higher NAPL saturation based on fluid sudsiness.
UV Fluorescence Exam	1 A 1 B 9 C	0 A 2 B 9 C	4 A 1 B 6 C	9 A 1 B 2 C	9 A 1 B 1 C	11 A 0 B 0 C	11 A 0 B 0 C	1. Very effective simple test for fluorescent NAPLs. 2. One false positive in 22 blank or dissolved samples. 3. Only 3 false negatives in 45 samples with estimated NAPL saturations between 1% and 23%. 4. Sensitivity depends on fluorescent intensity of NAPL: at low NAPL saturations, kerosene and chlorobenzene were easier to detect than tetrachloroethene. 5. Greater visual contrast evident between milky white fluorescence and darker soils. 6. Adding more water to the contaminated soil sample improved the detectability of NAPL in some cases by bringing more fluorescent fluid to the polybag wall.
Soil-Water Shake Test Exam	0 A 1 B 10 C	0 A 2 B 9 C	0 A 4 B 7 C	2 A 6 B 4 C	0 A 9 B 2 C	2 A 8 B 1 C	3 A 7 B 1 C	1. Difficult to positively identify clear, colorless NAPL. 2. At relatively high saturations (between 1% and 23%), NAPL presence was usually suspected based on fluid characteristics at the fluid-air interface. 3. As a result, colorless LNAPL (kerosene) was easier to detect than colorless DNAPL (chlorobenzene and tetrachloroethene) using the shake test.
Centrifugation Exam	0 A 1 B 10 C	0 A 1 B 10 C	0 A 4 B 7 C	2 A 5 B 5 C	4 A 3 B 4 C	6 A 1 B 4 C	3 A 4 B 4 C	1. Fairly effective for identification of LNAPL (kerosene), but not DNAPLs, based on fluid characteristics at the fluid-air interface. 2. Seventeen false negatives in 45 samples with estimated NAPL saturations between 1% and 23%; only 15 positive NAPL identifications in these 45 samples.
Hydrophobic Dye Shake Test Exam	0 A 0 B 11 C	0 A 0 B 11 C	4 A 2 B 5 C	8 A 1 B 3 C	10 A 0 B 1 C	11 A 0 B 0 C	11 A 0 B 0 C	1. Very effective simple test. 2. No false positives in 22 blank or dissolved samples. 3. Identified NAPL presence in 40 of 45 samples with estimated NAPL saturations >1%. False negatives recorded in only 4 of these 45 samples. 4. Dye coloration obvious even in black topsoil samples. 5. NAPL density relative to water was correctly determined in 21 samples and misjudged in 1 sample. 6. Can be used to estimate quantity of NAPL in sample.
Centrifugation of Hydrophobic Dye Shake Test Sample	0 A 1 B 10 C	0 A 0 B 11 C	5 A 1 B 5 C	9 A 2 B 1 C	11 A 0 B 0 C	11 A 0 B 0 C	11 A 0 B 0 C	1. Slight enhancement of hydrophobic dye shake test. 2. No false positives in 22 blank or dissolved samples. 3. Identified NAPL presence in 42 of 45 samples with estimated NAPL saturations >1%. False negative recorded in only 1 of these 45 samples. 4. NAPL density relative to water was correctly determined in 43 samples and misjudged in 3 samples. 5. Can be used to estimate quantity of NAPL in sample.

STRADDLE PACKER

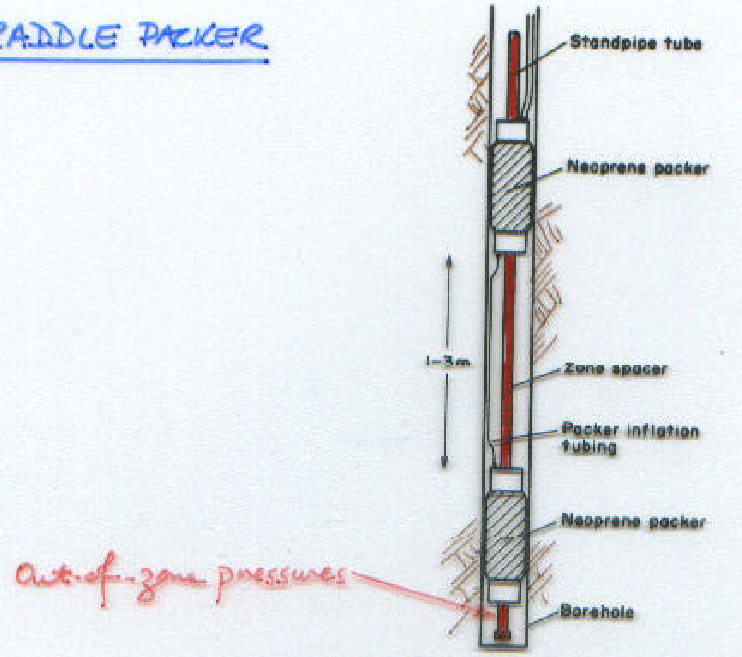

Figure 11 Packer system showing a straddle packer

PIEZOMETER INSTALLATION

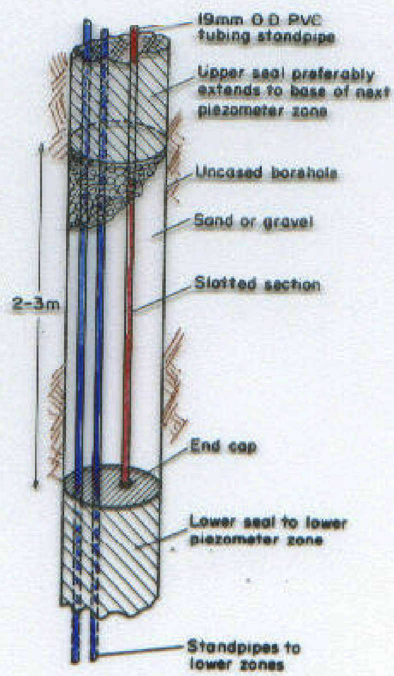

Figure 12 Standpipe piezometer installation

Table 1. Comparison of Well Casing and Screen Materials (1986)

Type	Advantages	Disadvantages
PVC (Polyvinylchloride)	• Lightweight • Excellent chemical resistance to weak alkalies, alcohols aliphatic hydrocarbons, and oils • Good chemical resistance to strong mineral acids, concentrated oxidizing acids, and strong alkalies • Readily available • Low priced compared to stainless steel and Teflon	• Weaker, less rigid, and more temperature-sensitive than metallic materials • May adsorb some constituents from groundwater • May react with and leach some constituents from groundwater • Poor chemical resistance to ketones, esters, and aromatic hydrocarbons
Polypropylene	• Lightweight • Excellent chemical resistance to mineral acids • Good-to-excellent chemical resistance to alkalies, alcohols, ketones, and esters • Good chemical resistance to oils • Fair chemical resistance to concentrated oxidizing acids, alphatic hydrocarbons, and aromatic hydrocarbons • Low priced compared to stainless steel and Teflon	• Weaker, less rigid, and more temperature-sensitve than metallic materals • May react with and leach some constituents into groundwater • Poor machinability—it cannot be slotted because it melts rather than cuts
Teflon	• Lightweight • High impact strength • Outstanding resistance to chemical attack insoluble in all organics except a few exotic fluorinated solvents	• Tensile strength and wear resistance low compared to other engineering plastics • Expensive relative to other plastics and stainless steel

Table 1. Continued

Type	Advantages	Disadvantages
Kynar	• Greater strength and water resistance than Teflon • Resistant to most chemicals and solvents • Lower priced than Teflon	• Not readily available • Poor chemical resistance to ketones, acetone
Mild steel	• Strong, rigid; temperature-sensitivity not a problem • Readily available • Low priced relative to stainless steel and Teflon	• Heavier than plasics • May react with and leach some constituents into groundwater • Not as chemically resistant as stainless steel
Stainless steel	• High strength at a great range of temperatures • Excellent resistance to corrosion and oxidation • Readily available • Moderate price for casing	• Heavier than plastics • May corrode and leach some chromium in highly acidic waters • May act as a catalyst in some organic reactions • Screens are higher priced than plastic screens

Source: Driscoll (1986).

Table 2. Comparison of Well Grouting Materials

Type	Advantages	Disadvantages
Bentonite	• Readily available • Inexpensive	• May produce chemical interference with water quality analysis • May not provide a complete seal because —There is a limit (14% to the amount of solids that can be pumped in a slurry. Thus, there are few solids in the seal; should wait for liquid to bleed off so solids will settle —During installation, bentonite pellets may hydrate before reaching proper depth, thereby sticking to formation or casing and causing bridging —Cannot determine how effectively material has been placed —Cannot assure complete bond to casing
Cement	• Readily available • Inexpensive • Can use sand and/or gravel filter • Possible to determine how well the cement has been placed by temperature logs or acoustic bond logs	• May cause chemical interferences with water quality analysis • Requires mixer, pump, and trémie line; generally more cleanup than with bentonite • Shrinks when it sets; complete bond to formation and casing not assured

Source: Driscoll (1986).

Table 9-4. Borehole and well annulus grout types and considerations (modified from Aller et al., 1989; Edil et al., 1992).

BENTONITE AND BENTONITE-CEMENT GROUTS: Bentonite is a hydrous aluminum silicate comprised primarily of montmorillonite clay. The volume of hydrated bentonite in water is typically 10 to 15 times greater than that of dry bentonite because water is incorporated within the expanding clay lattice. The low permeability and expansion of bentonite in water are desirable properties for sealing abandoned boreholes and well annular spaces. Bentonite grouts are best prepared using mechanical mixers and should be pumped under pressure in place from the base of the interval to be grouted through a tremie pipe. Bentonite grouts should be mixed in batches so that they can be pumped before becoming too viscous. Bentonite grout should not be placed in the vadose zone because it will dry, shrink, and fracture. Bentonite grout may also shrink and fracture in the presence of hydrophobic NAPLs. Several available bentonite grout types are described below.

Bentonite Slurry Grout is commonly prepared by mixing dry bentonite powder in fresh water at a ratio of 15 lbs of bentonite to 7 gallons of water to make 1 ft^3 of slurry. Thick slurries may gel prematurely and be impossible to emplace. Due to their low solids content, bentonite slurries tend to settle as liquid bleeds off, requiring the emplacement of more slurry.

Quick-Gel® Bentonite Drilling Mud Grout is slurry of sodium bentonite and water that is marketed primarily as a drilling mud. Grouts of varying viscosity and strength can be obtained by mixing different proportions of Quick Gel®, water, and sand. Slurries containing sand appear more stable than pure Quick Gel®. Edil et al. (1992) found that Quick Gel® slurries of different sand content and viscosity form poorer annulus seals than neat cement, cement-bentonite, and Benseal®-bentonite slurry grouts.

Volclay® Bentonite Powder Grout is a commercial bentonite-based clay grout that is formulated for sealing boreholes and well annular spaces. Edil et al. (1992) mixed 2.1 lbs of Volclay® per gallon of water and added 2 lbs of magnesium oxide powder as a setting inhibitor to each 50 lbs of Volclay® slurry. They determined that Volclay® grout has a stiff gel structure which adheres to PVC but not steel well casing; and that it is not as effective a well sealant as neat cement, cement-bentonite, and Benseal®-bentonite slurry grouts.

Benseal® - Bentonite Slurry Grout is a mixture of Benseal®, a granular nondrilling mud grade bentonite developed for use in sealing and grouting well casings, and bentonite powder with water. Edil et al. (1992) mixed 30 lbs of Natural Gel® (a natural, unaltered bentonite powder) with 100 gallons of water, and then used a venturi pump to mix in 125 lbs of Benseal® to the slurry. They found that this grout adheres to steel and PVC casing, has low permeability, good swelling characteristics, and flexibility, and is an excellent sealant.

Bentonite-Cement Grout is a slurry incorporating 5 to 6 gallons of water and 2 to 6 lbs of bentonite powder for each 94 lbs (1 ft^3) of Portland cement. Bentonite improves the workability of the cement slurry, reduces slurry density, and reduces grout shrinkage during setting. Edil et al. (1992) found the addition of 5 lbs of bentonite per 94 lbs of cement forms a rigid well annulus seal with low permeability and high durability; and that the grout adheres to steel casing, but appeared to allow some infiltration along the grout-PVC casing interface.

Bentonite Pellets can be used to seal borehole or well annulus intervals. Wet pellets, however, tend to stick to well casing and borehole walls, and bridge high above their intended placement depth. A tamper can be used to break up bridges, but this technique becomes ineffective at depths greater than approximately 20 ft. Pellets can be frozen using refrigeration or liquid nitrogen to increase their fall distance.

PORTLAND CEMENT: Neat cement is a mixture of Portland cement (ASTM C-150) and water in the proportion of 5 to 6 gallons of clean water per bag (94 lbs or 1 ft^3) of cement. Five types of Portland cement are produced: Type I for general use; Type II for moderate sulfate resistance of moderate heat of hydration; Type III for high early strength; Type IV for low heat of hydration; and Type V for high sulfate resistance. Type I is most widely-used in well construction or hole abandonment. A typical 14 lb/gallon neat cement slurry with a mixed volume of 1½ ft^3 will have a set volume of 1.2 ft^3, reflecting a 17% shrinkage. The setting time ranges from 48 to 72 hrs depending primarily on water content.

Common additives include: (1) 2 to 6% bentonite to reduce shrinkage, improve workability, reduce density, and produce a lower cost per volume of grout; (2) 1 to 3% calcium chloride to accelerate the setting time and thereby create higher early strength, of particular value in cold climates; (3) 3 to 6% gypsum to produce a quick-setting very hard cement that expands upon setting; (4) <1% aluminum powder to produce a quick-setting strong cement that expands upon setting; (5) 10 to 20% flyash to increase sulfate resistance and provide early compressive strength; (6) hydroxylated carboxylic acid to retard setting time and improve workability without compromising set strength; and (7) diatomaceous earth to reduce slurry density, increase water demand and thickening time, and reduce set strength.

Edil et al. (1992) found neat cement grout forms a rigid seal with low permeability and high durability that adheres fairly well to steel and PVC casing. Kurt and Johnson (1982), however, report that neat cement annular seals are subject to channeling between the casing and grout due to temperature changes during curing, swelling and shrinkage during curing, and poor bonding between the ground and casing. Cement shrinkage can produce fractures, thereby degrading the integrity of the grout seal. Cement slurries can infiltrate the well sandpack, particularly if well development occurs prior to when the cement has completely set. Thus, a minimum of 1 to 2 ft of filter pack is usually extended in the annulus above the top of the well screen. The high heat of cement hydration can compromise the integrity of thermoplastic casing. Cement is a highly alkaline substance with a pH that ranges from 10 to 12. This can alter groundwater pH.

Table 9-7. Advantages and disadvantages of some common well casing materials (modified from Driscoll, 1986; GeoTrans, 1989; and Nielsen and Schalla, 1991).

TYPE	ADVANTAGES	DISADVANTAGES
FLUOROPOLYMERS such as polytetrafluoroethyene (PTFE), tetrafluoroethylene (TFE), and fluorinated ethylene propylene (FEP)	• Excellent chemical resistance to organic chemicals and corrosive environments; practically insoluble in all organic liquids except a few fluorinated solvents • Lightweight • High impact strength	• Lower tensile strength and wear resistance compared to other plastics, iron, or steel • Expensive relative to steel and other plastics
THERMOPLASTICS: POLYVINYLCHLORIDE (PVC) AND ACRYLONITRILE BUTADIENE STYRENE (ABS)	• Lightweight • Easy workability (with threaded couplings) • Inexpensive compared to fluoropolymers and steel • Resistant to alcohols, aliphatic hydrocarbons, weak and strong alkalies, oils, strong mineral acids, and oxidizing acids • Completely resistant to galvanic and electrochemical corrosion • High strength-to-weight ratios, and resistant to abrasion	• More reactive than PTFE • Poor chemical resistance to aromatic hydrocarbons, esters, ketones, and organic solvents • Much lower tensile, compressive, and collapse strength than steel or iron • May adsorb or elute trace organics • PVC glues, if used, may contribute organic chemicals to well water
STAINLESS STEEL such as Type 304 and Type 316	• Stronger, more rigid, and less temperature-sensitive than plastic materials • Good chemical resistance to organic chemicals • Resistant to corrosion and oxidation • Readily available	• Expensive • May catalyze some organic chemical reactions • May corrode if exposed to long-term corrosive conditions and leach chromium • Heavy
CARBON STEEL	• Stronger, more rigid, and less temperature-sensitive than plastic materials • Less expensive than stainless steel or teflon	• Expensive • Rusts easily, providing high sorptive and reactive capacity for many metals and organic chemicals • Subject to corrosion (under conditions of low pH, high dissolved oxygen, H^2S present, > 1000 mg/L total dissolved solids, > 50 mg/L CO_2, or > 500 mg/L Cl^- • Heavy
GALVANIZED STEEL	• Stronger, more rigid, and less temperature-sensitive than plastic materials	• Expensive • Will rust if galvanized coating is scratched • Resistance to corrosion provided by zinc coating may be short-lived • May be source of zinc • Heavy

Table 9-1. Drilling and excavation costs in April, 1987 dollars (from GRI, 1987).

ITEM	HIGH COST	LOW COST	MEAN COST
Drilling Soil Borings (3½")	$39/ft	$18/ft	$28/ft
Rock Coring	$50/ft	$40/ft	$44/ft
Stainless Steel Screen (2", installed)	$375/5 ft	$175/5 ft	$252/5 ft
Stainless Steel Riser Pipe (2", installed)	$37/ft	$11/ft	$21/ft
PVC Screen (2", installed)	$50/5 ft	$35/5 ft	$43/5 ft
PVC Riser Pipe (2", installed)	$8/5 ft	$5/5 ft	$6/5 ft
Protective Casing	$150/each	$90/each	$113/each
Shelby Tube Samples (3")	$125/each	$40/each	$85/each
Water Truck Rental			$400/day
Steam Cleaner Rental	$125/day	$60/day	$85/day
Steam Cleaning Time	$140/hr	$112/hr	$125/hr
Stand By Time	$140/hr	$112/hr	$125/hr
Drilling in Level C Protection (Add)	$125/hr	$35/hr	$87/hr
Mobilization and Demobilization (200 miles)	$1250	$900	$1075
Test Pit Excavation Small Rubber Tired Backhoe and Operator			$70 - $110/hr
Large, Track-Mounted Backhoe (2 yd^3 shovel) and Operator			$100 - $170/hr
Mobilization and Demobilization			$50 - $100/hr