SAMPLE COLLECTION 2.1

Guidelines for selecting sample-collection equipment could differ for surface-water and ground-water applications. Documentation of equipment use and quality-control analyses are necessary if study objectives or site conditions result in a departure from published USGS requirements or recommendations. An example checklist of sample-collection equipment and supplies is given in section 2.4.

SURFACE-WATER SAMPLING EQUIPMENT 2.1.1

***By* W.E. Webb and D.B. Radtke**

Study objectives, flow conditions, and sampling structures (such as a bridge, cableway, or boat) must be considered when determining which sample-collection equipment to use. The equipment selected depends on whether the stream can be waded (preferred) or not. To determine whether stream depth and velocity are too great to wade safely (NFM 9), follow this rule of thumb:

RULE OF THUMB: Do NOT wade in flowing water when the product of depth (in feet) and velocity (in feet per second) equals 10 or greater.

Application of this rule varies among individuals according to their weight and stature, and to the condition of the streambed.

Two primary types of surface-water samplers are used by the USGS:

- Isokinetic depth-integrating samplers
- Nonisokinetic samplers

2.1.1.A Isokinetic Depth-Integrating Samplers

An isokinetic depth-integrating sampler is designed to accumulate a representative water sample continuously and isokinetically (that is, stream water approaching and entering the sampler intake does not change in velocity) from a vertical section of a stream while transiting the vertical at a uniform rate (Federal Interagency Sedimentation Project, 1986). Isokinetic depth-integrating samplers are categorized into two groups, based on the method of suspension: hand-held samplers and cable-and-reel samplers.

Types and pertinent characteristics of isokinetic depth-integrating samplers recommended for sampling in flowing water are summarized in table 2-2, illustrated on figure 2-1, and described below. For detailed descriptions of isokinetic depth-integrating samplers, refer to Szalona (1982), Ward and Harr (1990), Horowitz and others (1994), Edwards and Glysson (1998), and Federal Interagency Sedimentation Project, accessed August 7, 1998.

For collection of an isokinetic sample, minimum stream velocity must be greater than

- 1.5 feet per second (ft/s) for a depth-integrating sampler with a rigid bottle, or
- 3.0 ft/s for a bag sampler.

The maximum allowable transit rate (R_t) relative to mean velocity (V_m) for a given sampler varies with nozzle size and sample-bottle size (table 2-2). Do not exceed the listed R_t/V_m ratio for the given nozzle and bottle size. A lower R_t/V_m is better for ensuring that a representative velocity-weighted sample is collected, but care must be taken to not overfill the sampler bottle.

The cap and nozzle assembly is available in fluorocarbon polymer and polypropylene. The same cap and nozzle can be used for the US DH-81, US D-95, and the US D-77. If the cap vent is plugged, the same cap and nozzle can be used for bag-type samplers. In addition, fluorocarbon polymer adapters are available to mate the cap to either 1-L or 3-L fluorocarbon polymer bottles.

Table 2-2. Isokinetic depth-integrating water-quality samplers and sampler characteristics

[R_t, transit rate in feet per second (ft/s); V_m, mean stream velocity in the vertical being sampled, in ft/s; DH, depth integrating hand-held sampler; PN, polypropylene cap and nylon nozzle; PFA, fluorocarbon polymer; C&N, cap and nozzle; PC, plastic coated; PT, polypropylene or PFA bottle; PDC, plastic dip coated; ND, to be determined; D, depth integrating sampler; AL, aluminum; PTB, polypropylene bottle with plastic bag (Reynolds™ oven bag only type tested) or PFA bag; FB, D-77 cap and nozzle with frame and bag; L, liter; DFS, dependent on frame size; >, greater than]

Sampler designa-tion	Sampler construction material	Sampler dimensions			Distance of nozzle from bottom, in inches	Suspen-sion method	Maximum calibrated velocity, in feet per second	Maximum depth, in feet	Sampler container size, in liters[1]	Nozzle intake size,[2] in inches	Maximum transit rate ratio,[3] R_t/V_m
		Length (inch)	Width (inch)	Weight (pound)							
US DH-81	PN or PFA C&N	[4]6.5	3.2	[4]0.5	[5]4	Hand-held (PC)	8.9	15 15 14	1 (PT)	3/16 1/4 [2]5/16	0.2 .3 .4
US D-95	Bronze (PDC) with PN or PFA C&N	28.5	6.0	65	4.5	Reel and cable	ND	15 15 14	1 (PT)	3/16 1/4 [2]5/16	.2 .3 .4
US D-77	Bronze (PDC) with PN or PFA C&N	29	9.0	75	7	Cable & reel	7.2	15	3 (PT)	1/4 [2]5/16	.1 .2
US D-77AL	Aluminum (PDC) with PN or PFA C&N	29	9.0	42	7	Cable & reel	3.3	15	3 (PT)	1/4 [2]5/16	.1 .2
D-77 BAG[6]	Bronze (PDC) with PN or PFA C&N	29	9.0	75	7	Cable & reel	7.2	95 56 36	3 (PTB)	3/16 1/4 5/16	.4 .4 .4
FB (3 L)[6,7]	Steel (PDC) with PN or PFA C&N	DFS			DFS	Cable & reel	ND	95 56 36	3 (PTB)	3/16 1/4 5/16	.4 .4 .4
FB (8 L)[6,7]	Steel (PDC) with PN or PFA C&N	DFS			DFS	Cable & reel	ND	>200 160 100	8 (PTB)	3/16 1/4 5/16	.4 .4 .4

[1]Bottle with standard mason jar threads.
[2]Nozzle sizes are those recommended for the application shown.
[3]Refer to NFM 4, Appendix A, for maximum transit-rate ranges, and to Office of Surface Water Technical Memorandum 94.05, dated January 31, 1994.
[4]Length, width, and weight will depend on specific bottle dimensions. Weight indicated is for cap and nozzle only. Handle is plastic coated with clear heat-shrinking tubing.
[5]Distance of nozzle from the bottom will depend on specific bottle dimensions.
[6]Do not use D-77 bag sampler if water temperature is less than 7°C.
[7]Hydraulic efficiency of bag samplers has not been verified.

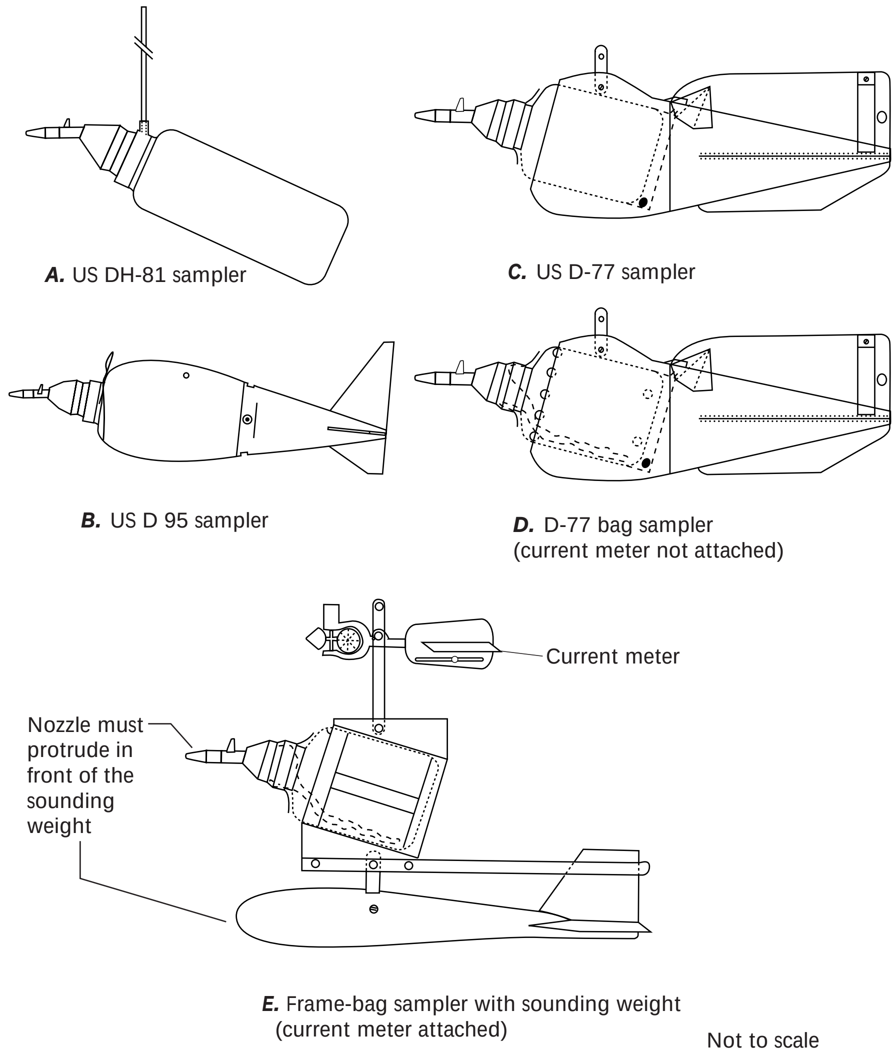


Figure 2-1. Isokinetic depth-integrating samplers: (*A*) US DH-81, (*B*) US D-95, (*C*) US D-77, (*D*) D-77 Bag without current meter attached, and (*E*) Frame-Bag sampler with sounding weight and current meter attached. (Illustrations courtesy of Federal Interagency Sedimentation Project, Waterways Experiment Station, Vicksburg, Miss.)

- Use the US DH-81, US D-95, US D-77, D-77 Bag, or Frame-Bag (FB) samplers to collect samples in flowing waters for all analyses except inorganic gases and volatile organic compounds.
  - Samples of water for determination of metals and other trace elements (hereafter referred to collectively as "trace elements") must contact only noncontaminating materials, typically flurocarbon polymer or polypropylene.
  - Samples of water for determination of organic compounds must contact only noncontaminating materials, typically metal (such as stainless steel), fluorocarbon polymers (such as Teflon™), or ceramics (such as hard-fused microcrystalline alumina).
- Discontinue use of the US DH-48, US DH-59, US DH-76, US D-49, US D-74, US P-61, US P-63, and US P-72 samplers for collecting trace-element samples: they contaminate samples with measurable concentrations of trace elements.
  - Some of these samplers may be acceptable for major ions, nutrients, and suspended sediments.
  - Additional quality-control samples need to be collected if it is necessary to use any of these samplers (Horowitz and others, 1994).

Hand-held samplers

The US DH-81 (fig. 2-1*A*) or US D-95 (fig. 2-1*B*) sampler is used to collect water samples where flowing water can be waded or where a bridge is accessible and low enough to sample from. The sampler components (cap, nozzle, and bottle) are interchangeable. Both inorganic and organic samples can be collected with either sampler as long as the construction material of the sampler components (table 2-1) does not affect ambient concentrations of target analytes. Isokinetic depth-integrated samples for bacteria analysis also can be collected with these samplers because the cap, nozzle, and bottle can be autoclaved. All hand-held samplers should be tested and maintained as described on table 2-3.

Table 2-3. Prefield checklist for hand-held and cable-and-reel samplers

Hand-held and cable-and-reel sampler checklist		
✓	Items	Comment
	Mechanical operation	Test the working condition of the sampler.
	Nozzles	Replace nozzles that have burrs or are damaged. Use only nozzles purchased from the Federal Interagency Sedimentation Project.
	Air exhaust vent of the US D-77	Do not plug US D-77 vent. (Air vent on cap-and-nozzle assembly of bag-type sampler is plugged.)
	Plastic coating	If plastic coating is damaged or any metal parts are exposed, recoat in plastic dip or touch up with plasti-dip spray.
	Sampler is clean	Clean appropriate parts of the sampler according to procedures described in NFM 3.
	Laboratory results from analysis of sampler blank	Make sure that sampler has been quality assured with annual equipment blank and certified for water-quality use (see NFM 1 and NFM 4).
	Separate equipment sets	If at all feasible, for a given field trip when collecting multiple water samples, prepare and use separate sets of sampler bottles, caps, and nozzles for each sampling site.
	Field-cleaning supplies and blank water	If separate sets of sampler components are not available, then clean equipment between sampling sites (see NFM 3) and be prepared to process the number of field blanks needed to document that equipment was adequately cleaned.

When using the US DH-81:

- Use a 1/4- or 5/16-in. nozzle.
- Make sure that flow velocity exceeds 1.5 ft/s (to collect an isokinetic sample).
- Use the 1-L bottle (not the 3-L bottle).

When using the US D-95:

- Use either a 3/16-, 1/4-, or 5/16-in. nozzle.
- Make sure that flow velocity exceeds 1.5 ft/s (to collect an isokinetic sample).
- Use the 1-L bottle.

Cable-and-reel samplers

Cable-and-reel samplers are used to collect water samples where flowing water cannot be waded. These include the US D-77, the D-77 Bag, and the Frame-Bag samplers. (Refer to table 2-2 for sampler characteristics and sampling limitations.) Like the US DH-81 and US D-95, these samplers can be used for collecting inorganic and organic samples; however, sampler components (cap, nozzle, and bottle) must be selected so as not to bias concentrations of target analytes. Isokinetic depth-integrated samples for bacteria analysis also can be collected with these samplers because the cap, nozzle, bottle, and bags can be autoclaved.

The US D-77 sampler (fig. 2-1*C*) is used where water is less than 15 ft deep. The D-77 Bag and the Frame-Bag (FB) samplers (fig.2-1*D*, *E*) are designed to collect isokinetic depth-integrated samples at depths greater than 15 ft. The capability of collapsible bag-type samplers to collect isokinetic depth-integrated water-quality samples is being evaluated by the USGS (Office of Water Quality and Office of Surface Water).

Metal parts of the US D-77 Bottle sampler and D-77 Bag and Frame-Bag samplers must be coated with plastic ("plasti-dip") and recoated periodically to prevent possible sample contamination from metallic surfaces. All cable-and-reel samplers should be tested and maintained before use, as described on table 2-3.

When using the US D-77 bottle sampler:

- ▶ Use a 5/16-in. nozzle.
- ▶ Make sure that flow velocity exceeds 1.5 ft/s.
- ▶ Use in water less than 15 ft deep for an isokinetic, depth-integrated sample.

When using the D-77 Bag sampler:

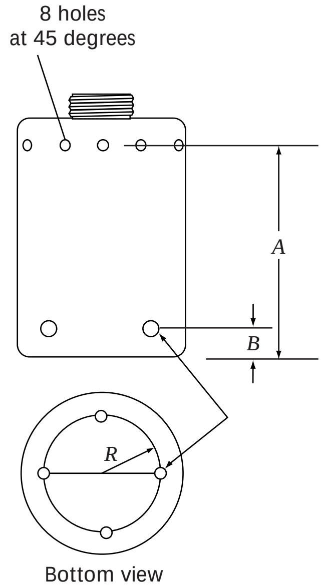
- Use a 1/4- or 5/16-in. nozzle.
- Make sure that flow velocity exceeds 3 ft/s (to collect an isokinetic sample). Isokinetic capability decreases at flow velocities less than 3 ft/s.
- Use in water with depth greater than 15 ft for an isokinetic, depth-integrated sample.
- Make sure that a clean, noncontaminating object such as a glass (not rubber) BOD bottle stopper is in the bag.
- Water temperature must be above 8°C.
- Field calibrate the bag sampler each time it is used because streamflow characteristics vary each time a sample is collected. (An example of the field-calibration worksheet is shown in fig. 2-3.)

The D-77 Bag sampler uses a collapsible Reynolds™ oven or fluorocarbon polymer bag that is placed in a special slotted 3-L bottle (fig. 2-2) with a US D-77 cap and nozzle assembly in which the vent is plugged.

The advantage of the D-77 Bag sampler over the Frame-Bag sampler is that use of the D-77 Bag sampler results in a smaller unsampled zone (distance between the nozzle and the bottom of the sampler).

When using the Frame-Bag sampler:

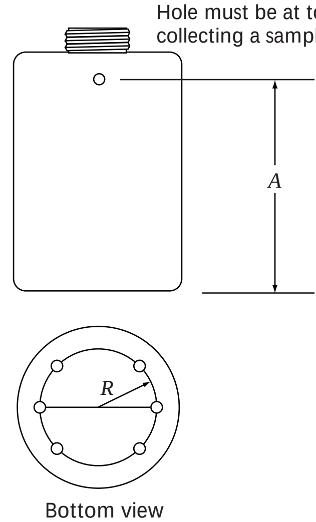
- Use a 3/16-, 1/4- or 5/16-in. nozzle (not a 1/8-in. nozzle).
- Make sure that flow velocity exceeds 3.0 ft/s (to collect an isokinetic sample).
- Keep a clean, noncontaminating object such as a glass BOD bottle stopper or a fluorocarbon polymer-coated magnetic stirring bar in the bag. Do not use a rubber stopper.
- Water temperature must be above 8°C.
- Field calibrate bag samplers each time they are used because streamflow characteristics vary each time a sample is collected. (See worksheet, fig. 2-3.)



Bottle size	3 Liters
Manufacturer	Nalgene
Number	2115-3000
Hole diameter bottom and side	2.54 cm 1 in.
Hole diameter top	0.63 cm 1/4 in.
A	18.4 cm 7 1/4 in.
B	1.90 cm 3/4 in.
R	3.81 to 4.45 cm 1 1/2 to 1 3/4 in.

Not to scale

A. D-77 Bag sampler



Bottle size	3 Liter	4 Liter	8 Liter
Manufacturer	Nalgene	Bel Art	Bel Art
Number	2115-3000	F10916	F10917
Hole diameter	1.91 cm 3/4 in.	1.91 cm 3/4 in.	2.54 cm 1 in.
A	18 cm 7 in.	21 cm 8 1/4 in.	24.5 cm 9 5/8 in.
R	5 to 5.5 cm 2 to 2 1/4 in.	5 to 5.5 cm 2 to 2 1/4 in.	7 to 7.5 cm 2 3/4 to 3 in.

Not to scale

B. Frame bag sampler

Figure 2-2. Slotted bottle hole configurations for (*A*) D-77 Bag sampler and (*B*) Frame-Bag sampler. (Illustrations courtesy of Federal Interagency Sedimentation Project, Waterways Experiment Station, Vicksburg, Miss.)

FIELD CALIBRATION WORKSHEET FOR BAG SAMPLER

SITE DESCRIPTION

SITE ________________________________ DATE ______________________________

TIME __________________ TEMPERATURE ________ TRIAL NO. ___________

NOZZLE DIAMETER AND AREA

Diameter: inches	Diameter: millimeters	Area: square centimeters
3/16	4.7625	0.178139
1/4	6.3500	0.316692
5/16	7.9375	0.494832

NOZZLE VELOCITY (V_{nozzle})

SAMPLE VOLUME ____ milliliter

NOZZLE DIAMETER ______________________________________ inch

NOZZLE AREA ____ square centimeter

SAMPLING TIME ____ seconds

V_{nozzle} = ____________ feet per second

$$V_{nozzle} = \frac{\text{(Sample volume)}}{\text{(Area) (Time)}} \times \frac{1}{30.48}$$

STREAM VELOCITY (V_{stream})

REVOLUTIONS (R) ____

TIME (t) ____ seconds

$$V_{stream} = \frac{2.170R}{t} \div 0.030 \text{ (for } V_{stream} \geq 2.20 \text{ feet per second)*}$$

V_{stream} ________________________ feet per second

*(Equation for Price AA current meter with a standard rating)

HYDRAULIC EFFICIENCY (E)

Efficiency ____

$$E = \frac{V_{nozzle}}{V_{stream}}$$

Computed by _______________________

Checked by _______________________

Figure 2-3. Example of a field worksheet for calibration of D-77 Bag and Frame-Bag samplers.

The Frame-Bag sampler uses a collapsible bag that is placed in a special slotted 3- or 8-L bottle (fig. 2-2) with a US D-77 cap and nozzle assembly in which the vent is plugged. The slotted bottle is held in a plastic-coated metal frame to which various sizes of sounding weights can be attached. The size of the weight depends on the stream velocity along the cross section that will be sampled. The advantages of the Frame-Bag sampler over the D-77 Bag sampler are that the Frame-Bag sampler can be used to collect a larger sample volume and, therefore, to sample greater depths; and it can be used to collect samples in streams with greater velocities because heavier weights can be attached to maintain proper orientation of the sampler in the stream.

To prepare the Frame-Bag sampler (fig. 2-1E):

1. Attach cap to bottle with bag in place before drilling holes in the bottle, in order to achieve the correct alignment of the holes.

2. Align the cap and nozzle correctly to the hole configuration of the slotted bottle.

3. Dedicate the slotted bottle to that particular cap and nozzle.

Nonisokinetic Samplers 2.1.1.B

Use of a bailer or other thief sampler that is lowered and raised repeatedly in the well to collect a sample is not recommended because disturbance to the water column often creates turbidity. As with all samplers, the materials that contact the sample must not bias concentrations of target analytes by sorbing or leaching target analytes.

Open-mouth samplers

Open-mouth samplers used for the collection of water samples include the hand-held bottle, the weighted-bottle sampler, the BOD sampler, and the VOC sampler (fig. 2-4).

The hand-held bottle sampler is the simplest type of open-mouth sampler. A bottle is dipped to collect a sample (fig. 2-4*A*) where depth and velocity are less than the minimum requirements for depth-integrated samplers.

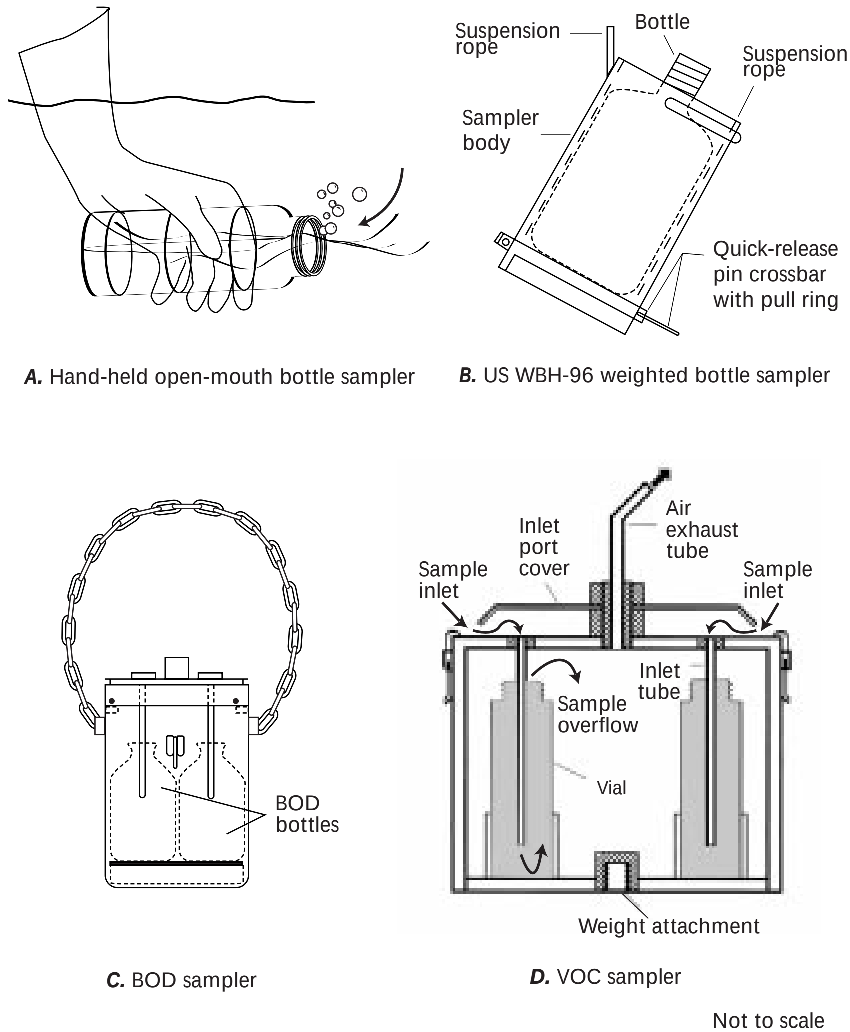


Figure 2-4. Examples of nonisokinetic open-mouth samplers: (*A*) hand-held open-mouth bottle sampler, (*B*) US WBH-96 weighted-bottle sampler, (*C*) biochemical oxygen demand (BOD) sampler, and (*D*) volatile organic compound (VOC) sampler. (*A*, from U.S. Environmental Protection Agency, 1982b; *B*, courtesy of Federal Interagency Sedimentation Project, Waterways Experiment Station, Vicksburg, Miss.; *C*, published with permission of Wildlife Supply Company; *D*, from Shelton, 1997.)

The weighted-bottle sampler is available in stainless steel (US WBH-96) (fig. 2-4B) or polyvinyl chloride. The weighted-bottle sampler can be used to collect samples where flow velocities are less than the minimum requirement for isokinetic depth-integrating samplers and where the water body is too deep to wade. An open bottle is inserted into a weighted holder that is attached to a handline for lowering. Sampling depth is restricted by the capacity of the bottle and the rate of filling.

The biochemical oxygen demand (BOD) sampler and the volatile organic compound (VOC) sampler (fig. 2-4*C*-*D*), are open-mouth samplers designed to collect nonaerated samples. The BOD sampler accommodates 300-mL glass BOD bottles specifically designed to collect samples for dissolved-oxygen determination (American Public Health Association and others, 1992, p. 4-99). The VOC sampler is specifically designed to collect nonaerated samples in 40-mL glass septum vials for determination of volatile organic compounds.

Thief samplers

Thief samplers are used to collect instantaneous discrete (point) samples. Thief samplers have been used primarily to collect samples from lakes, reservoirs, and some areas of estuaries. Smaller versions, designed to collect ground-water samples, also have been used in still and flowing surface water. The most commonly used thief samplers are the Kemmerer sampler, Van Dorn sampler, and double check-valve bailer with bottom-emptying device (fig. 2-5). These samplers are available in various sizes, mechanical configurations, and in various types of construction material (such as stainless steel, glass, polyvinyl chloride, fluorocarbon polymer). Disposable fluorocarbon polymer bailers also are available. For descriptions of additional thief samplers, see U.S. Environmental Protection Agency (1982b), Ward and Harr (1990), and American Public Health Association and others (1992) or consult the manufacturer of environmental sampling equipment.

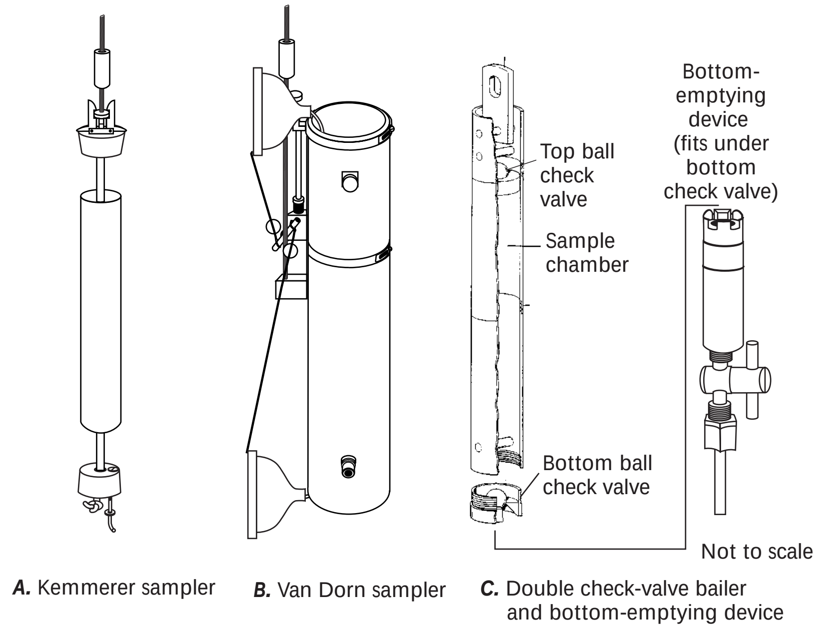


Figure 2-5. Examples of nonisokinetic thief samplers: (*A*) Kemmerer sampler, (*B*) Van Dorn sampler, and (*C*) double check-valve bailer with bottom-emptying device. (*A-B*, from *Standard Methods for Examination of Water and Wastewater*, 18th Edition. Copyright 1992 by the American Public Health Association, the American Water Works Association and the Water Environment Federation. Used with permission.; *C*, published with permission of Timco Mfg. Inc.)

Single-stage samplers

Single stage-samplers such as the US U-59 (fig. 2-6*A*) and US U-73 were designed to obtain suspended-sediment samples from streams at remote sites or at streams where rapid changes in stage make it impractical to use a conventional isokinetic depth-integrating sampler. Single-stage samplers can be mounted above each other to collect samples from different elevations or times as streamflow increases and the hydrograph rises (fig. 2-6*B*). (See Federal Interagency Sedimentation Project, 1986, p. 48-57, and Edwards and Glysson, 1998.)

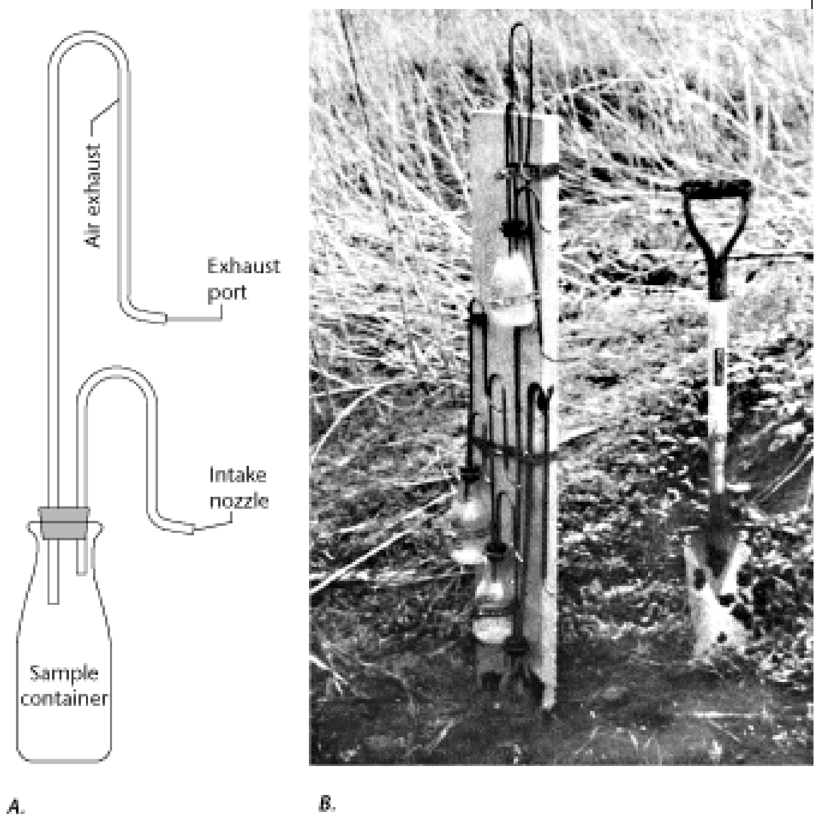


Figure 2-6. US U-59sampler: (*A*) single stage, and (*B*) a bank of U-59 samplers installed on a plank post. (A, from Edwards and Glysson, 1986; B, photograph by J.C. Mundorff.)

- ▶ The US U-59 is a simple container mounted to collect a water sample as stage rises above the sampler intake.
  - – The vertical-intake sampler is used to sample streams carrying sediments finer than 0.062 mm and is less likely to become clogged or fouled by floating solid materials than it is with a horizontal-type intake.
  - – The horizontal-intake sampler is used to sample streams carrying sediment coarser than 0.062 mm.
- ▶ The US U-73, which can be used to sample water during either rising or falling stage, is constructed to provide some protection from trash or other solids that could clog or foul the intake.

Automatic samplers and pumps

Automatic pumping samplers with fixed-depth intake(s)[4] are sometimes used to collect samples at remote sites; from ephemeral, small streams; or from urban storm drains where stage rises quickly (American Public Health Association and others, 1992; Edwards and Glysson, 1998). These samplers can be programmed to collect samples at preset time intervals or at selected stages, thus reducing the personnel requirements for time-intensive sampling. Whenever automatic samplers or pumps are used, the sample is considered to be a point or grab sample.

Pumps used for water sampling are grouped into two general categories: suction-lift pumps and submersible pumps. Pumps can be used to collect water samples from lakes, reservoirs, and estuaries (Radtke and others, 1984; Radtke, 1985; Ward and Harr, 1990). Suction-lift and submersible pumps are described in section 2.1.2, "Ground-Water Sampling Equipment."

2.1.1.C Support Equipment

Much of the equipment used to measure streamflow also can be used as support equipment when collecting water samples in water bodies that cannot be waded. Commonly used support equipment are listed in section 2.4.

Clean Hands/Dirty Hands techniques described in NFM 4 are required when sampling for trace elements (Horowitz and others, 1994) and are recommended as a general practice in sample collection, particularly when using heavy-duty support equipment.

Exercise great care to avoid sample contamination when using support equipment to handle samplers for collecting trace-element samples.

[4]Automatic pumping samplers include the US PS 69 and similar commercially available samplers, such as those manufactured by American Sigma, ISCO, and Manning.

GROUND-WATER SAMPLING EQUIPMENT 2.1.2

By **Jacob Gibs and F.D. Wilde**

The type of sampler or sampling system selected depends on type of well, depth to water from land surface, physical characteristics of the well, ground-water chemistry, and the analytes targeted for study. Selecting the appropriate equipment for collecting ground-water samples is important in order to obtain data that will meet study objectives and data-quality requirements. Ground-water sampling equipment is available from commercial sources.

Ground water most commonly is collected using either pumps designed specifically for water sampling from monitoring wells, pumps installed in supply wells, or a bailer or other point or thief-type sampler.[5] General considerations for selecting ground-water equipment are listed in table 2-4.

- ▶ Monitoring wells: Samplers can be portable, dedicated, or permanently installed in the well.
  - Portable equipment is commonly used at multiple well sites and cleaned after each use.
  - Portable samplers and sample tubing often are dedicated to be used only at a site with large contaminant concentrations.
  - Some types of portable equipment can be installed in a well for the duration of the monitoring program. Remove the sampler periodically for cleaning.
- ▶ Supply wells (for domestic, public (municipal), industrial or commercial, and agricultural use): Equipment selection is limited as such wells normally are equipped with permanent, large-capacity pumps.
  - Choice of equipment usually depends on well configuration and type of pump installation (permanent or temporary).
  - Modifications to the well and ancillary equipment attached at the wellhead are necessary in some cases (see section 2.1.2.A.)

---

[5]Additional categories of sampling equipment not described in this report include multilevel collection systems (LeBlanc and others, 1991; Smith and others, 1991; Gibs and others, 1993); samplers designed to collect ground water under natural-gradient flow conditions (Margaritz and others, 1989); and pump-and-packer systems.

Table 2-4. General requirements and considerations for selecting ground-water sampling equipment (pumps or thief samplers)

Requirements	Considerations
Construction materials	• Is the sampler constructed from materials that (initially or over time) could leach targeted analytes? If left in the well, is the sampler constructed of materials that will degrade appreciably within the lifetime of the study? • Can the sampler be cleaned? Can it withstand the level of decontamination needed and subsequently produce clean equipment blanks?
Operation, capabilities, and limitations	• Could operation of the sampler compromise sample integrity with respect to study objectives or data quality? For example, does the sampler heat or aerate the sample, or subject it to negative pressure, leading to volatilization of purgeable organic compounds, oxidation of target analytes, or changes in partial pressure of carbon dioxide? • Is the sampler capable of evacuating standing water (that is, can it be used for purging in addition to sample collection)? • Is the sampler capable of providing flow or sample volumes sufficient for sample collection and in a manner that minimizes suspension of sediments or colloids that could bias chemical measurements? • Is the sampler mechanically capable of withdrawing formation water from the desired depth?
Power requirements	• What are the power requirements of the sampler or the manner in which it will be deployed? Will it require electrical power (alternating or direct current), gasoline or other fuel-powered generators, or compressed gas such as air or nitrogen? • Will the capacity of the power source be sufficient to allow the sampler to run continuously throughout purging and sample collection? • Could the power source contaminate samples? (For example, gasoline-powered generators or compressors are a potential source of volatile organic compounds.) • Could the fuel be changed to a noncontaminating type (for example, convert a gasoline-powered generator to propane fuel)?
Transport	• Is the sampler easily transported to remote sites and rugged enough for field use?
Sampler repair	• Can the sampler be repaired in the field?
Availability and cost	• Are the available samplers suitable for study use? Are funds available to purchase, operate, and maintain the sampler?

Sampling equipment must not be a source of contamination or otherwise affect analyte concentration (table 2-1). Of specific importance for ground-water sampling is a potential change in ground-water chemistry due to atmospheric exposure.

- ▶ Select equipment that minimizes sample aeration.
- ▶ Select equipment that will not leach or sorb significant concentrations of the target analytes, with respect to data-quality requirements.
  - – Samplers that tested successfully[6] for inorganic constituents[7] were the Grundfos Redi-Flo2™, Fultz SP-300, bladder, and Bennett CF 800 submersible pumps, and double-check valve fluorocarbon polymer bailers.
  - – Samplers tested that achieved a greater than 95-percent recovery of volatile organic compounds were Grundfos Redi-Flo2™, Fultz SP-300, bladder pumps, and the Bennett pump. Recovery for double-check valve fluorocarbon polymer bailers was less than 95 percent (U.S. Geological Survey, 1992a and b).

Choice of equipment is constrained by many factors, including equipment construction and specifications. For example, it is necessary to consider the power requirements and lift capability of submersible pumps. Ideal equipment for sample collection might not exist, and compromise is often necessary. Field personnel must understand the application, advantages, disadvantages, and limitations of the available equipment with respect to study objectives and site characteristics and must document the compromises made.

[6]Unpublished results of testing by the USGS confirmed that commonly used sampling equipment does not, in general, affect sample concentrations of inorganic constituents or organic compounds (USGS-Office of Water Quality, written commun., 1994). (The samplers tested were precleaned and fitted with new, cleaned tubing and had fluorocarbon polymer interior parts, where available.)

[7]Trace-element concentrations in blank samples processed through these samplers were within the margin of analytical variability at a method reporting level of one microgram per liter.

2.1.2.A Pumps

Pumps transport water from depth to land surface either by suction lift or positive pressure.[8] The pumping mechanism for most suction-lift pumps (peristaltic, jet, and some nonsubmersible centrifugal pumps) is at land surface. Positive-pressure pumps (helical rotor, gear, bladder, piston, inertial submersible, and centrifugal pumps) are grouped together as submersible pumps because they are placed below static water level.

Supply-well pumps

Jet (venturi) pumps and above-land surface centrifugal pumps (fig. 2-7), as well as high-capacity submersible pumps and turbine pumps are common in domestic, municipal, and other supply wells.

- ▶ Be aware that large- and small-capacity pumps used in supply wells can affect analyte concentrations. (See NFM 1 and Lapham and others, 1997.)
  - – Erroneous data by using these pumps are most likely for dissolved gases, VOCs, and reduction-oxidation (redox) chemical species.
  - – Oil in the water column is common for oil-lubricated pumps.
  - – Chemical treatment systems and holding tanks can compromise sample integrity.

[8]For more detailed information on pumps, refer to manufacturers' instructions and specifications and to U.S. Environmental Protection Agency (1982b), Morrison (1983), Driscoll (1986), Imbrigiotta and others (1988), Ward and Harr (1990), American Public Health Association and others (1992), Gibs and others (1993), Sandstrom (1995), Koterba and others (1995), and Edwards and Glysson (1998).

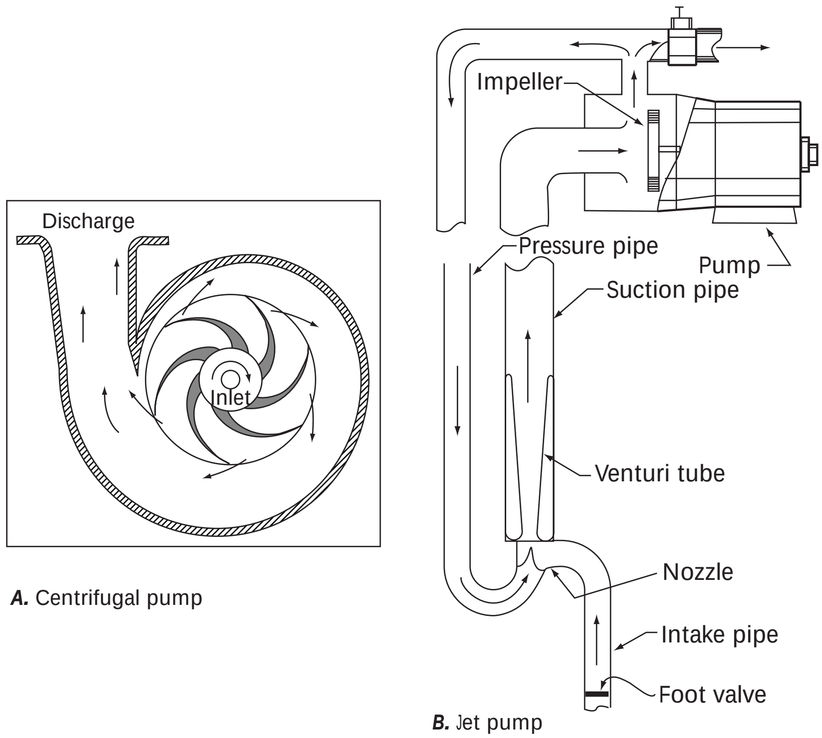


Figure 2-7. Pumps typically used to obtain water from supply wells: (*A*) centrifugal pump, and (*B*) jet pump. (From Driscoll, 1986, and published with permission of US Filter/Johnson Screens.)

- ▶ Install a hookup system for transfer of sample from the wellhead to the chamber or area where samples will be processed (NFM 4 and 5). Clean such equipment of oils and other manufacturing and shipping residues (NFM 3) before use.
  - – Ensure that the point of sample discharge from the hookup system on supply wells is ahead of chemical treatments or holding tanks. Obtain permission to modify the discharge point by installing a spigot or other plumbing appropriate to preserve the quality of the sample, if possible. Otherwise, do not use the well. The spigot or other plumbing also must be cleaned before use.
  - – Install an antibacksiphon device in line with the hookup system.

Monitoring-well pumps

Suction-lift and positive-displacement pumps are commonly used to collect water samples from monitoring wells. Field personnel should consider the criteria and guidelines listed in tables 2-4 and 2-5 when selecting a pump for sampling from monitoring wells.

- ▶ Suction-lift pumps create a vacuum in the intake line that draws the sample up to land surface (fig. 2-8*A*).
  - – The vacuum can result in the loss of dissolved gases and VOCs.
  - – Intake tubing could diffuse atmospheric gases sufficiently to affect some target analytes unless thick-walled low-diffusion tubing is used.
  - – Use of a peristaltic pump (1 to 2 L/min pumping rate) is limited to wells in which depth to water is less than about 25 ft (approximately 9 m). The operational lift may be as small as 20 ft.
  - – Peristaltic pumps have the advantages of few moving parts, easily replaceable heads, and portability.
  - – Provided that data quality is not compromised, properly operated peristaltic pumps can be used to obtain samples from shallow wells, especially those that produce small volumes of water.
- ▶ Submersible pumps (positive pressure or other types of positive-displacement pumps) designed specifically for collection of water samples from monitoring wells generally are preferred because they do not create a vacuum (fig. 2-8*B-E*).

Table 2-5. Examples of pump capability as a function of well and pump characteristics in a 2-inch-diameter well

[Table modified from Koterba and others (1995), p. 18-19. ft, foot; gal, gallon; TDH, total dynamic head; gal/min, gallon per minute; ~, approximately]

Well characteristics			Pump characteristics			
			Example: Fultz SP-300 (lift capacity is exceeded at ~160 ft)		Example: Grundfos RediFlo2™ (lift capacity is exceeded at ~260 ft)	
Water-column height (ft)	Lift or TDH[1] (ft)	Three-well-volume purge protocol[2] (gal)	Pumping rate at lift or TDH shown (gal/min)	Maximum capability after 2 hours pumping[3] (gal)	Pumping rate at lift or TDH shown (gal/min)	Maximum volume after 2 hours pumping (gal)
20	25	10	1.0	120	7.0	840
40	160	20	---	---	~4.8	538

[1]In these examples, the lift is equivalent to TDH and is estimated as the depth to water in the well (see Koterba and others, 1995, for explanation).
[2]Standard procedure is to purge a minimum of three well volumes while monitoring field measurements (NFM 4, NFM 6): purge volume = $V=0.0408HD^2$, where H is water-column height (in feet) and D is the well diameter (in inches).
[3]Maximum pumped volume is calculated from the pumping rate for a given pump system (from manufacturer's specifications) at the lift (or TDH) multiplied by an assumed total purging time of 2 hours (see Koterba and others, 1995).

- Do not use submersible pumps for well development. This can ruin the pump, shorten its functional life, or damage smooth internal surfaces, causing leaching of target analytes.
  - Install an antibacksiphon device in-line to prevent well contamination.
  - Select suitable materials for sample line, sample-line connectors (see "Pump tubing," section 2.2.4), and sample-line reels (see "Support equipment," section 2.1.2.C, and "Lists of Equipment and Supplies," section 2.4) for use with portable submersible pumps.

- ▶ The suitability and application of commonly used submersible pumps depends on pump and well characteristics and on practical constraints (tables 2-4 and 2-5). It is necessary to determine that
  - – the rate of pumping is suitable for a given lift (table 2-5)
  - – the maximum lift of the pump is not greater than the lift to land surface
  - – the power source is sufficient to allow the pump to run continuously throughout purging and sample collection
  - – the height of the water column is greater than the length of the pump plus 5 ft (to avoid getting the pump intake too close to the bottom of the well)
  - – the pumping rate will not cause excessive drawdown, resulting in intersection of the water level with the screen or open interval or causing the well to go dry.

Portability and repairability are important logistical considerations. All the pumps shown in figure 2-8 are made for transport to and from the field, but power requirements make some more awkward to transport to remote sites than others. The inertial-lift pump has no external power requirement. Bladders on bladder pumps can rupture, but are easily replaced in the field. The impellers used in gear pumps are subject to wear and can be replaced in the field but usually with some difficulty. (Fluorocarbon polymer impellers are easily abraded and ruined by particulate-laden water.) Submersible centrifugal pumps and piston pumps usually are not easily repaired in the field and can be awkward to transport manually, but combine other features such as variable speed and greater depth capabilities that make them favored for many applications.

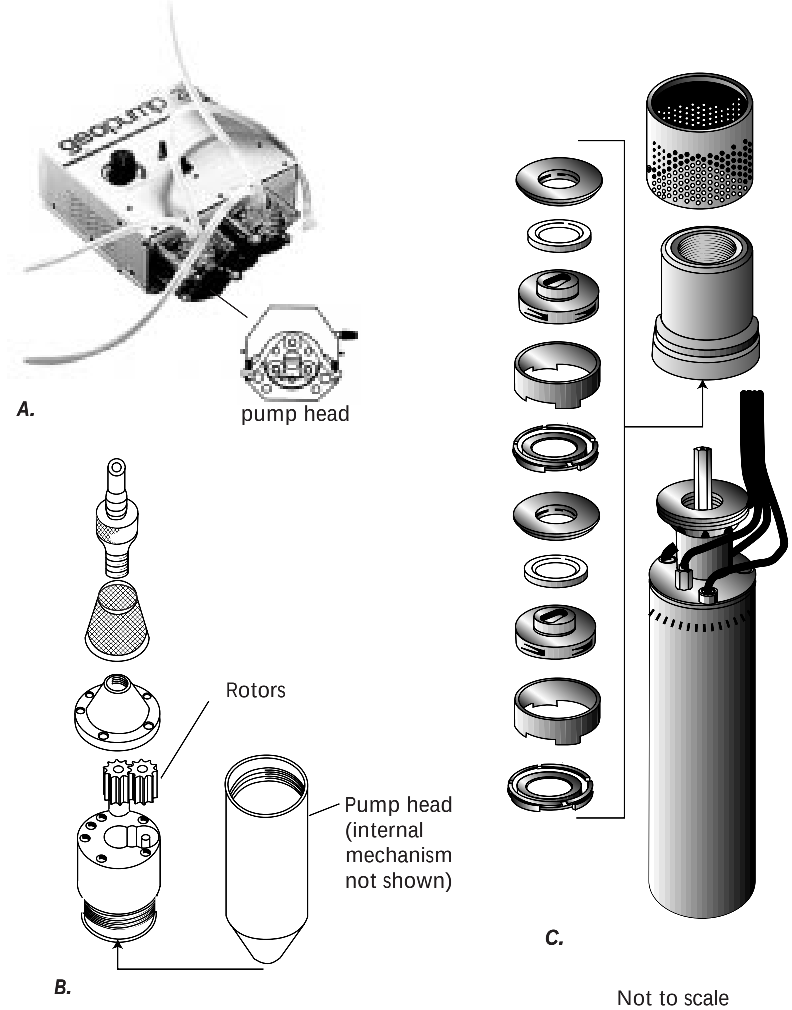


Figure 2-8. Pumps typically used for withdrawal of water samples from monitoring wells: (*A*) peristaltic suction-lift pump and (*B*-*F*) examples of submersible positive-displacement pumps: (*A*) peristaltic pump showing detail of pump head, (*B*) electrical gear or rotor pump, (*C*) electrical centrifugal impeller pump showing detail of impeller assembly. (Illustrations published with permission: *A*, GeoTech Environmental Equipment, Inc., with pump head from Cole-Parmer Instrument Company; *B*, Fultz Pumps, Inc.; *C*, Grundfos Pumps Corporation.)

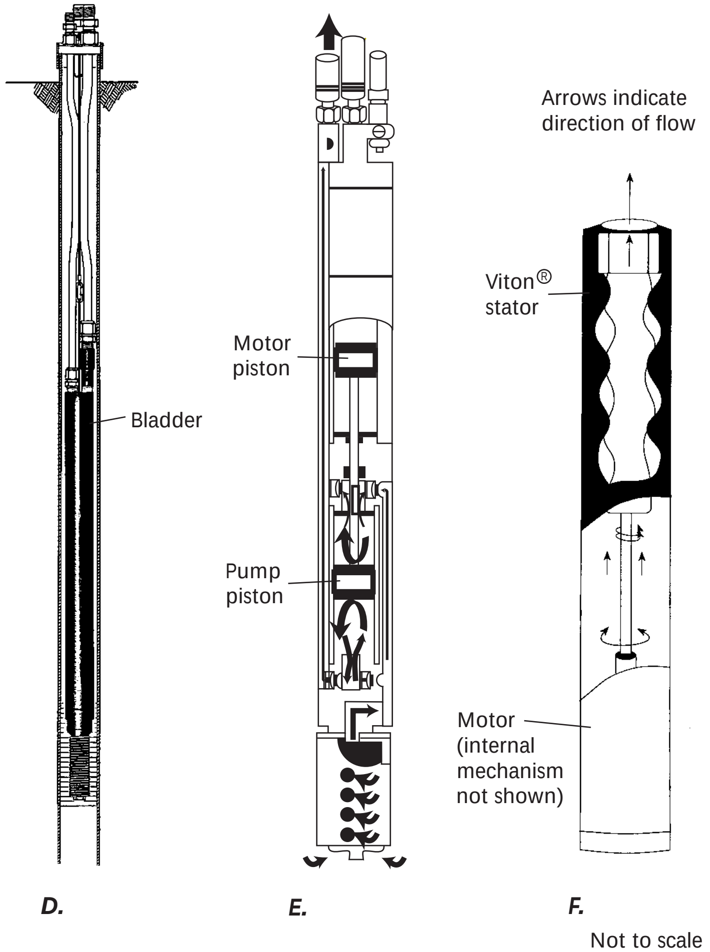


Figure 2-8. Pumps typically used for withdrawal of water samples from monitoring wells: (*A*) peristaltic suction-lift pump, and (*B-F*) examples of submersible positive-displacement pumps—*Continued*. (*D*) bladder pump, (*E*) reciprocating piston pump, and (*F*) progressing cavity pump. (Illustrations published with permission: *D*, GeoTech Environmental Equipment, Inc.; *E*, Bennett Sample Pumps, Inc.; *F*, Keck Instruments, Inc.)

Bailers and Specialized Thief Samplers 2.1.2.B

Use of a bailer or other thief sampler that is lowered and raised repeatedly in the well to collect a sample disturbs the water column and is not recommended for this reason. The disturbance can result in stirring up or mobilizing particulates, including colloidal matter or mineral precipitates that are artifacts of well construction and are not part of the ambient ground-water flow. This, in turn, can result in substantially greater than ambient concentrations of trace elements and hydrophobic organic compound(s).

Bailers

Bailers can have some necessary and useful applications, even though they are not generally recommended for ground-water sampling. Bailers are the only option available for sampling some ground-water systems, especially at great depth. Use of a bailer is preferred at sites where concentrations of contaminants are extremely large, because bailers are easier to clean (some are disposable) and less expensive to replace than pumps. The following recommendations apply in situations where bailers are the only reasonable choice for sampling wells:

- Select fluorocarbon polymer bailers with double check valves (fig. 2-5*C*), to ensure that a point sample has been collected and to help prevent sample aeration.
- Consider using disposable fluorocarbon polymer bailers (one use only) at sites where concentrations of contaminants are large.
- Use a bottom-emptying device through which the rate of sample flow can be controlled. Place bailer into a holding stand while emptying sample from the bailer through the bottom-emptying tube.
- Use either fluorocarbon polymer-coated or colorless (white) polypropylene line for lowering the sample; keep the line on a reel. Polypropylene is easy to clean and inexpensive, and can be discarded after one use.

Specialized thief samplers

Specialized sealed downhole samplers, grouped loosely under the thief-sampler category (fig. 2-5), are designed to capture and preserve in situ ground-water conditions by precluding sample aeration and pressure changes from sample degassing (escape of VOCs) or outgassing (escape of inorganic gases). Such sampling equipment includes syringe samplers (Gillham, 1982), true thief samplers (Ficken, 1988), samplers using hermetic isolation methods (Gibs and others, 1993; Torstensson and Petsonk, 1988), and chlorofluorocarbon (CFC) samplers (Busenberg and Plummer, 1992).

2.1.2.C. Support Equipment

The support equipment used during ground-water sampling depends on the type and size of the pump or sampler used, field conditions, and depth to water or to sampling interval in the well. A reel should be used for efficient and clean deployment of the sample line. Commonly used support equipment is listed in section 2.4. A detailed description of the various types of support equipment is beyond the scope of this manual; refer to Corbett and others (1943), Buchanan and Somers (1969), and Rantz and others (1982).