Techniques of Water-Resources Investigations

Book 9
Handbooks for Water-Resources Investigations

National Field Manual for the Collection of Water-Quality Data

Chapter A2.
SELECTION OF EQUIPMENT FOR WATER SAMPLING

Edited by
Franceska D. Wilde, Dean B. Radtke, Jacob Gibs, and Rick T. Iwatsubo

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Foreword

The mission of the Water Resources Division of the U.S. Geological Survey (USGS) is to provide the information and understanding needed for wise management of the Nation's water resources. Inherent in this mission is the responsibility to collect data that accurately describe the physical, chemical, and biological attributes of water systems. These data are used for environmental and resource assessments by the USGS, other government and scientific agencies, and the general public. Reliable and objective data are essential to the credibility and impartiality of the water-resources appraisals carried out by the USGS.

The development and use of a *National Field Manual* is necessary to achieve consistency in the scientific methods and procedures used, to document those methods and procedures, and to maintain technical expertise. USGS field personnel use this manual to ensure that data collected are of the quality required to fulfill our mission.

Robert M. Hirsch
Chief Hydrologist

Techniques of Water-Resources Investigations

Book 9
Handbooks for Water-Resources Investigations

Chapters of Section A: National Field Manual for the Collection of Water-Quality Data

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[1]**Bold type indicates published chapters and chapter sections, and** shaded type **indicates chapters and chapter sections that are in preparation.**

SELECTION OF EQUIPMENT FOR WATER SAMPLING

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Chapter A2. SELECTION OF EQUIPMENT FOR WATER SAMPLING

***Edited by* Franceska D. Wilde, Dean B. Radtke, Jacob Gibs, and Rick T. Iwatsubo**

ABSTRACT

The *National Field Manual for the Collection of Water-Quality Data (National Field Manual)* describes protocols and provides guidelines for U.S. Geological Survey (USGS) personnel who collect data used to assess the quality of the Nation's surface-water and ground-water resources. This chapter of the manual addresses the selection of equipment commonly used by USGS personnel to collect and process water-quality samples.

Each chapter of the *National Field Manual* is published separately and revised periodically. Newly published and revised chapters will be announced on the USGS Home Page on the World Wide Web under "New Publications of the U.S. Geological Survey." The URL for this page is <http://water.usgs.gov/lookup/get?newpubs>.

INTRODUCTION

As part of its mission, the U.S. Geological Survey (USGS) collects data needed to assess the quality of our Nation's water resources. The *National Field Manual for the Collection of Water-Quality Data (National Field Manual)* describes protocols (requirements and recommendations) and provides guidelines for USGS personnel who collect those data on surface-water and ground-water resources. Chapter A2 provides information about equipment used to collect and process water samples. Requirements, recommendations, and guidelines are described that pertain to the selection and use of field equipment by USGS personnel.

Formal training and field apprenticeship are needed in order to correctly implement the requirements and recommendations described in this chapter.

The *National Field Manual* is Section A of Book 9 of the USGS publication series "Techniques of Water-Resources Investigations" and consists of individually published chapters. Chapter numbers are preceded by an “A” to indicate that the report is part of the *National Field Manual*. Chapters of the *National Field Manual* are referred to in the text by the abbreviation "NFM" followed by the chapter number (or chapter and section number). For example, NFM 4 refers to Chapter 4 on "Collection of Water Samples," and NFM 4.1 refers to the section on surface-water sampling methods.

PURPOSE AND SCOPE

The *National Field Manual* is targeted specifically toward field personnel in order to (1) establish and communicate scientifically sound methods and procedures, (2) provide methods that minimize data bias and, when properly applied, result in data that are reproducible within acceptable limits of variability, (3) encourage consistent use of field methods for the purpose of producing nationally comparable data, and (4) provide citable documentation for USGS water-quality data-collection protocols.

The purpose of chapter 2 of the *National Field Manual* is to provide field personnel and other interested parties with a description of the requirements, recommendations, and guidelines routinely used for equipment selection in USGS studies involving the collection and processing of water-quality samples. (The terms "required" and "recommended," as used in this report, are explained below under "Requirements and Recommendations.") The information provided covers topics fundamental to the collection and processing of surface-water and ground-water samples that are representative of the ambient environment. This chapter does not attempt to encompass the entire spectrum of data-collection objectives, site characteristics, environmental conditions, and technological advances related to water-quality studies. Also beyond the scope of this chapter is discussion of equipment to collect and process samples for analysis of suspended solids or biological materials.

REQUIREMENTS AND RECOMMENDATIONS

As used in the *National Field Manual*, the terms required and recommended have USGS-specific meanings.

Required (require, required, or requirements) pertains to USGS protocols and indicates that USGS Office of Water Quality policy has been established on the basis of research and (or) consensus of the technical staff and has been reviewed by water-quality specialists and selected District[1] or other professional personnel, as appropriate. Technical memorandums or other internal documents that define the policy pertinent to such requirements are referenced in this manual. Personnel are instructed to use required equipment or procedures as described herein. Departure from or modifications to the stipulated requirements that might be necessary to accomplishing specific data-quality requirements or study objectives must be based on referenced research and good field judgment, and be quality assured and documented.

Recommended (recommend, recommended, recommendation) pertains to USGS protocols and indicates that USGS Office of Water Quality policy recognizes that one or several alternatives to a given procedure or equipment selection are acceptable on the basis of research and (or) consensus. References to technical memorandums and selected publications pertinent to such recommendations are cited in this chapter to the extent that such documents are available. Specific data-quality requirements, study objectives, or other constraints affect the choice of recommended equipment or procedures. Selection from among the recommended alternatives should be based on referenced research and good field judgment, and reasons for the selection must be documented. Departure from or modifications to recommended procedures must be quality assured and documented.

[1]"District" refers to an organizational unit of the USGS, Water Resources Division, in any of the States or Territories of the United States.

FIELD MANUAL REVIEW AND REVISION

Chapters of the *National Field Manual* will be reviewed, revised, and reissued periodically to correct any errors, incorporate technical advances, and address additional topics. Comments or corrections can be sent to NFM-QW, USGS, 412 National Center, Reston, VA 20192 (or send electronic mail to nfm-owq@usgs.gov). Newly published and revised chapters will be announced on the USGS Home Page on the World Wide Web under "New Publications of the U.S. Geological Survey." The URL for this page is <http://water.usgs.gov/lookup/get?newpubs>.

ACKNOWLEDGMENTS

The information included in this chapter of the *National Field Manual* is based on existing manuals, various reference documents, and a broad spectrum of colleague expertise. In addition to the references provided, important source materials included USGS handbooks, manuals, and technical memorandums. The following USGS personnel developed the manuals that provided the foundation for this *National Field Manual*: M.E. Dorsey, T.K. Edwards, W.B. Garrett, W.J. Gibbons, R.T. Kirkland, L.R. Kister, J.R. Knapton, M.T. Koterba, C.E. Lamb, W.W. Lapham, R.F. Middelburg, Jr., J. Rawson, L.R. Shelton, M.A. Sylvester, and F.C. Wells.

The editors wish to thank and pay tribute to R.W. Lee and S.W. McKenzie for their final technical reviews, which contributed to the accuracy and quality of this report. The technical content of this report was enhanced by expertise from B.A. Bernard, Dallas Childers, Jr., T.K. Edwards, G.D. Glysson, J.R. Gray, A.J. Horowitz, H.E. Jobson, J.W. LaBaugh, R.H. Meade, Jr., W.C. O'Neal, R.L. Rickman, S.K. Sando, J.V. Skinner, R.L. Snyder, and Y.E. Stoker. Valuable editorial assistance was provided by I.M. Collies, C.M. Eberle, B.B. Palcsak, and Chester Zenone. Production assistance from L.S. Rogers, C.T. Mendelsohn, L.E. Menoyo, and A.M. Weaver was instrumental in maintaining the quality of this report.

Special thanks go to T.L. Miller, whose encouragement and faith in this project has been instrumental to its achievement, and to D.A. Rickert and J.R. Ward for providing the support needed to produce a national field manual for water-quality studies.

Appreciation is extended to the following companies who granted us permission to publish their illustrations in this manual: Bennett Sample Pumps, Inc., Amarillo, Tex.; Cole-Parmer Instrument Company, Vernon Hills, Ill.; Fultz Pumps, Inc., Lewistown, Pa.; Gelman Sciences, Ann Arbor, Mich.; GeoTech Environmental Equipment, Inc., Denver, Colo.; Keck Instruments, Inc., Williamston, Mich.; Savillex Corporation, Minnetonka, Minn.; Timco Manufacturing Company, Prairie du Sac, Wis.; US Filter/Johnson Screens, St. Paul, Minn.; and Wildlife Supply Company, Saginaw, Mich.

SELECTION OF EQUIPMENT FOR WATER SAMPLING A2.

***Edited by* F.D. Wilde, D.B. Radke, Jacob Gibs, and R.T. Iwatsubo**

This chapter provides information to assist field personnel in selecting the water-collection and -processing equipment[2] that are appropriate to study objectives, data-quality requirements[3], and site conditions. Selection of equipment for collecting or processing water-quality samples depends on the physical constraints and safe operation of the equipment and on its suitability with respect to achievement of study objectives. Criteria for selecting equipment for water sampling depend on (1) the mechanical constraints of the equipment to perform adequately under given environmental conditions, (2) the adequacy of equipment operation to obtain water-quality samples that represent the environmental conditions of the sample source, and (3) the adequacy of the equipment materials and construction to maintain sample integrity and not be a source of leaching and sorption of chemical substances.

- ▶ Always operate equipment safely.
- ▶ Be thoroughly familiar with requirements for equipment operation and maintenance.
- ▶ Be aware of the limitations as well as applications of the equipment with respect to your field site.
- ▶ Maintain and test each piece of equipment on a regular schedule. Record test procedures, test results, and repairs in a logbook dedicated to the equipment.

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[2]Equipment used for field measurements of physical or chemical properties of water (temperature, dissolved oxygen, specific electrical conductance (conductivity), pH, reduction-oxidation potential, alkalinity, and turbidity) is described in NFM 6; equipment used for biological indicator determination is described in NFM 7; equipment used for bottom-material sampling is described in NFM 8; and safety equipment is described in NFM 9

[3]As used in this publication, the term data-quality requirements refers to that subset of data-quality objectives pertaining specifically to the analytical detection level for concentrations of target analytes and the variability (or error brackets) allowable to fulfill the scientific objectives of the study.

CHEMICAL COMPATIBILITY OF EQUIPMENT AND THE WATER SAMPLE 2.0

***By* D.B. Radtke and F.D. Wilde**

The materials used to construct equipment can directly affect sample chemistry (table 2-1). Equipment designed for water-quality work commonly is constructed of a combination of materials, the most inert being used for components that will contact the sample. Nonsample-wetted components also can be a source of sample contamination, and field personnel must use techniques to minimize potential contamination, implement quality-assurance procedures, and quantify potential effects by using quality-control sample analysis.

When planning equipment use, consider having several sets of precleaned equipment available. A clean set of equipment for each sampling site prevents cross contamination between sites, eliminates the need for time-consuming equipment cleaning in the field, and serves as backup should equipment break or become greatly contaminated.

Check that the equipment to be used will not affect the sample chemistry.

Materials used in equipment can include plastics, glass, and metals. Chemical reactivity varies widely within the same group of materials, depending on the chemical composition, the physical configuration, and the manufacturing process. Thus, regarding reactivity with water and most other chemical substances, plastics such as fluorocarbon polymers are less reactive than plastics such as polyethylene, and 316-type stainless steel (SS 316) is less reactive than brass, iron, or galvanized steel. For plastics and metals in general:

- The softer or more flexible forms of any plastic or metal are more reactive than the rigid forms.
- The more polished the surface, the less reactive the material tends to be.

Table 2-1. General guidelines for selecting equipment on the basis of construction material and target analyte(s)

[✓, generally appropriate for use shown; Si, silica; Cr, chromium; Ni, nickel; Fe, iron; Mn, manganese; Mo, molybdenum; $^3H/^3He$, tritium/helium-3; CFC, chlorofluorocarbon; B, boron]

Construction material for sampling equipment (does not apply to well casing)		Target analyte(s)	
Material	Description	Inorganic	Organic
Plastics[1]			
Fluorocarbon polymers[2] (other varieties available for differing applications)	Chemically inert for most analytes.	✓ (Potential source of fluoride.)	✓ (Sorption of some organics.)
Polypropylene	Relatively inert for inorganic analytes.	✓	Do not use.
Polyethylene (linear)	Relatively inert for inorganic analytes.	✓	Do not use.
Polyvinyl chloride (PVC)	Relatively inert for inorganic analytes.	✓	Do not use.
Silicone	Very porous. Relatively inert for most inorganic analyte(s).	✓ (Potential source of Si.)	Do not use.
Metals[3]			
Stainless steel 316 (SS 316)	SS-316—metal having the greatest corrosion resistance. Comes in various grades. Used for submersible pump[3] casing.	✓ (Potential source of Cr, Ni, Fe, and possibly Mn and Mo.) Do not use for surface water unless encased in plastic (does not apply to submersible pumps).	✓ Do not use if corroded.[4]
Stainless steel 304	Similar to SS 316, but less corrosion resistant.	Do not use.	✓ Do not use if corroded.[4]
Other metals: brass, iron, copper, aluminum, galvanized and carbon steels	Refrigeration-grade copper or aluminum tubing are used routinely for collection of $^3H/^3He$ and CFC samples.	Do not use. (except as noted for isotopes).	✓ Routinely used for CFCs. Do not use if corroded.
Glass			
Glass, borosilicate (laboratory grade)	Relatively inert. Potential sorption of analytes.	✓ Potential source of B and Si.	✓

[1]Plastics used in connection with inorganic trace-element sampling must be uncolored or white (Horowitz and others, 1994).
[2]Fluorocarbon polymers include materials such as Teflon™, Kynar™, and Tefzel™ that are relatively inert for sampling inorganic or organic analytes.
[3]Most submersible sampling pumps have stainless steel components. One can minimize effects on inorganics sample by using fluorocarbon polymers in construction of sample-wetted components (for example, for a bladder, stator, impeller) to the extent possible.
[4]Corroded/weathered surfaces are active sorption sites for organic compounds.

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.

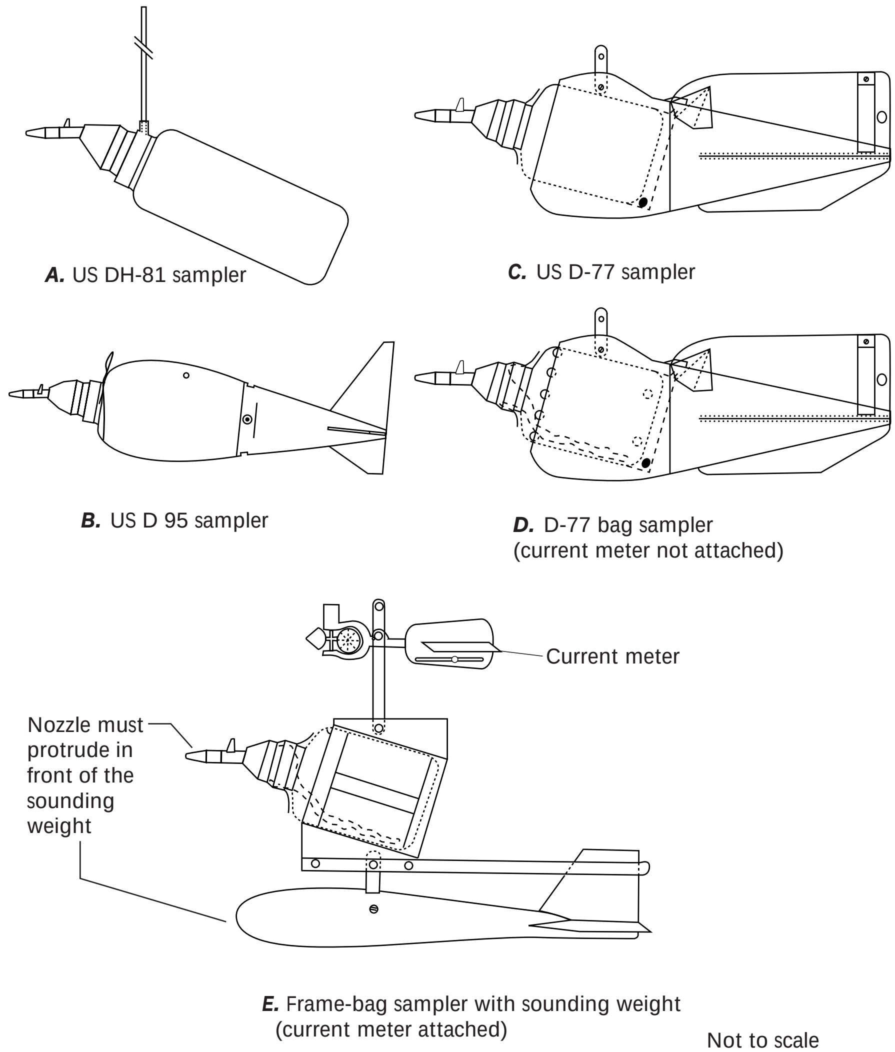


Figure 2-1. Isokinetic depth-integrating samplers: (*A*) US DH-81, (*B*) US D-95, (*C*) US D-77, (*D*) D-77 Bag without current meter attached, and (*E*) Frame-Bag sampler with sounding weight and current meter attached. (Illustrations courtesy of Federal Interagency Sedimentation Project, Waterways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

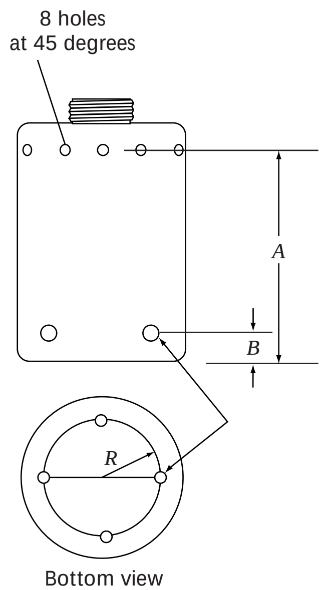
- Use a 1/4- or 5/16-in. nozzle.
- Make sure that flow velocity exceeds 3 ft/s (to collect an isokinetic sample). Isokinetic capability decreases at flow velocities less than 3 ft/s.
- Use in water with depth greater than 15 ft for an isokinetic, depth-integrated sample.
- Make sure that a clean, noncontaminating 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:

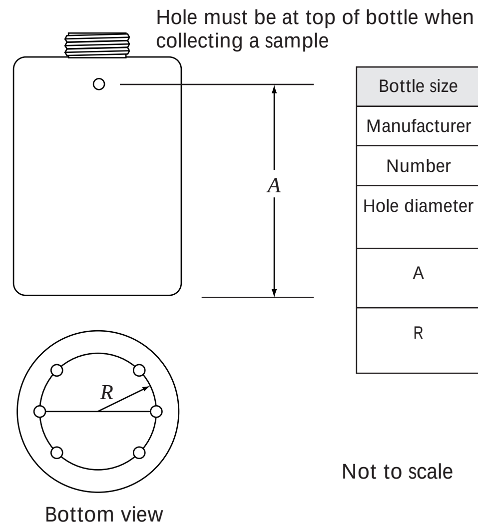
- Use a 3/16-, 1/4- or 5/16-in. nozzle (not a 1/8-in. nozzle).
- Make sure that flow velocity exceeds 3.0 ft/s (to collect an isokinetic sample).
- Keep a clean, noncontaminating object such as a glass BOD bottle stopper or a fluorocarbon polymer-coated magnetic stirring bar in the bag. Do not use a 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.

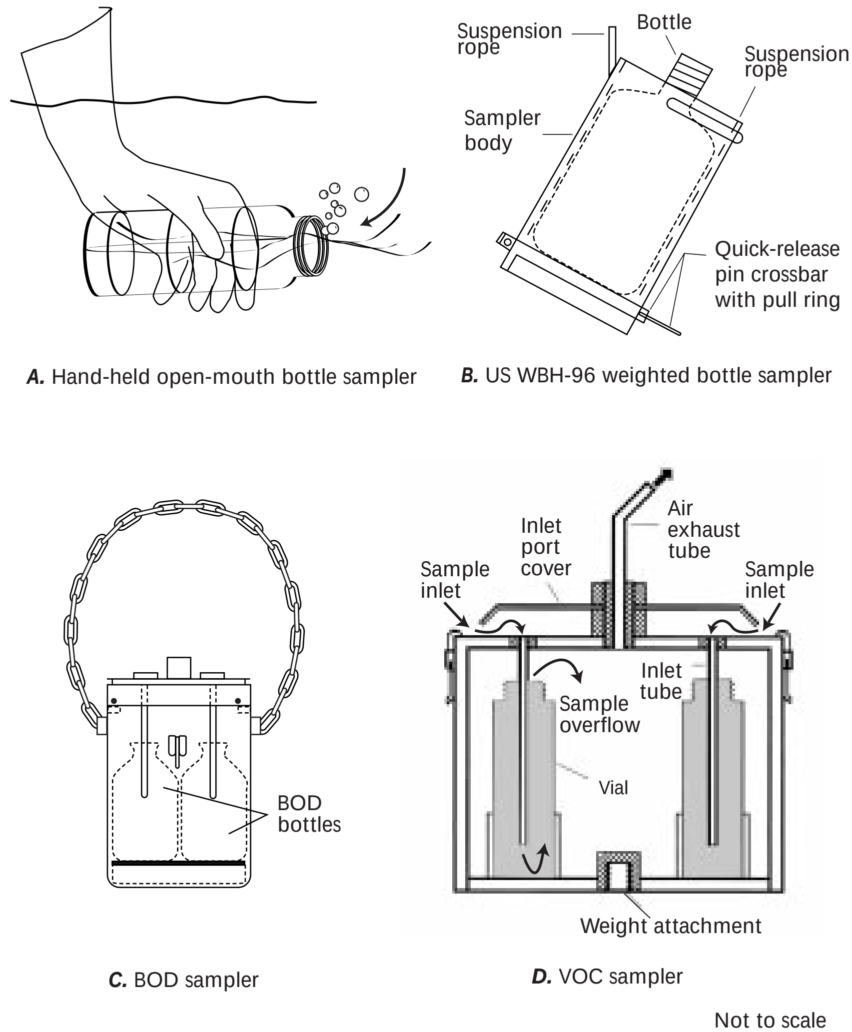


Figure 2-4. Examples of nonisokinetic open-mouth samplers: (*A*) hand-held open-mouth bottle sampler, (*B*) US WBH-96 weighted-bottle sampler, (*C*) biochemical oxygen demand (BOD) sampler, and (*D*) volatile organic compound (VOC) sampler. (*A*, from U.S. Environmental Protection Agency, 1982b; *B*, 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.

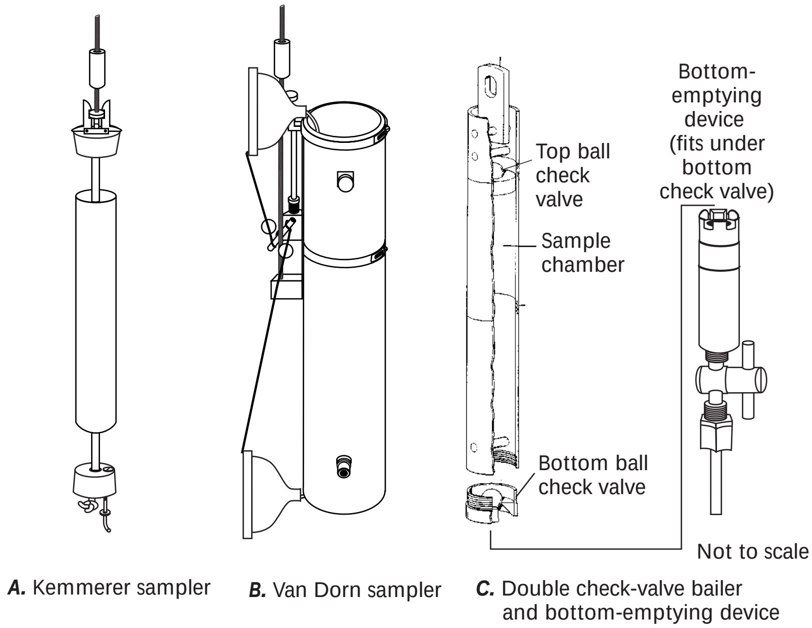


Figure 2-5. Examples of nonisokinetic thief samplers: (*A*) Kemmerer sampler, (*B*) Van Dorn sampler, and (*C*) double check-valve bailer with bottom-emptying device. (*A-B*, from *Standard Methods for Examination of Water and Wastewater*, 18th Edition. Copyright 1992 by the American Public Health Association,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

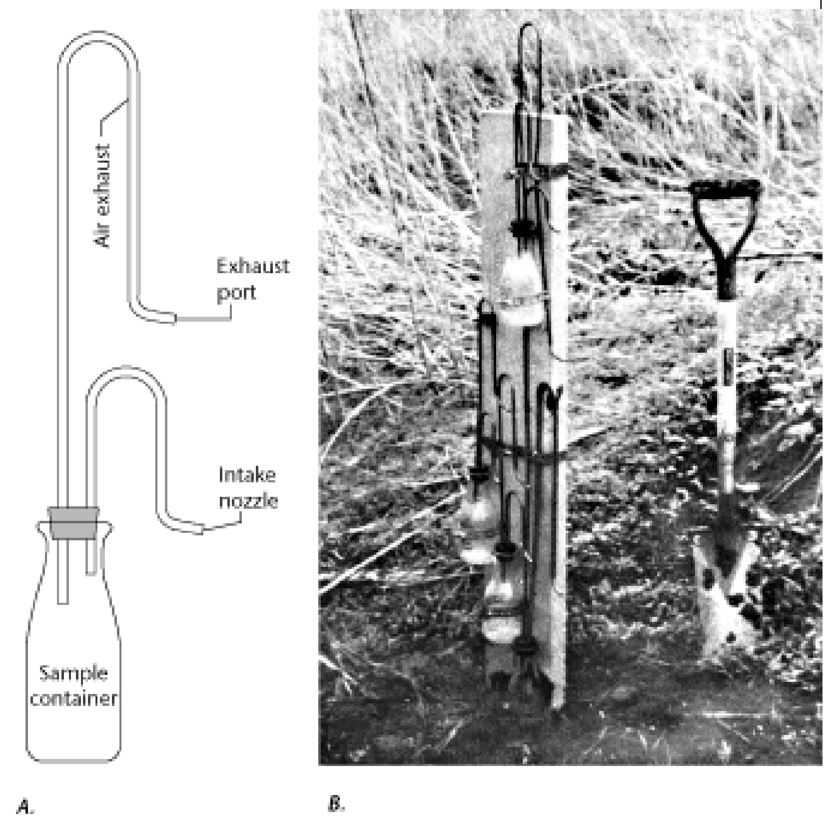


Figure 2-6. US U-59sampler: (*A*) single stage, and (*B*) a bank of U-59 samplers installed on a plank post. (A, from Edwards and Glysson, 1986; B, photograph by J.C. Mundorff.)

- 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.)

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[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.

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[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).

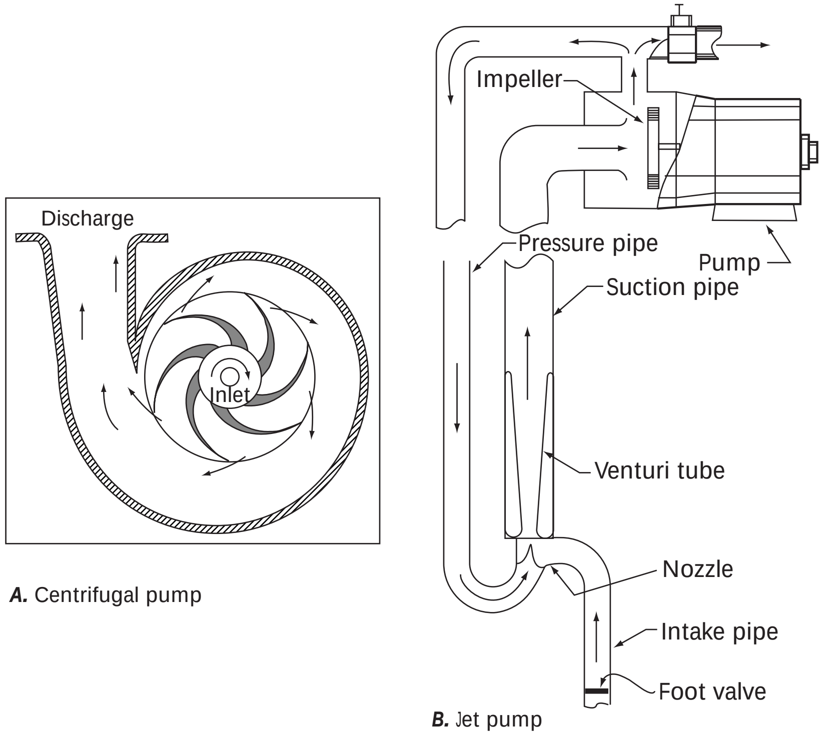


Figure 2-7. Pumps typically used to obtain water from supply wells: (*A*) centrifugal pump, and (*B*) jet pump. (From Driscoll, 1986, and published with permission of US Filter/Johnson Screens.)

- ▶ 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.

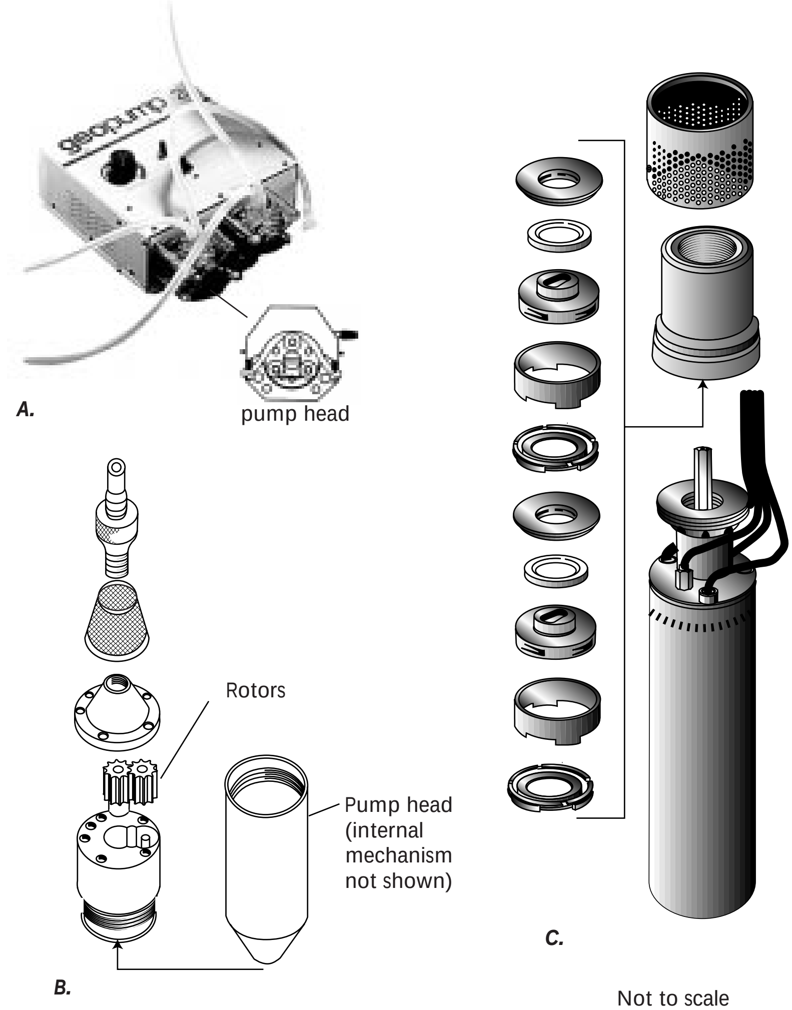


Figure 2-8. Pumps typically used for withdrawal of water samples from monitoring wells: (*A*) peristaltic suction-lift pump and (*B-F*) examples of submersible positive-displacement pumps: (*A*) peristaltic pump showing detail of pump head, (*B*) electrical gear or rotor pump, (*C*) electrical centrifugal 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.)

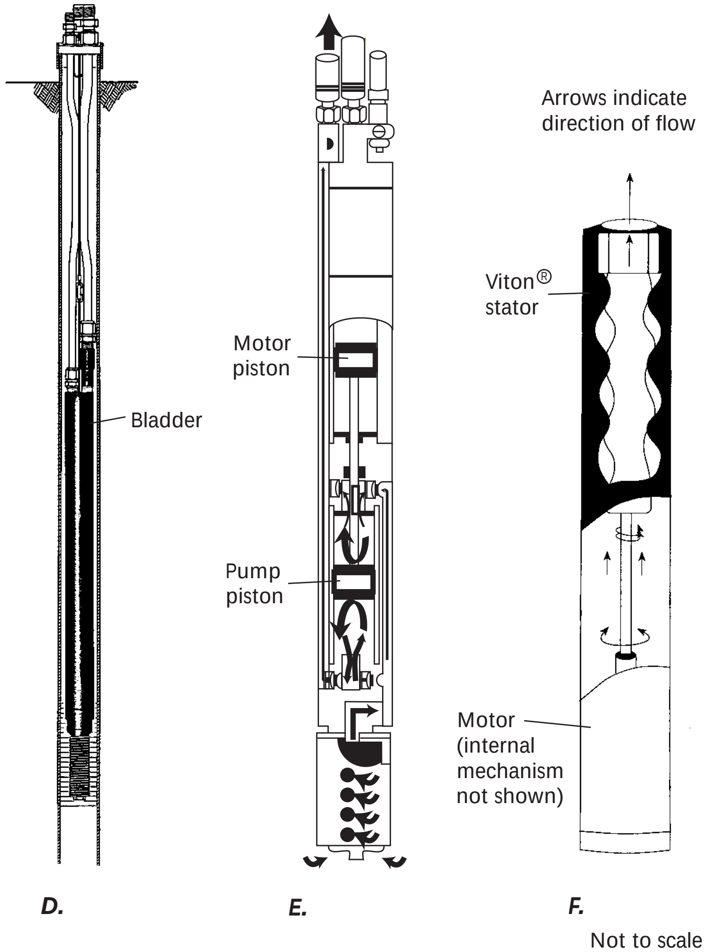


Figure 2-8. Pumps typically used for withdrawal of water samples from monitoring wells: (*A*) peristaltic suction-lift pump, and (*B*-*F*) examples of submersible positive-displacement pumps—*Continued*. (*D*) bladder pump, (*E*) reciprocating piston pump, and (*F*) progressing cavity pump. (Illustrations 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).

SAMPLE PROCESSING 2.2

By D.B. Radtke, F.D. Wilde, M.W. Sandstrom, and K.K. Fitzgerald

Water samples must be processed as quickly as possible after collection. The equipment most commonly used for sample processing includes sample splitters, filtration units or assemblies, solid-phase extraction systems, and chambers in which samples are processed and treated with chemical preservatives. Having several available sets of cleaned processing equipment is recommended. The equipment and supplies used to process surface-water and ground-water samples are listed in section 2.4.

SAMPLE SPLITTERS 2.2.1

The collection of surface water generally results in a single composite sample. A ground-water sample generally is not composited; instead the sample is pumped directly into separate bottles for designated analyses. There are exceptions. For example, a ground-water sample can be composited when the sample is collected using a nonpumping method (bailer or thief sampler).

Once a sample has been composited, the sample is often subdivided (split) into subsamples for analysis. Each whole-water subsample should contain suspended and dissolved concentrations of target analytes that are virtually equal to those in every other subsample. Uses of the churn splitter (fig. 2-9) and the cone splitter (fig. 2-10) are discussed in sections 2.2.1.A and 2.2.1.B, respectively, and testing and comparative data between the splitters are described in Capel and others (1995, 1996) and in Office of Water Quality Technical Memorandum 97.06.

2.2.1.A Churn Splitter

The 8 or 14-L plastic churn splitter is recommended to composite and split surface-water samples for trace-element analysis (fig. 2-9). Stainless steel and glass containers are used to composite samples for organic analysis. To avoid sample contamination, do not collect or extract samples for trace-element analyses from a metal container, or samples for organic-compound analysis from a nonflurocarbon-polymer plastic container.

The following modifications to the churn splitter and its deployment are required:

- Modified churn spigot: This spigot is described in Horowitz and others (1994) and is available from the USGS Quality of Water Service Unit (QWSU) in Ocala, Fla.
  - The spigot contains a metal spring to keep the spigot valve closed when not in use. If the spigot leaks, sample can contact the spring. The spring represents a potential source of metal contamination.
  - To prevent leakage of the spigot, silicone sealant is injected inside the push-button mechanism.

Figure 2-9. Churn splitter (from Capel and Larson, 1996).

- Funnel assembly: To meet requirements for trace-element sampling, a funnel assembly is inserted into a 1-in. hole drilled through the lid of the churn splitter (fig. 2-9).
  - The funnel is used when pouring whole-water samples into the churn splitter so that the churn lid can be left on, thus minimizing exposure of the composite sample to atmospheric contamination.
  - To make the funnel assembly, cut the top section (at the shoulder line) from a 1-L polypropylene sample bottle and insert into the hole drilled in the churn lid. Cut the bottom two-thirds from of a 1-L NALGENE™ or other larger diameter sampler bottle and use as a funnel cap.
- Churn covering: To keep the entire churn-splitter assembly clean during sampling and prevent potential contamination, the churn splitter is placed inside two pliable, clear plastic bags (double bagged). These bags should be large enough to completely enclose the churn splitter, including funnel and churn handle, with enough excess material so that the bag openings can be gathered, folded over, and kept closed.
- Churn carrier: The carrier is a white plastic container, with lid, large enough to hold the double-bagged churn splitter assembly.
  - The lid of the carrier serves both as a seal for the carrier and as a windbreak when the collected subsample is poured into the churn funnel.
  - The purpose of the carrier is to minimize contamination during transport. In exposed areas, such as bridges and roadways, the carrier can protect against atmospheric sources of contamination, particularly material from motor vehicles.

Volume of sample needed:

- Subsamples totaling 10 L can be withdrawn from the 14-L churn for whole-water analysis, whereas subsamples totaling 5 L can be withdrawn from the 8-L churn for whole-water analysis.
- The 4 L remaining in the 14-L churn and the 3 L remaining in the 8-L churn should not be used for total, total recoverable, or suspended material subsamples because they will not be representative. However, the sample mixture remaining in either churn can be used for filtered subsamples for the determination of dissolved constituents.

Advantages of the churn splitter:

- Simple to operate.
- Easy to clean.

Limitations of the churn splitter (see also Ward and Harr (1990), Horowitz and others (1994), and Capel and Larson (1996), and Office of Water Quality Technical Memorandum 97.06):

- Although it can be used to split samples with particle sizes ≤ 250 µm and suspended-sediment concentrations ≤ 1,000 mg/L, splitting accuracy becomes unacceptable for particle sizes >250 µm and suspended-sediment concentrations >1,000 mg/L.
- Sample volumes less than 3 L or greater than 13 L cannot be split for whole-water subsamples.
- Plastic (nonfluorocarbon polymer) churn splitters should not be used to composite samples for determination of organic compounds.
- Samples for bacteria determinations are not to be taken from a churn splitter because the splitter cannot be autoclaved.

Cone Splitter 2.2.1.B

The cone splitter is a pour-through device constructed entirely of fluorocarbon polymers (fig. 2-10). The cone splitter may be used to process samples with particle sizes ≤ 250 µm and suspended-sediment concentrations ≤ 10,000 mg/L. Its primary function is to split the sample simultaneously into as many as 10 equal-volume samples. Some cone splitters have a 2-mm mesh screen in the reservoir funnel to retain large debris, such as leaves and twigs, that could clog or interfere with the splitting process. Below the funnel is a short standpipe that directs sample water in a steady stream, into a splitting chamber that contains a notched, cone-shaped splitting head with 10 equally spaced exit ports around its base. There should be no ridges, benches, or surfaces inside the splitting chamber that could retain material or interfere with the splitting process. The cone splitter is supported either by tripod legs or with an adjustable clamp and stand.

Figure 2-10. Cone splitter (from Capel and Larson, 1996).

The cone splitter is built to very close tolerances in order to achieve accurate and reliable operation. Bias to data can result from splitter imperfections or improper operation; therefore, calibration and proper use is necessary when processing samples.

Advantages of the cone splitter

- Used to process samples with suspended-sediment concentrations from 1,000 to 10,000 mg/L.
- Samples as small as 250 mL can be split into 10 equal subsamples.
- Samples greater than 13 L can be processed.
- Samples to be analyzed for organic compounds (except for volatile organic compounds) can be processed through the fluorocarbon polymer cone splitter.
- Samples containing sediment particles ranging in size from very fine clay and silt (1 to 10 µm) to sand-size particles (250 µm) can be split.

Limitations of the cone splitter

- Accuracy of the volume equivalents must be verified before using a new or modified cone splitter (see instructions below).
- Splitter is awkward to operate and clean in the field.
- Sample is vulnerable to contamination from atmospheric sources or from improper operation.
- Splitting capability for sediment particles >250 µm must be quantified.
- Samples for bacteria determinations are not to be collected with the cone splitter because the splitter cannot be adequately sterilized.
- The cone splitter must be level for proper operation.

Before using a new or modified cone splitter, test the splitter to be used as follows (Office of Water Quality Technical Memorandum 80.17):

1. Inspect the cone splitter housing and outlet ports. They should be smooth and symmetrical without any visible burrs or chips. The cone splitter must be clean.

2. Place the cone splitter on a stable platform or bench. The splitter must be level for proper operation. Use a bull's-eye level to check leveling and recheck during use (leveling changes with movement in the field vehicle).

3. Connect 10 discharge tubes to the outlet ports. The tubes must be the same length, and as short as possible. Label the outlets from 1 to 10.

   - All tubes must be pushed in as far as possible to the machined surface in the Swagelok™ fitting in the splitter ports. The ends should be flush with the bottom of the inside of the port.
   - Tubes need only extend into the receiving containers sufficiently to prevent spillage.
   - Tubes must not extend in so far that the ends become submerged.

4. Wet the cone splitter by pouring several liters of deionized water through it.

   - Lightly tap the system to dislodge adhering water drops, then discard the water.
   - Place empty sample bottle under each outlet tube.

5. Accurately measure 3 L of deionized water into a 1-gal narrow-mouth plastic bottle.

6. Rapidly invert the 1-gal bottle over the reservoir, letting deionized water flow out as fast as possible. For proper operation, the standpipe must be discharging at its full flowing capacity.

7. After all deionized water has passed through the splitter, tap the assembly several times to dislodge adhering water drops. Check for spills and leaks. If any are observed, stop the test, correct the problem, and repeat steps 1-7.

8. Measure the volumes of the 10 subsamples carefully, within an accuracy of ±1.0 mL. Record the volumes for each outlet on a form similar to table 2-6.

9. Repeat the test a minimum of three times. Use the same initial volume for each test.

Calculate and document the results of the cone-splitter accuracy test as follows:

1. Referring to the example in table 2-6, calculate the mean volume of each subsample ($\bar{x}$) and standard deviation (S_x) for each test:

$$\bar{x} = \frac{\Sigma x_i}{n} \text{ and}$$

$$S_x = \sqrt{\frac{\sum (x_i - \bar{x})^2}{n-1}},$$

where x_i is the measured volume for each subsample and
n is the number of subsamples (outlet ports).

2. Calculate the standard deviation in percent (E_x):

$$E_x = \frac{S_x}{\bar{x}} \text{ x } 100.$$

3. Calculate the error for each subsample (E_i):

$$E_i = \frac{x_i - \bar{x}}{\bar{x}} \text{ x } 100.$$

4. Compute the mean standard error ($\bar{E}_{\bar{x}}$) for the three tests and document the maximum and minimum errors (E_i) for all tests on field forms.

5. If data-quality requirements warrant, note the error patterns for individual outlets to determine which outlets produce consistent bias and label them with their mean percent bias error. Depending on the objectives of the study and how the subsamples will be used, this pattern of error may not be of concern.

A cone splitter is considered acceptable for sample processing if the mean standard error ($\bar{E}_{\bar{x}}$) for the three tests is 3 percent or less, and no individual error (E_i) exceeds ±5 percent.

Table 2-6. Example of six cone-splitter accuracy tests using deionized water

[Modified from Office of Water Quality Technical Memorandum 80.17]

Test number Initial sample weight (grams)	**1** 2,499.4		**2** 2,499.5		**3** 2,499.5		**4** 2,499.5		**5** 2,499.5		**6** 2,499.4		Averages	
Outlet number	Outlet volume (x_i)	Per-cent (E_i)	Outlet volume (x_i)	Per-cent (E_i)	Outlet volume (x_i)	Per-cent (E_i)	Outlet volume (x_i)	Per-cent (E_i)	Outlet volume (x_i)	Per-cent (E_i)	Outlet volume (x_i)	Per-cent (E_i)	Mean volume (x_i)	Per-cent (E_i)
1	248.4	-0.5	249.5	-0.1	247.4	-0.9	248.1	-0.7	247.8	-0.8	249.2	-0.2	248.4	-0.6
2	246.8	-1.2	246.8	-1.2	245.6	-1.6	248.4	-.6	246.3	-1.4	246.7	-1.2	246.8	-1.2
3	249.4	-.1	251.0	.5	250.6	.4	251.1	.5	249.8	0	248.7	-.4	250.1	.1
4	250.7	.4	252.6	1.1	252.5	1.1	251.3	.6	251.8	.8	250.5	.3	251.6	.7
5	248.1	-.6	248.3	-.6	249.8	0	249.3	-.2	250.2	.2	248.1	-.6	249.0	-.3
6	252.2	1.0	250.3	.2	252.7	1.2	252.0	.9	252.7	1.2	250.6	.4	251.8	.8
7	245.7	-1.6	246.2	-1.4	246.0	-1.5	246.3	-1.4	246.6	-1.3	245.9	-1.5	246.1	-1.5
8	252.7	1.2	254.2	1.8	252.9	1.3	253.3	1.4	253.1	1.3	254.6	2.0	253.5	1.5
9	248.7	-.4	247.3	-1.0	247.5	-.9	247.1	-1.1	248.2	-.6	249.5	-.1	248.0	-.7
10	253.9	1.7	252.1	.9	251.8	.8	250.6	.3	251.7	.8	253.0	1.3	252.0	1.0
Final sample weight	2,496.6		2,498.3		2,496.8		2,497.5		2,498.2		2,496.8		2,497.4	
Sample loss	2.8		1.2		2.7		2.0		1.3		2.6			
Mean weight ($\bar{x}$)	249.7		249.8		249.7		249.8		249.8		249.7		249.8	
Standard deviation (S_x)	2.7		2.7		2.8		2.3		2.5		2.7			
Error percent (E_x)	1.1		1.1		1.1		.9		1.0		1.1			

2.2.2 PROCESSING AND PRESERVATION CHAMBERS

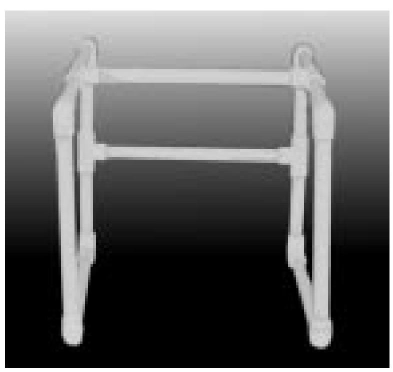
Processing and preservation chambers reduce the possibility of random atmospheric contamination during sample splitting, filtration, and preservation. These chambers are required for samples for trace-element determinations (Horowitz and others, 1994). The processing chamber can serve also as a collection chamber for pumped samples. There is no standard design for either fixed or portable chambers; however, to prevent contamination of inorganic samples with metals, the materials used in their construction should be either nonmetallic or completely covered by or embedded in nonmetallic material. Plastic components have been tested and do not emit volatile substances that might contaminate a VOC sample. This can be further documented by collecting an ambient blank in the chamber(s).

Fixed chambers can be enclosures permanently installed in a field vehicle for the sole purpose of sample collection, processing, or preservation. Fixed chambers must not be used as a storage area. The portable chamber illustrated is inexpensive and easily constructed with 1/2-in. white polyvinyl chloride (PVC), tubes which are used to support a clear plastic bag (fig. 2-11). The transparent bag forms a protective tent to work within while collecting, processing, or preserving samples. Another option is to purchase or construct a fixed or portable glove box. The glove box also should have no exposed metal parts. Glove boxes that can be filled with inert gas should be used for samples to be excluded from contact with atmospheric gases.

- The processing chamber sits over a fixed or portable sink lined with plastic to which a waste-disposal funnel has been attached, allowing rinse water to drain to waste. If a sink is not available, a waste bottle is placed inside the chamber to contain liquid waste and overflow. A hole can be drilled through the top crossbar of the processing chamber through which sample tubing can be inserted and a filter assembly attached.
- The preservation chamber consists only of the frame and bag cover. A suitable container placed inside the preservation chamber is needed to contain spent preservative ampoules (see NFM 5).

Use of separate chambers for sample processing and sample preservation can be the most convenient approach and is necessary if more than one type of chemical preservation will be used. Multiple preservation chambers can help prevent cross contamination and also save time by eliminating the need to change covers between treatments. However, when only a single preservative is needed (such as nitric acid), it can be added while the sample is in the processing chamber without a bag change, after all other samples have been removed.

Where space inside the field vehicle is extremely limited, having both a processing chamber and a preservation chamber set up at the same time might not be feasible. Under such circumstances, the processing-chamber frame may also function as a preservation-chamber frame as long as the cover is changed before sample preservation and is clipped to the chamber frame rather than supported over the frame. The preservation chamber cover must be changed every time the preservation procedure requires a change in gloves (NFM 5).



A.

B.

Figure 2-11. Example of (*A*) a polyvinyl chloride frame of a processing or preservation chamber, and (*B*) sample being processed within the chamber. (*A*, Photograph by B.A. Bernard; *B*, photograph by Jacob Gibs.)

2.2.3 FILTRATION SYSTEMS

Filtration separates particulate substances (solid-phase and biological materials) from the solute or aqueous phase of a water sample. Water samples are filtered for analysis of inorganic constituents, organic compounds, and biological materials to help determine the environmental fate and quantify the transport of these target analytes. Detailed information about filtration can be found in Kennedy and others (1976), Ward and Harr (1990), Horowitz and others (1994), and Koterba and others (1995).

For surface water, the most common filtration system consists of a reversible, variable-speed battery-operated peristaltic pump or a metering pump that forces the whole-water sample through tubing into a filter assembly. For ground water, the sample ordinarily is pumped through a sample line directly into a filter assembly. If the sample is collected by bailer, the sample generally is emptied through a valve with fluorocarbon polymer tubing and is transferred to the filter assembly by means of a peristaltic pump. Some bailers can be directly fitted with a filter and hand-pump system.

> TECHNICAL NOTE: Separation of solid from aqueous phases can be achieved by methods other than filtration, and data requirements may dictate the need for an alternative method such as centrifugation, ultracentrifugation, dialysis or lipid-membrane separation, and reverse-flow osmosis and tangential-flow filtration.

The filter assembly to be used depends on the type of target analytes, which are discussed in the following sections. Membrane filters commonly used to filter inorganic samples generally are made of cellulose nitrate, polycarbonate polymers, or polyethersulfone-based media. These filter media are not suitable for filtering samples to be analyzed for organics; glass microfiber is the media used for filtering most organic samples (silver filters are used for dissolved-organic compound samples).

A filtered sample is defined operationally by the nominal pore size of the filter media used.

- The filter pore size selected depends on study objectives, data requirements, and industry standards.
- The standard pore sizes of filter media used by the USGS are
  - 0.7 µm for pesticides, most other organic compounds, and some bacteria (NFM 7).
  - 0.45 µm for inorganic constituents (including major ions, radiochemicals, and trace elements), some bacteria (NFM 7), and dissolved organic carbon.
  - 0.2 µm or less for trace-element samples to be analyzed for some geochemical applications and interpretive studies and for nutrient samples for which exclusion of bacteria at the 0.2-µm threshold is desirable.
- See NFM 7 for a description of filter media for biological analysis.

Inorganic Constituents 2.2.3.A

Samples for analyses of inorganic constituents are filtered by use of either a disposable capsule-filter assembly or a plate-filter assembly (table 2-7). Construction materials of filtering systems must not be a source of sample contamination with respect to the substances for which the sample will be analyzed.

Table 2-7. Capsule filter or plate filter requirements for processing of samples for analysis of inorganic chemical constituents

[Table modified from Horowitz and others (1994) and includes only those constituents evaluated in the experiments described in the reference]

Disposable capsule filter required[1]		Disposable capsule filter recommended; plate-filter assembly acceptable
Aluminum	Lead	Anions (chloride, sulfate)
Antimony	Lithium	Calcium
Barium	Manganese	Magnesium
Beryllium	Molybdenum	Nutrients (nitrogen, phosphorus)
Boron	Nickel	Radiochemicals
Cadmium	Silver	Silica
Chromium	Thallium	Sodium
Cobalt	Uranium	Strontium
Copper	Zinc	
Iron		

[1]Requirements for surface-water sampling described in Horowitz and others (1994) are generally applicable to ground-water studies, with the caveat that study objectives and data-quality requirements must be fulfilled.

Disposable capsule filter

The protocol for filtering a sample for analysis of inorganic constituents (inorganic sample) is to use a disposable capsule filter such as the Gelman 12175 ground-water sampling capsule (fig. 2-12). Use of a disposable capsule filter eliminates the potential for contamination from a reusable filter assembly (such as the plate filter) and also eliminates time-consuming field-cleaning procedures that are required for a reusable assembly after each sample is filtered.

Horowitz and others (1994) concluded that the disposable capsule filter would not be a probable source of sample contamination for inorganic constituents, including trace elements, major ions, nutrients, stable isotopes, and radiochemicals (table 2-7) if precleaned with a minimum of 1 L of deionized water. Filter media of capsule filters are available in several nominal pore sizes in addition to the standard 0.45 μm.

Advantages of the disposable capsule filter compared to the plate-type filter:

- Capsule filters are sealed units; hence, the likelihood of contamination is reduced because the filter itself is not handled.
- Surface area of the capsule filter is roughly three times that of the 142-mm plate filter and is less subject to clogging.
- Cleaning the filter between samples is not necessary because each capsule filter is used only once and then discarded.
- QWSU provides quality-control checks of each lot of capsule filters and provides a certificate of analysis with each filter.

Do not use the disposable polyethersulfone capsule filter for organic samples.

Figure 2-12. Disposable capsule filter (published with permission of Gelman Sciences).

Do not reuse filters

Plate-filter assembly

Before 1994, the most common filtration assembly used for USGS studies for filtering inorganic samples was the nonmetallic backflushing plate-filter assembly designed to hold a 142-mm filter. Two screens support the filter media (one above and one below) and allow water flow in either direction without disruption of the membrane. A smooth-tipped plastic forceps is needed to transfer the filter media to the plate of the filter assembly. (Kennedy and others, 1976, give a detailed description of and instructions for use of the plate-filter assembly.)

- ▶ Types of plate-filter assemblies for inorganic samples include:
  - – Plastic backflushing assembly (described above), available for 47-mm, 142-mm, and 293-mm filters (fig. 2-13).
  - – Plastic vacuum filter assembly for 47-mm-diameter filter; used with either a hand vacuum pump or a peristaltic pump.
  - – Fluorocarbon polymer filter assembly designed for 47-mm-diameter filters; can be used for in-line filtering of inorganic or organic samples by changing to the appropriate filter media.
- ▶ The plate-filter assembly is no longer recommended for routine filtration of samples for analysis of inorganic constituents, but is still used to filter samples for analysis of major ions, nutrients, stable isotopes, and radiochemicals (table 2-7).

Figure 2-13. Nonmetallic backflushing plate-filter assembly for 142-millimeter diameter filter media. (Illustration reproduced with permission of Gelman Sciences.)

Trace Organic Compounds 2.2.3.B

Filtering whole-water samples isolates suspended solid-phase substances from the aqueous phase, thus allowing separate determinations of organic compounds in each phase.

As preparation for determining organic compounds that partition onto suspended matter (hydrophobic compounds)—Filtering primarily concentrates suspended materials on the filter, enhancing extraction efficiency and lowering analytical detection limits. This is especially useful for whole-water samples with small concentrations of suspended material where large volumes of sample (4 to 40 L) must be filtered to provide an analyzable mass of suspended materials.

As preparation for determining organic compounds that are more water soluble (hydrophilic)—Filtering is used to remove suspended material, because it often contains interfering constituents that are co-extracted with target analytes.

Filtering also helps to preserve samples for organic determinations because microorganisms that could degrade compounds in the sample are removed (Ogawa and others, 1981).

Equipment needed to filter samples for determination of organic compounds is described in detail in Sandstrom (1995) and includes a positive displacement pump, an aluminum plate-filter assembly (different filter assemblies can be required, depending on the analysis to be done), the filter media, and metal forceps. All equipment and components used for filtering whole-water samples for organic determinations should be made of materials that will not contaminate the sample or sorb analytes and that are suitable for use with organic cleaning solvents. Such materials include stainless steel or aluminum, fluorocarbon polymer, glass, and nonporous ceramics (hard-fused microcrystalline alumina). Other materials can be used, but they must not introduce contaminants or cause sorptive losses, and they must be sufficiently resistant to degradation by cleaning solvents. Use of plastics, rubber, oils and other lubricants are to be avoided because they can result in sample contamination, analytical interference, and (or) sorptive losses.

Metering pump

The valveless piston metering pump consists of a pump head with a reciprocating piston driven by a 12-volt direct current (DC), variable-speed motor (fig. 2-14). It has a delivery rate of up to 500 mL per minute.

The pump head and all wetted parts are constructed of ceramic, fluorocarbon polymer, or stainless steel components, which are resistant to organic solvents. These pumps can tolerate some suspended materials in the sample being pumped, but large concentrations of suspended materials can cause excessive wear of pump parts and strain on the pump motor.

The ceramic piston and shaft of these pumps will break if motor amperage exceeds 4 amps. To avoid this, either a 4-amp DC circuit breaker should be used in-line with the pump power line or an alternating to direct current converter with 4-amp maximum output should be used.

The pump and filter assembly are connected by 1/4-in.-diameter convoluted fluorocarbon polymer tubing with appropriate fittings. The convoluted tubing does not crimp when bent, unlike straight fluorocarbon polymer tubing.

Figure 2-14. Valveless piston metering pump. (Photograph by B.A. Bernard, 1998).

Filtration assemblies

The filtration equipment described in the following list includes various types of plate-filter assemblies, one of which is used for solid-phase extraction.

- The most common plate-filter assembly consists of two machined aluminum or stainless steel plates, designed to hold a 142-mm-diameter filter, which are held together by locking bolts or a locking ring (fig. 2-15).
  - The plates have fluorocarbon polymer-coated silicone or Viton™ O-rings set in grooves to seal the filter assembly. A stainless steel screen on the lower plate supports the filter.
  - A valve is built into the upper plate to exhaust trapped air. Connectors are built into the center of the top and bottom plates so that inlet and outlet fluorocarbon polymer tubing can be attached.
  - Plate-filter assemblies are available for filters with diameters ranging from 13 to 293 mm. The size selected is determined by the sample volume to be filtered and the concentration of suspended materials in the sample.
- In-line filter assemblies used specifically for organonitrogen sample filtering include 13-mm stainless steel or 25-mm disposable nylon membrane filter assemblies. The filter assembly is connected to the pumping system by means of appropriate tubing connectors. Further details are given in NFM 5 and in Sandstrom and others (1994).

Figure 2-15. Aluminum plate-filter assembly for 142-millimeter diameter filter media. (Photograph published with permission of GeoTech Environmental Equipment, Inc.)

- For solid-phase extraction (SPE), a special disposable in-line plastic filter capsule is used to filter organonitrogen herbicide samples before sending the filtrate to the NWQL.
  - Although filter assemblies made from plastic components should not be used to process water-sediment samples for organic compound determination, they have been approved for a specific SPE method.
  - The housing of this capsule filter is a thin nylon membrane filter, 25 mm in diameter, with a pore size of 0.45 µm. The capsule contains polypropylene with luer lock inlet and outlet connectors.
  - Filter units for organonitrogen herbicides by SPE are available from QWSU.

Filter media

Tortuous-path depth filters made of borosilicate glass fibers are used to filter most samples for organic determination because the filter materials are basically inert and can be precleaned with organic solvents or baked at 450˚C for at least 2 hours. Depth filters also can process larger fluid volumes than membrane filters without clogging. Membrane filters (cellulose or polycarbonate polymers) commonly used to process samples for determination of nutrients and other inorganic constituents are not suitable for filtering samples for organic determinations, mainly because they are not resistant to organic solvents used to preclean sampling and processing equipment. Membrane filters made of silver metal with a 0.45-µm pore size are resistant to organic solvents, but they become clogged too quickly for filtering the relatively large sample volumes (1 to 5 L) often needed for determination of organic compounds.

For organic samples (except for organonitrogen herbicides and suspended/dissolved organic carbon):

- Use glass-fiber filter with 0.7-µm nominal pore size, baked at 450˚C for at least 2 hours.
  - Obtain 142-mm diameter filter through QWSU.
  - Obtain filters with other diameters (0.7-µm nominal pore size and baked) through NWQL by special request.

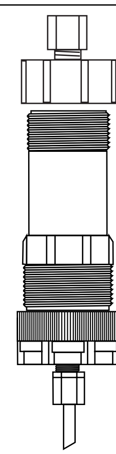
- Use only filters without binders. (Acrylic resin binders can leach and contaminate samples, or might not be completely combusted when baked at 450˚C.) Binder-free glass-fiber filters are available in various diameters ranging from 13 to 293 mm.

Dissolved and Suspended Organic Carbon 2.2.3.C

A stainless steel or fluorocarbon polymer pressure filter assembly (fig. 2-16) fitted with a 47-mm, 0.45-µm-pore-size silver membrane filter is used to separate dissolved from suspended phases of organic carbon.

- Use a hand-pressure pump, peristaltic pump, or an organic-free nitrogen gas tank fitted with clean tubing to apply pressure to filter dissolved organic carbon (DOC) from suspended organic carbon (SOC) samples (Office of Water Quality Technical Memorandum 78.06, see "Internal Documents").

A. Stainless steel filter assembly



B. Fluorocarbon polymer filter assembly

Figure 2-16. Apparatus for filtering samples for analysis of dissolved/suspended organic carbon: (*A*) stainless steel pressure-filter assembly and (*B*) fluorocarbon polymer pressure-filter assembly. (Published with permission: *A*, Gelman Sciences; *B*, Savillex Corporation.)

- Maintain gas pressure applied to the filter assembly at less than 15 lb/in^2.
- Ensure that the gas is clean by way of gas-purveyor certification or by attaching an in-line 0.2-mm Gelman Acro™ 50 hydrophobic membrane filter disk. Do not use any other type of filter.
  - Because the sample does not contact the in-line gas-filter disk, the disk can be used to filter gas used to process multiple samples, or until the disk clogs or is contaminated.
  - Store in-line filter disk in a resealable plastic bag between uses.

2.2.4 PUMP TUBING

Pump tubing refers to the sample lines used with peristaltic, metering, and submersible pumps. Field personnel are cautioned to evaluate possible artifacts in a sample associated with pump tubing and tubing connections.

- Tubing connectors and connections that contact the sample should be made of inert material, to the extent possible. Stainless steel connections must be the highest grade available (SS 316). If flexible copper, aluminum, or stainless steel tubing is used for CFC sampling, it should be refrigeration grade. Such fittings ordinarily are delivered with coatings of machining lubricants, which must be removed by cleaning before use.
  - Greaseless fittings can be ordered. Fluorocarbon polymer, silicone, C-Flex™ pump tubing commonly are used with portable submersible pumps and with peristaltic or metering pumps. Use of a fluorocarbon polymer material generally is recommended because fluorocarbon polymers are relatively inert with respect to many inorganic and organic analytes (table 2-8).

- Silicone tubing is suitable when sampling for inorganic analytes only, and only after appropriate cleaning (see NFM 3).
  - Measurable concentrations of silica (0.09 to 0.24 mg/L) have been detected in blank samples passed through silicone tubing (Horowitz and others, 1994). These concentrations are likely to be significant only if low-ionic-strength water is being sampled.
  - Silicone tubing was not designed for use with acids.
  - Silicone tubing is gas permeable and very sorptive of organic compounds.
- C-Flex™ tubing is made from a thermoplastic elastomer and is suitable for use when sampling for all inorganic analytes.
  - C-Flex™ is relatively resistant to acid. Acid resistance is a factor because dilute hydrochloric acid is required in cleaning procedures (see NFM 3).
  - C-Flex™ is less permeable to gas than silicone tubing.

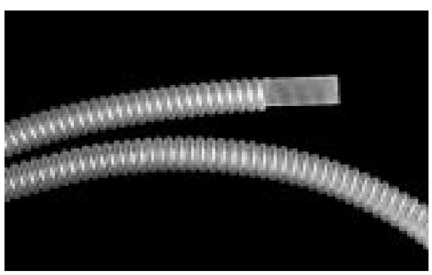
Table 2-8. Common varieties and characteristics of fluorocarbon polymer tubing

FEP (fluorinated ethylene polypropylene) • Most transparent • Best abrasion resistance • High flexibility • Least expensive of the Teflon™ varieties
PFA (perfluoroalkoxy) • Less transparent than FEP • Virtually nonporous (nonpermeable) • Most expensive of the Teflon™ varieties
PTFE (polytetrafluoroethylene) • Least transparent; milky to white • Most flexible • Midpriced between FEP and PFA
Kynar™ (polyvinylidene fluoride) • Translucent • Not very flexible • Less expensive than the Teflon™ varieties
Tefzel™ (Ethylenetetrafluoroethylene) • Withstands higher pressure than Teflon™ • Most expensive

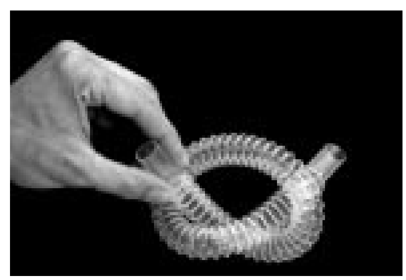
- Fluorocarbon polymer tubing is recommended when sampling for most inorganic and organic analytes. Fluorocarbon polymer tubing is available in corrugated, convoluted, and straight-wall configurations (fig. 2-17).
  - Fluorocarbon polymer tubing premolded to the shape of the pump head is available.
  - Convoluted fluorocarbon polymer tubing is flexible and easy to handle. Attach convoluted tubing to each end of the premolded tubing.
  - Fluorocarbon polymer tubing sheathed in another plastic is available at lower cost but is not recommended because the fluorocarbon polymer twists, constricts, and cracks.
- Polyvinyl chloride (PVC) tubing (Tygon™) is suitable for inorganic samples only, and it must be appropriately cleaned prior to contact with inorganic samples.
  - PVC tubing can be washed with dilute acid.
  - PVC tubing has the lowest gas permeability of any peristaltic pump tubing.
  - For use with a peristaltic pump, PVC tubing has a shorter life than silicone, C-Flex™, or Norprene™.
  - PVC tubing may leach plasticizers.

- Norprene™ tubing is made from a thermoplastic elastomer (a polypropylene base with USP mineral oil) and is suitable when sampling for inorganic analytes only. It must be appropriately cleaned prior to contact with samples collected for inorganic analysis.
  - Norprene™ tubing can be washed with dilute acid.
  - Norprene™ tubing may leach USP mineral oil.
  - For use with a peristaltic pump, Norprene™ tubing has the longest life of any manufacturer-recommended tubing material.
  - The gas permeability of Norprene™ tubing is lower than that of silicone tubing and greater than that of PVC tubing.

For filtering ground-water samples that are pumped directly from the well to a filter assembly, C-Flex™ or fluorocarbon polymer tubing is recommended. (Nylon tubing also might be an acceptable alternative, but it has not been tested as a source of trace-element or organic compound contamination.) Silicone tubing is not recommended because it is gas permeable.



A. Convoluted (spiral) design



B. Corrugated (parallel) design

Figure 2-17. Flexible fluorinated ethylene polypropylene (FEP) tubing: (*A*) convoluted design and (*B*) corrugated design. (Published with permission of Cole-Parmer Instrument Company: *A*, Copyright 1992. Cole-Parmer does not warrant this illustration to be current, accurate, or suitable for any purpose; *B*, Copyright 1987. Cole-Parmer does not warrant this illustration to be current, accurate, or suitable for any purpose.)

FIELD VEHICLES 2.3

By **D.B. Radtke**

Water samples should be processed within vehicles that are designed, designated, prepared, and dedicated for that purpose. If a multiple-use vehicle must be used for water-quality work, then use of portable processing and preservation chambers is mandatory, and additional quality-control samples must be collected to document that the quality of the data has not been compromised. Contamination of some target analytes is much more likely when multiple-use vehicles are used for collection of water-quality data.

Whether using a field vehicle dedicated for water-quality work or a multi-use vehicle, every effort must be made to keep the work area clean and to eliminate sources of sample contamination.

- ▶ Keep metallic objects, such as surface-water and ground-water sampling support equipment, out of the inorganic sample-processing and -preservation area.
- ▶ Install a dustproof barrier between the vehicle's cab and the sample-processing and -preservation area.
- ▶ Cover metal surfaces (cabinets or shelving that cannot be replaced) with plastic sheeting. Replace the sheeting periodically.
- ▶ Store chemical substances so that chemical fumes will not enter the sample-processing and -preservation area.

For additional discussions of field-vehicle recommendations and requirements, refer to Horowitz and others (1994), Shelton (1994), and Koterba and others (1995).

SAFETY REQUIREMENT: Store acids, bases, and solvents in separate storage areas so that the chemicals cannot mix if a spill occurs (NFM 9).

LISTS OF EQUIPMENT AND SUPPLIES 2.4

***By* D.B. Radtke**

Checklists of the equipment and supplies commonly used to collect and process water samples are provided in the tables that follow (tables 2-9 through 2-15) to aid field personnel in selecting equipment needed to prepare for a water-quality field trip. These lists are not exhaustive and should be modified to meet specific study needs. Many of the items listed are explained in greater detail in other NFM chapters, as indicated. Refer to other chapters of this *National Field Manual* series for lists of equipment and supplies for field measurements (NFM 6), biological indicators (fecal indicator bacteria, NFM 7), and bottom-material samples (NFM 8). Equipment must be cleaned and tested before field work begins (NFM 3).

Don't forget backup equipment.

Table 2-9. Support equipment for surface-water sampling

[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).]

Cranes		
✔	Type	Sampler maximum recommended weight (pounds)
	Type A	100
	Type E	Heavier than for type A
	Bridge board	50
	Other	

Crane Bases		
✔	Type	Sampler maximum recommended weight (pounds)
	Three-wheel	100
	Four-wheel	150

✔	Miscellaneous
	Battery or hydraulic power motor system for B-56 or E-53 reel
	Hanger bars, connectors, and pins for connecting sampler to cable
	Counterweights for four-wheel crane base
	Safety equipment (flotation jacket, cable cutter, traffic cones, and warning signs)
	Other

Reels						
✔	Reel	Cable diameter (inches)	Maximum weight (pounds)	Cable capacity (feet)	Brake	Operation type
	A-55	0.084 .10	50 100	95 80	No	Hand
	B-56	.10 .125	150 200	144 115	Yes	Hand or power
	E-53	.10 .125	150 300	206 165	Yes	Power
	Other					

NOTE: Selection of type of reel should be based largely on maximum cable length needed and weight of sampler that must be supported.

Table 2-10. Support equipment for ground-water sampling

✔	Ground-water support equipment
	Handline or manual/power reel with line
	Tripod assembly with manual or power reel
	Wellhead guide for flexible sample line to pump
	Wheeled carts to transport portable sampling equipment
	Energy source for reels and pumps (batteries, compressor, or generator)
	Other

Table 2-11. Sample-collection equipment for (*A*) surface water and (*B*) ground water

[NFM, *National Field Manual for the Collection of Water-Quality Data*]

✔	(***A***) Surface-water-quality sample collection (refer to NFM 4)
	Weighted bottle and handline (plastic or stainless steel) bottle
	US DH-81 (handle and collar) Nylon or fluorocarbon polymer nozzle[1] (3/16, 1/4, or 5/16 inch) and cap Plastic or fluorocarbon polymer bottle (0.5 or 1 liter)
	US D-77 (plastic dipped) Bottle (3 liter) Nylon or fluorocarbon polymer nozzle[1] (5/16 inch) and cap
	US DH-95 Nozzle[1] (3/16, 1/4, or 5/16 inch) and cap Plastic or fluorocarbon polymer bottle (1 liter)
	D-77 Bag (plastic dipped) Slotted bottle (plastic) Nylon or fluorocarbon polymer nozzle[1] (3/16, 1/4, or 5/16 inch) and cap Reynolds™ oven bag[2]
	Frame-Bag (plastic dipped) Slotted bottle (plastic, 3 or 8 liter) Nylon or fluorocarbon polymer nozzle[1] (1/4 or 5/16 inch) and cap Reynolds™ oven bag[2]
	Crane with 3- or 4-wheel base and counterweights
	Reel, hanger bars, and pins
	Sounding weights for frame sampler
	Current meter for D-77 Frame-Bag sampler
	Bridge board and reel
	Plastic sheeting with weighted corners to cover bridge rail
	Biochemical Oxygen Demand sampler
	Volatile Organic Compound sampler
	Thief sampler
	Pumping sampler(s)
	Other

Table 2-11. Sample-collection equipment for (*A*) surface water and (*B*) ground water—*Continued*

✔	(***B***) Ground-water-quality sample collection (refer to NFM 4)
	Positive-displacement submersible pump, discharge line, and reel
	Water-supply-well sample line and garden-hose threaded adaptor
	Thief-type sampler. (Examples: bailer, single or double-check valve, and bottom emptying device)
	Suction-lift pump (peristaltic or centrifugal)
	Antibacksiphon device
	Sample-water manifold to split sample water flow
	Flowthrough chamber for field-measurement electrodes (pH, conductivity, dissolved oxygen, water temperature, oxidation/reduction)
	Tubing, appropriate for type of pump and target analytes
	Tubing connectors, compatible with tubing and target analytes
	Water-level measuring tape, steel or electric
	Water-level indicator (blue chalk for steel tape)
	Weight, to attach to water-level measuring tape or sample line. Do not use lead. Use stainless steel or other relatively noncontaminating material.
	Power source for pump or reel
	Graduated bucket (to measure rate of discharge)
	Containers for disposal of purge water
	Flow controller for sampling pump
	Ground cloth, plastic
	Other

[1]Use only nozzles purchased from the Federal Interagency Sedimentation Project.
[2]The Reynolds™ oven bag is the only plastic bag tested as of the date of publication. Other bags might be appropriate, but quality-control tests would be required before they could be certified for use.

Table 2-12. Sample-processing equipment and supplies

[NFM, *National Field Manual for the Collection of Water-Quality Data;* L, liter; mm, millimeter; µm, micrometer; in., inch; g, gram; mL, milliliter]

✔	Sample splitters (refer to NFM 5)
	Churn splitter, modified with funnel 8 or 14 L Polyethylene (polypropylene—inorganics only) Composite-sample container for organic-sample analytes
	Churn carrier
	Cone splitter Splitting chamber for cone splitter Bull's-eye bubble level and shims for cone splitter
	Large clear plastic bags Covering for churn splitter or cone splitter Covering for use as chamber cover
	Subsample bottle kits for whole-water samples
	Other
✔	Filtering systems for inorganics (refer to NFM 5)
	Processing chamber and chamber covers
	Peristaltic pump
	Pump tubing from ground-water pump (C-Flex™, silicon, fluorocarbon polymer)
	Filter assembly (disposable capsule, plate-type, other)
	Filter media (various diameters, pore sizes, and materials)
	Forceps (plastic or ceramic)
	Subsample bottle kits for filtered inorganic samples
	Deionized water
	Gloves (powderless, disposable vinyl)
	Other
✔	Filtering systems for organics (refer to NFM 5)
	Plate-filter assembly, aluminum or stainless steel, for 142, 13, or 293-mm diameter filter media
	Filter media, borosilicate glass fiber, 0.7-µm pore size, 142-mm diameter, baked; or 13-, 47-, or 293-mm diameter filter media
	Pump, ceramic piston valveless metering, with fluorocarbon polymer convoluted tubing or ground-water pump tubing
	Filter assembly, 25-mm diameter, in-line, with disposable nylon filter media
	Powderless disposable latex or nitrile gloves

Table 2-12. Sample-processing equipment and supplies—*Continued*

✔	Filtration system for dissolved and suspended organic carbon (refer to NFM 5)
	Dissolved organic carbon filtering assembly, 47-mm diameter, stainless steel or fluorocarbon polymer
	Filter, silver metal, 47-mm diameter, 0.45-µm pore size
	Hand pressure, peristaltic pump, or organic-grade compressed nitrogen-gas tank and pressure regulator
	Tubing with in-line 0.2-µm air filter
	Cylinder, graduated, glass
	Holding stand, ring, and medium three-prong clamp
	Forceps, stainless steel or fluorocarbon polymers
	Petri dish and sealable plastic bag
	Foil, aluminum, heavy duty
	Power source for pump (battery, generator, other)
	Other
✔	Solid-phase extraction (SPE) system (refer to NFM 5)
	Valveless piston metering pump (ceramic) with fluorocarbon polymer convoluted tubing
	Fluorocarbon polymer tubing, 1/8-in. outside diameter
	Various tubing fittings, adaptors, connectors, and unions
	Portable balance, 1 to 6,000 g
	Graduated glass cylinders
	Beaker (plastic), 1,000 mL
	Spike mixture and micropipette kit
	Surrogate mixture and micropipette kit
	SPE column (C-18 or Carbopac-B™)
	Methanol, ascorbic acid, sodium chloride, and pesticide-grade organic water, all in fluorocarbon polymer dispenser bottles
	Gloves, disposable, nonpowdered, latex or nitrile
	Stopwatch
	Aluminum foil

Table 2-13. Sample-preservation equipment and supplies: surface water and ground water

[NFM, *National Field Manual for the Collection of Water-Quality Data*]

✔	Preservation equipment and supplies (refer to NFM 5)
	Preservation chamber(s)
	Chamber bags (large clear)
	Waste containers for spent preservative ampoules, dedicated for each chemical used
	Apron, goggles, powderless disposable gloves (vinyl, latex, nitrile)
	Nitric acid (analytical grade), in glass or fluorocarbon polymer ampoule
	Nitric acid/potassium dichromate ampoule
	Sulfuric acid ampoule
	Phosphoric acid/cupric sulfate ampoule
	Sodium hydroxide ampoule
	Hydrochloric acid
	Ascorbic acid
	Zinc acetate
	Phytoplankton kit
	Radon kit
	Cooler and ice
	Other

Table 2-14. Cleaning equipment and supplies

[NFM, *National Field Manual for the Collection of Water-Quality Data*; ASTM, American Society for Testing and Materials; qw, Office of Water Quality Technical Memorandum; NWQL, National Water Quality Laboratory Technical Memorandum]

✔	General cleaning equipment and supplies (refer to NFM 3)
	Basins or standpipes (clear or white plastic, fluorocarbon polymer, stainless steel)
	Brushes (nonmetallic, clear or white)
	Detergent, laboratory phosphate-free (0.1-2 percent by volume)
	Apron
	Goggles
	Gloves
	Tap water
	Deionized water, District produced or equivalent (ASTM type 1) (qw 92.01)
	Wash bottles
	Material Safety Data Sheet for each chemical to be used
	Sealable plastic bags without color closure strips
	Other
✔	Inorganic constituents
	Hydrochloric acid, analytical grade (5 percent by volume)
	Neutralization container and marble chips
	Wash bottle for hydrochloric acid
	Inorganic-grade blank water (IBW) (NWQL 92.01)
	Safety equipment, such as Laboratory coat or apron Goggles Gloves Eyewash station Acid spill kit Safety shower
	Large plastic bags (clear or white)
	Plastic sheeting (clear or white)
	Other
✔	Organic Compounds
	Methanol, pesticide grade
	Waste container, methanol
	Wash bottle, methanol
	Aluminum foil
	Fluorocarbon polymer bags/sheeting
	Solvent spill kit
	Methanol Material Safety Data Sheet
	Pesticide- or volatile-grade blank water (PBW or VBW) (NWQL 92.01)
	Deionized water, District-produced or equivalent (ASTM Type 1)

Table 2-15. Shipping equipment and supplies

[NFM, *National Field Manual for the Collection of Water-Quality Data*; qw, Office of Water Quality Technical Memorandum]

✔	Shipping equipment and miscellaneous supplies (refer to NFM 5)
	Coolers, 1 to 5 gallon
	Boxes (sturdy)
	Packing material (foam sleeves, bubble wrap)
	Ice
	Large plastic bags for lining coolers and boxes
	Sample-bottle labels
	Analytical Services Request (ASR) form
	Return-address label and account number
	Sealable plastic bag for forms and return label
	Tape, fiber
	Shipping label (forms)
	Other
✔	Miscellaneous equipment and supplies
	Notebook and pen (indelible ink)
	Field instruments (NFM 6; qw 94.02)
	Calibration logbook for each instrument (NFM 6)
	Field folder(s) with station, site, and well information and permission form
	Field documentation forms
	Calculator and extra batteries
	Watch
	Tagline
	Stopwatch and headset for discharge measurement
	Hip boots
	Chest waders
	Rain gear
	Personal flotation device
	Traffic safety vest, cones, signs, warning lights
	First aid kit
	Highway emergency kit
	Tool kit
	Tape (electrical, fiber, fluorocarbon polymer, other)
	Plastic coat spray
	Fire extinguisher
	Flashlight with extra batteries
	Rechargeable batteries and backups, as needed
	Keys to sampling site, security locks, and vehicle (extra set)
	Weather report
	Field trip itinerary (copy to supervisor)

Table 2-15. Shipping equipment and supplies—*Continued*

✔	Miscellaneous equipment and supplies—***Continued***
	Cellular phone or two-way radio
	Camera with extra film and batteries
	Work gloves
	Shovel, ice chisel/auger
	Boat, motor, gasoline, oil, paddle, oars
	Insect repellent (odorless)
	Sunscreen
	Soap (antibacterial)
	Paper towels (lint free)
	Safety plan(s) (NFM 9)
	Map(s)
	Locations and telephone numbers of hospitals and other emergency facilities (NFM 9)
	Other

CONVERSION FACTORS, SELECTED TERMS, AND ABBREVIATIONS

CONVERSION FACTORS

Multiply	By	To obtain
inch (in.)	25.4	millimeter (mm)
square inch (in^2)	645.16	square millimeter (mm^2)
foot (ft)	0.3048	meter (m)
gallon (gal)	3.785	liter (L)
pound, avoirdupois (lb)	0.4536	kilogram
meter(m)	3.281	foot
centimeter (cm)	0.3937	inch
micrometer (μm)	3.9372×10^{-5}	inch
millimeter (mm)	0.03937	inch
liter (L)	0.264	gallon
milligrams per liter (mg/L)	0.5841	grains per gallon
milliliter (mL)	0.0338	ounce, fluid
milliliter (mL)	2.64×10^{-4}	gallon
milligram (mg)	3.527×10^{-5}	ounce, avoirdupois
gram (g)	0.03527	ounce, avoirdupois
kilogram (kg)	2.205	pound

Temperature: Water and air temperature are given in degrees Celsius (˚C), which can be converted to degrees Fahrenheit (˚F) by use of the following equation:

$$^\circ F = 1.8(^\circ C) + 32$$

SELECTED TERMS

Analyte (target analyte): "Substances being determined in an analysis" (from Bennett, H., ed., 1986). The term "target analyte" is used in this report to refer to any chemical or biological substance for which concentrations in a sample will be determined. Target analyte does not include field-measured parameters such as temperature, conductivity, dissolved-oxygen concentration, pH, Eh, alkalinity, color, or turbidity.

Fluorocarbon polymers: Fluorocarbon polymers (polyfluorocarbons) are composed of monomers (smallest repeating compound segment of polymer) consisting of carbon, fluorine, hydrogen, and, for one polymer, oxygen also. The fluorocarbon polymers have trade names that include, for example, Teflon™

FEPC (fluorinated ethylene polypropylene), Teflon™ PFA (perfluoroalkoxy), Teflon™ PTFE (polytetrafluoroethylene), Kynar™ (polyvinylidene fluoride), and Tefzel™ (ethylene tetrafluoroethylene). Each fluorocarbon polymer has different chemical and physical properties; however, all are relatively nonreactive chemically at ambient temperatures and do not leach monomers.

Trace element(s): For the purpose of this report and to maintain consistency with common usage, the term "trace element(s)" is used to refer to metals and other elements such as arsenic, antimony, selenium, and tellurium that usually are present in natural surface- and ground-water systems in concentrations less than 1 mg/L (modified from Hem, 1985). Common usage of this term, as defined above, is inexact and not rigorous with respect to aqueous chemistry.

Whole water: Water as sampled from its source and not subjected to filtration or other phase-separation process. Common synonymous terms include: raw (water) sample and unfiltered (water) sample.

ABBREVIATIONS

ft/s	feet per second
mg/L	milligram per liter
lb/in^2	pounds per square inch
L/min	liter per minute
BOD	biochemical oxygen demand
CFC	chlorofluorocarbon
FISP	Federal Interagency Sedimentation Project, Waterways Experiment Station, Vicksburg, Miss.
HCl	hydrochloric acid
HIF	USGS Hydrologic Information Facility, Stennis Space Center, Miss.
NFM	*National Field Manual for the Collection of Water-Quality Data*
NWQL	USGS National Water Quality Laboratory
PVC	polyvinyl chloride
QWSU	USGS Quality of Water Service Unit, Ocala, Fla.
SPE	solid-phase extraction
TWRI	Techniques of Water-Resources Investigations
USGS	U.S. Geological Survey
VOC	volatile organic compounds

SELECTED REFERENCES AND INTERNAL DOCUMENTS

SELECTED REFERENCES FOR SELECTION OF EQUIPMENT FOR WATER SAMPLING

American Public Health Association, American Water Works Association, and Water Environment Federation, 1992, Standard methods for the examination of water and wastewater (18th ed.): Washington, D.C., American Public Health Association, variously paged.

Bennett, Harry, ed., 1986, Concise chemical and technical dictionary (4th ed.): New York, Chemical Publishing Co., 1,271 p.

Buchanan, T.J., and Somers, W.P., 1969, Discharge measurements at gaging stations: U.S. Geological Survey Techniques of Water-Resources Investigations, book 3, chap. A8, 65 p.

Busenberg, E., and Plummer, L.N., 1992, Use of chlorofluorocarbons (CCl_3F and CCl_2F_2) as hydrologic tracers and age-dating tools—Example, the alluvium and terrace system of central Oklahoma: Water Resources Research, v. 28, no. 9, p. 2257-2283.

Capel, P.D., and Larson, S.J., 1996, Evaluation of selected information on splitting devices for water samples: U.S. Geological Survey Water-Resources Investigations Report 95-4141, 103 p.

Capel, P.D., Nacionales, F.C., and Larson, S.J., 1995, Precision of a splitting device for water samples: U.S. Geological Survey Open-File Report 95-293, 6 p.

Cole-Parmer Instrument Company, 1984, Pump applications guide, 1984-1985: Chicago, Cole-Parmer Instrument Company, 144 p.

Corbett, D.M., and others, 1943, Stream-gaging procedure—a manual describing methods and practices of the Geological Survey: U.S. Geological Survey Water-Supply Paper 888, 245 p.

Driscoll, F.G., 1986, Groundwater and wells (2d ed.): St. Paul, Minn., Johnson Filtration Systems, Inc., 1,089 p.

Edwards, T.K., and Glysson, D.G., 1998, Field methods for measurement of fluvial sediment: U.S. Geological Survey Techniques of Water-Resources Investigations, book 3, chap. C2, 80 p.

Federal Interagency River Basin Committee, Subcommittee on Sedimentation, 1952, The design of improved types of suspended sediment samplers—Inter-Agency Report 6: Minneapolis, Minn., St. Anthony Falls Hydraulics Laboratory, 5 p.

Federal Interagency Sedimentation Project of the Interagency Advisory Committee on Water Data, 1986, Instruments and reports for fluvial sediment investigations: Vicksburg, Miss., U.S. Army Engineer Waterways Experiment Station, [catalog] p. 48-57.

Federal Interagency Sedimentation Project, Catalog: accessed August 8, 1998, at URL http://fisp.wes.army.mil/Catalog%20Index.htm.

Ficken, J.R., 1988, Recent development of downhole water samplers for trace organics, *in* Collins, A.G., and Johnson, A.I., eds., Ground-water contamination--field methods: Philadelphia, American Society for Testing and Materials Special Technical Publication 963, p. 253-257.

Gibs, Jacob, Brown, G.A., Turner, K.S., MacLeod, C.L., Jelinski, J.C., and Koehnlein, S.A., 1993, Effects of small-scale vertical variations in well-screen inflow rates and concentrations of organic compounds on the collection of representative ground-water-quality samples: Ground Water, v. 31, no. 2, p. 201-208.

Gillham, R.W., 1982, Syringe devices for ground-water sampling: Ground Water Monitoring Review, v. 2., no. 2, p. 36-39.

Hem, J.D., 1985, Study and interpretation of the chemical characteristics of natural water (3d ed.): U.S. Geological Survey Water-Supply Paper 2254, 263 p.

Horowitz, A.J., Demas, C.R., Fitzgerald, K.K., Miller, T.L., and Rickert, D.A., 1994, U.S. Geological Survey protocol for the collection and processing of surface-water samples for the subsequent determination of inorganic constituents in filtered water: U.S. Geological Survey Open-File Report 94-539, 57 p.

Imbrigiotta, T.E., Gibs, Jacob, Fusillo, T.V., Kish, G.R., and Hochreiter, J.J., 1988, Field evaluation of seven sampling devices for purgeable organic compounds in ground water, *in* Collins, A.G., and Johnson, A.I., eds., Ground-water contamination—field methods: Philadelphia, American Society for Testing and Materials Special Technical Publication 963, p. 258-273.

Keith, L.H., 1988, Principles of environmental sampling: Washington, D.C., American Chemical Society, ACS Professional Reference Book, 458 p.

Keith, L.H., ed., 1991, Compilation of EPA's sampling and analysis methods: Chelsea, Mich., Lewis Publishers, 803 p.

Kennedy, V.C., Jenne, E.A., and Burchard, J.M., 1976, Backflushing filters for field processing of water samples prior to trace-element analysis: U.S. Geological Survey Open-File Report 76-126, 12 p.

Koterba, M.T., Wilde, F.D., and Lapham, W.W., 1995, Ground-water data-collection protocols and procedures for the National Water-Quality Assessment Program—Collection and documentation of water-quality samples and related data: U.S. Geological Survey Open-File Report 95-399, 113 p.

Lapham, W.W., Wilde, F.D., and Koterba, M.T., 1995, Ground-water data-collection protocols and procedures for the National Water-Quality Assessment Program—Selection, installation, and documentation of wells, and collection of related data: U.S. Geological Survey Open-File Report 95-398, 69 p.

_____1997, Guidelines and standard procedures for studies of ground-water quality—selection and installation of wells, and supporting documentation: U.S. Geological Survey Water-Resources Investigations Report 96-4233, 110 p.

LeBlanc, D.R., Garabedian, S.P., Hess, K.M., Gelhar, L.W., Quadri, R.D., Stollenwerk, K.G., and Wood, W.W., 1991, Large-scale natural gradient tracer test in sand and gravel, Cape Cod, Massachusetts. 1. Experimental design and observed tracer movement: Water Resources Research, v. 27, no. 5, p. 895-910.

Margaritz, Mordeckai, Wells, Mona, Amiel, A.J., and Ronen, Daniel, 1989, Application of a multi-layer sampler based on the dialysis cell technique for the study of trace metals in groundwater: Applied Geochemistry, v. 4, p. 617-624.

Morrison, R.D., 1983, Ground water monitoring technology—Procedures, equipment and applications: Prairie Du Sac, Wis., TIMCO Manufacturing Inc., 111 p.

Norris, J., 1988, Techniques for sampling surface and industrial waters—Special considerations and choices, *in* Keith, L.H., ed., Principles of environmental sampling: Washington, D.C., American Chemical Society, p. 247-253.

Ogawa, I., Junk, G.A., and Scev, H.J., 1981, Degradation of aromatic compounds in groundwater, and methods of sample preservation: Talanta, v. 28, p. 725-729.

Plumb, R., Jr., 1981, Procedures for handling and chemical analysis of sediment and water samples: Vicksburg, Miss., U.S. Army Corps of Engineers Waterways Experiment Station, Environmental Laboratory, Technical Report EPA/CE-81-1, p. 3-73 to 3-76.

Rantz, S.E, and others, 1982, Measurement and computation of streamflow, volume 1, measurement of stage and discharge: U.S. Geological Survey Water Supply Paper 2175, 284 p.

Radtke, D.B., 1985, Sediment sources and transport in Kings Bay and vicinity, Georgia and Florida, July 8-16, 1982: U.S. Geological Survey Professional Paper 1347, 120 p.

Radtke, D.B., Buell, G.R., and Perlman, H.A., 1984, Limnological studies of West Point Reservoir, Georgia-Alabama: U.S. Army Corps of Engineers Water Quality Management Study Technical Report, COE SAM/PDEE -84/004, 527 p.

Sandstrom, M.W., 1995, Filtration of water-sediment samples for the determination of organic compounds: U.S. Geological Survey Water-Resources Investigations Report 95-4105, 13 p.

Sandstrom, M.W., Wydoski, D.S., Schroeder, M.P., Zamboni, J.L., and Foreman, W.T., 1994, Methods of analysis by the U.S. Geological Survey National Water Quality Laboratory--Determination of organonitrogen herbicides in water by solid-phase extraction and capillary-column gas chromatography/mass spectrometry with selected-ion monitoring: U.S. Geological Survey Open-File Report 91-519, 26 p.

Savillex Corporation, 1994, Teflon PFA, molded products for science and industry: Minnetonka, Minn., Catalog 15, 24 p.

Shelton, L.R., 1997, Field guide for collecting samples for analysis of volatile organic compounds in stream water for the National Nater-Quality Assessment Program: U.S. Geological Survey Open-File Report 97-401, 14 p.

Shelton, L.R., 1994, Field guide for collecting and processing stream-water samples for the National Water-Quality Assessment program: U.S. Geological Survey Open-File Report 94-455, 42 p.

Smith, R.L., Harvey, R.W., and LeBlanc, D.R., 1991, Importance of closely spaced vertical sampling in delineating chemical and microbiological gradients in groundwater studies: Journal of Contaminant Hydrology, v. 7, p. 285-300.

Szalona, J.J., 1982, Development of a bag-type suspended-sediment sampler: Minneapolis, Minn., St. Anthony Falls Hydraulics Laboratory, Federal Inter-Agency Sedimentation Project, Report Y, 32 p.

Torstensson, Bengt-Arne, and Petsonk, A.M., 1988, A mermetically isolated sampling method for ground-water investigations, *in* Collins, A.G., and Johnson, A.I., eds., Ground-water contamination—field methods: Philadelphia, American Society for Testing and Materials Special Technical Publication 963, p. 274-289.

U.S. Environmental Protection Agency, 1980, Samplers and sampling procedures for hazardous waste stream: Cincinnati, Ohio, Municipal Environmental Research Laboratory, EPA 600/ 2-80-018, 70 p.

______1982a, Sampling protocols for collecting surface water, bed sediment, bivalves, and fish for priority pollutant analysis: Washington, D.C., Office of Water Regulations and Standards Monitoring and Data Support Division, EPA 68-01-6195, variously paged.

U.S. Environmental Protection Agency, 1982b, Handbook for sampling and sample preservation of water and wastewater: Cincinnati, Ohio, Environment Monitoring and Support Laboratory, EPA 600/4-82-029, 402 p.

______1983, Addendum to handbook for sampling and sample preservation of water and wastewater: Cincinnati, Ohio, Environment Monitoring and Support Laboratory, EPA 600/ 4-82-029, 28 p.

______1987, A compendium of Superfund field operations methods: Washington, DC., Office of Emergency and Remedial Response, EPA 540-P-87/001, 508 p.

______1989, Soil sampling quality assurance user's guide: Las Vegas, Nev., Environment Monitoring Systems Laboratory, EPA 600/8-89-046, 268 p.

U.S. Geological Survey, 1978, Sediment, chap. 3 *in* U.S. Geological Survey, National handbook of recommended methods for water-data acquisition: p. 3-1 to 3-100.

______1984, Chemical and physical quality of water and sediment, chap. 5 *in* U.S. Geological Survey, National handbook of recommended methods for water-data acquisition: p. 5-1 to 5-194.

U.S. Geological Survey, 1992a, Indiana District tests ground-water sampling devices, *in* WRD Instrument News, Debra Tracey, ed.: Stennis Space Center, Miss., Hydrologic Instrumentation Facility, no. 57, p. 1.

_____1992b, Ground-water sampler testing in a standpipe system, *in* WRD Instrument News, Debra Tracey, ed.: Stennis Space Center, Miss., Hydrologic Instrumentation Facility, no. 59, p. 6.

Ward, J.R., and Harr, C.A., eds., 1990, Methods for collection and processing of surface-water and bed-material samples for physical and chemical analyses: U.S. Geological Survey Open-File Report 90-140, 71 p.

Winterstein,T.A., and Stefan, H.G., 1983, Suspended sediment sampling in flowing water, laboratory study of effects of nozzle orientation, withdrawl rate and particle size: Minneapolis, Minn., University of Minnesota, St. Anthony Falls Hydraulic Laboratory External Memorandum M-168, 97 p.

Internal Documents

Office of Water Quality, Office of Surface Water, and National Water Quality Laboratory Technical Memorandums are available electronically on the Internet through the USGS Home Page on the World Wide Web. The site address (URL) is http://water.usgs.gov/lookup/get?techmemo.

Water Quality

Memo No.	Title	Date
qw78.06	WATER QUALITY: Field filtering of water samples for chemical analysis	April 5, 1978
qw80.17	EQUIPMENT AND SUPPLIES: New sample splitter for water-quality samples	July 3, 1980
qw92.01	Distilled/Deionized Water for District Operations	December 20, 1991
qw94.02	EQUIPMENT: Discontinuance of field use of mercury liquid-in-glass thermometers	November 22, 1993
qw97.06	Comparison of the suspended-sediment splitting capabilities of the churn and cone splitters	May 5, 1997

Surface Water

Memo No.	Title	Date
sw94.05	Maximum sampling depths and transit rates for suspended sediment and water-quality samplers	January 31, 1994

National Water Quality Laboratory (NWQL)

Memo No.	Title	Date
92.01	Availability of equipment blank water for inorganic and organic analysis	March 25, 1992

PUBLICATIONS ON TECHNIQUES OF WATER-RESOURCES INVESTIGATIONS

The U.S. Geological Survey publishes a series of manuals describing procedures for planning and conducting specialized work in water-resources investigations. The material is grouped under major subject headings called books and is further divided into sections and chapters. For example, Section A of Book 9 (Handbooks for Water-Resources Investigations) pertains to collection of water-quality data. The chapter, which is the unit of publication, is limited to a narrow field of subject matter. This format permits flexibility in revision and publication as the need arises.

The Techniques of Water-Resources Investigations (TWRI) reports listed below are for sale by the U.S. Geological Survey, Branch of Information Services, Box 25286, Federal Center, Denver, CO 80225 (authorized agent of the Superintendent of Documents, Government Printing Office). Prepayment is required. Remittance should be sent by check or money order payable to the U.S. Geological Survey. Prices are not included because they are subject to change. Current prices can be obtained by writing to the above address. When ordering or inquiring about prices for any of these publications, please give the title, book number, chapter number, and "U.S. Geological Survey Techniques of Water-Resources Investigations." An updated list of TWRI reports can be found by accessing the World Wide Web url: http://water.usgs.gov/lookup/get?TWRI.

Book 1. Collection of Water Data by Direct Measurement

Section D. Water Quality

1–D1.Water temperature—influential factors, field measurement, and data presentation, by H.H. Stevens, Jr., J.F. Ficke, and G.F. Smoot: USGS—TWRI Book 1, Chapter D1. 1975. 65 pages.

1–D2.Guidelines for collection and field analysis of ground-water samples for selected unstable constituents, by W.W. Wood: USGS—TWRI Book 1, Chapter D2. 1976. 24 pages.

Book 2. Collection of Environmental Data

Section D. Surface Geophysical Methods

2–D1.Application of surface geophysics to ground-water investigations, by A.A.R. Zohdy, G.P. Eaton, and D.R. Mabey: USGS—TWRI Book 2, Chapter D1. 1974. 116 pages.

2–D2.Application of seismic-refraction techniques to hydrologic studies, by F.P. Haeni: USGS—TWRI Book 2, Chapter D2. 1988. 86 pages.

Section E. Subsurface Geophysical Methods

2–E1.Application of borehole geophysics to water-resources investigations, by W.S. Keys and L.M. MacCary: USGS—TWRI Book 2, Chapter E1. 1971. 126 pages.

2–E2.Borehole geophysics applied to ground-water investigations, by W.S. Keys: USGS—TWRI Book 2, Chapter E2. 1990. 150 pages.

Section F. Drilling and Sampling Methods

2–F1.Application of drilling, coring, and sampling techniques to test holes and wells, by Eugene Shuter and W.E. Teasdale: USGS—TWRI Book 2, Chapter F1. 1989. 97 pages.

Book 3. Applications of Hydraulics

Section A. Surface-Water Techniques

3–A1.General field and office procedures for indirect discharge measurements, by M.A. Benson and Tate Dalrymple: USGS—TWRI Book 3, Chapter A1. 1967. 30 pages.

3–A2.Measurement of peak discharge by the slope-area method, by Tate Dalrymple and M.A. Benson: USGS—TWRI Book 3, Chapter A2. 1967. 12 pages.

3–A3.Measurement of peak discharge at culverts by indirect methods, by G.L. Bodhaine: USGS—TWRI Book 3, Chapter A3. 1968. 60 pages.

3–A4.Measurement of peak discharge at width contractions by indirect methods, by H.F. Matthai: USGS—TWRI Book 3, Chapter A4. 1967. 44 pages.

3–A5.Measurement of peak discharge at dams by indirect methods, by Harry Hulsing: USGS—TWRI Book 3, Chapter A5. 1967. 29 pages.

3–A6.General procedure for gaging streams, by R.W. Carter and Jacob Davidian: USGS—TWRI Book 3, Chapter A6. 1968. 13 pages.

3–A7.Stage measurement at gaging stations, by T.J. Buchanan and W.P. Somers: USGS—TWRI Book 3, Chapter A7. 1968. 28 pages.

3–A8.Discharge measurements at gaging stations, by T.J. Buchanan and W.P. Somers: USGS—TWRI Book 3, Chapter A8. 1969. 65 pages.

3–A9.Measurement of time of travel in streams by dye tracing, by F.A. Kilpatrick and J.F. Wilson, Jr.: USGS—TWRI Book 3, Chapter A9. 1989. 27 pages.

3–Al0.Discharge ratings at gaging stations, by E.J. Kennedy: USGS—TWRI Book 3, Chapter A10. 1984. 59 pages.

3–A11.Measurement of discharge by the moving-boat method, by G.F. Smoot and C.E. Novak: USGS—TWRI Book 3, Chapter A11. 1969. 22 pages.

3–A12.Fluorometric procedures for dye tracing, Revised, by J.F. Wilson, Jr., E.D. Cobb, and F.A. Kilpatrick: USGS—TWRI Book 3, Chapter A12. 1986. 34 pages.

3–A13.Computation of continuous records of streamflow, by E.J. Kennedy: USGS—TWRI Book 3, Chapter A13. 1983. 53 pages.

3–A14.Use of flumes in measuring discharge, by F.A. Kilpatrick and V.R. Schneider: USGS—TWRI Book 3, Chapter A14. 1983. 46 pages.

3–A15.Computation of water-surface profiles in open channels, by Jacob Davidian: USGS—TWRI Book 3, Chapter A15. 1984. 48 pages.

3–A16.Measurement of discharge using tracers, by F.A. Kilpatrick and E.D. Cobb: USGS—TWRI Book 3, Chapter A16. 1985. 52 pages.

3–A17.Acoustic velocity meter systems, by Antonius Laenen: USGS—TWRI Book 3, Chapter A17. 1985. 38 pages.

3–A18.Determination of stream reaeration coefficients by use of tracers, by F.A. Kilpatrick, R.E. Rathbun, Nobuhiro Yotsukura, G.W. Parker, and L.L. DeLong: USGS—TWRI Book 3, Chapter A18. 1989. 52 pages.

3–A19.Levels at streamflow gaging stations, by E.J. Kennedy: USGS—TWRI Book 3, Chapter A19. 1990. 31 pages.

3–A20.Simulation of soluble waste transport and buildup in surface waters using tracers, by F.A. Kilpatrick: USGS—TWRI Book 3, Chapter A20. 1993. 38 pages.

3–A21.Stream-gaging cableways, by C. Russell Wagner: USGS—TWRI Book 3, Chapter A21. 1995. 56 pages.

Section B. Ground-Water Techniques

3–B1. Aquifer-test design, observation, and data analysis, by R.W. Stallman: USGS—TWRI Book 3, Chapter B1. 1971. 26 pages.

3–B2.Introduction to ground-water hydraulics, a programed text for self-instruction, by G.D. Bennett: USGS—TWRI Book 3, Chapter B2. 1976. 172 pages.

3–B3.Type curves for selected problems of flow to wells in confined aquifers, by J.E. Reed: USGS—TWRI Book 3, Chapter B3. 1980. 106 pages.

3–B4.Regression modeling of ground-water flow, by R.L. Cooley and R.L. Naff: USGS—TWRI Book 3, Chapter B4. 1990. 232 pages.

3–B4.Supplement 1. Regression modeling of ground-water flow—Modifications to the computer code for nonlinear regression solution of steady-state ground-water flow problems, by R.L. Cooley: USGS—TWRI Book 3, Chapter B4. 1993. 8 pages.

3–B5.Definition of boundary and initial conditions in the analysis of saturated ground-water flow systems—An introduction, by O. L. Franke, T.E. Reilly, and G.D. Bennett: USGS—TWRI Book 3, Chapter B5. 1987. 15 pages.

3–B6.The principle of superposition and its application in ground-water hydraulics, by T.E. Reilly, O.L. Franke, and G.D. Bennett: USGS—TWRI Book 3, Chapter B6. 1987. 28 pages.

3–B7.Analytical solutions for one-, two-, and three-dimensional solute transport in ground-water systems with uniform flow, by E.J. Wexler: USGS—TWRI Book 3, Chapter B7. 1992. 190 pages.

Section C. Sedimentation and Erosion Techniques

3–C1.Fluvial sediment concepts, by H. P. Guy: USGS—TWRI Book 3, Chapter C1. 1970. 55 pages.

3–C2.Field methods for measurement of fluvial sediment, by T.K. Edwards and G.D. Glysson: USGS—TWRI Book 3, Chapter C2. 1998. 80 pages.

3–C3.Computation of fluvial-sediment discharge, by George Porterfield: USGS—TWRI Book 3, Chapter C3. 1972. 66 pages.

Book 4. Hydrologic Analysis and Interpretation

Section A. Statistical Analysis

4–A1.Some statistical tools in hydrology, by H.C. Riggs: USGS—TWRI Book 4, Chapter A1. 1968. 39 pages.

4–A2.Frequency curves, by H.C. Riggs: USGS—TWRI Book 4, Chapter A2. 1968. 15 pages.

Section B. Surface Water

4–B1.Low-flow investigations, by H.C. Riggs: USGS—TWRI Book 4, Chapter B1. 1972. 18 pages.

4–B2.Storage analyses for water supply, by H.C. Riggs and C.H. Hardison: USGS—TWRI Book 4, Chapter B2. 1973. 20 pages.

4–B3.Regional analyses of streamflow characteristics, by H.C. Riggs: USGS—TWRI Book 4, Chapter B3. 1973. 15 pages.

Section D. Interrelated Phases of the Hydrologic Cycle

4–D1.Computation of rate and volume of stream depletion by wells, by C. T. Jenkins: USGS—TWRI Book 4, Chapter D1. 1970. 17 pages.

Book 5. Laboratory Analysis

Section A. Water Analysis

5–A1.Methods for determination of inorganic substances in water and fluvial sediments, by M.J. Fishman and L.C. Friedman, editors: USGS—TWRI Book 5, Chapter A1. 1989. 545 pages.

5–A2.Determination of minor elements in water by emission spectroscopy, by P.R. Barnett and E.C. Mallory, Jr.: USGS—TWRI Book 5, Chapter A2. 1971. 31 pages.

5–A3.Methods for the determination of organic substances in water and fluvial sediments, edited by R.L. Wershaw, M.J. Fishman, R.R. Grabbe, and L.E. Lowe: USGS—TWRI Book 5, Chapter A3. 1987. 80 pages.

5–A4.Methods for collection and analysis of aquatic biological and microbiological samples, by L.J. Britton and P.E. Greeson, editors: USGS—TWRI Book 5, Chapter A4. 1989. 363 pages.

5–A5.Methods for determination of radioactive substances in water and fluvial sediments, by L.L. Thatcher, V.J. Janzer, and K.W. Edwards: USGS—TWRI Book 5, Chapter A5. 1977. 95 pages.

5–A6.Quality assurance practices for the chemical and biological analyses of water and fluvial sediments, by L.C. Friedman and D.E. Erdmann: USGS—TWRI Book 5, Chapter A6. 1982. 181 pages.

Section C. Sediment Analysis

5–C1.Laboratory theory and methods for sediment analysis, by H. P. Guy: USGS—TWRI Book 5, Chapter C1. 1969. 58 pages.

Book 6. Modeling Techniques

Section A. Ground Water

6–A1.A modular three-dimensional finite-difference ground-water flow model, by M. G. McDonald and A. W. Harbaugh: USGS—TWRI Book 6, Chapter A1. 1988. 586 pages.

6–A2.Documentation of a computer program to simulate aquifer-system compaction using the modular finite-difference ground-water flow model, by S.A. Leake and D.E. Prudic: USGS—TWRI Book 6, Chapter A2. 1991. 68 pages.

6–A3.A modular finite-element model (MODFE) for areal and axisymmetric ground-water-flow problems, Part 1: Model Description and User's Manual, by L. J. Torak: USGS—TWRI Book 6, Chapter A3. 1993. 136 pages.

6–A4.A modular finite-element model (MODFE) for areal and axisymmetric ground-water-flow problems, Part 2: Derivation of finite-element equations and comparisons with analytical solutions, by R.L. Cooley: USGS—TWRI Book 6, Chapter A4. 1992. 108 pages.

6–A5.A modular finite-element model (MODFE) for areal and axisymmetric ground-water-flow problems, Part 3: Design philosophy and programming details, by L.J. Torak: USGS—TWRI Book 6, Chapter A5, 1993. 243 pages.

6–A6.A coupled surface-water and ground-water flow model (MODBRANCH) for simulation of stream-aquifer interaction by E.D. Swain and Eliezer J. Wexler: USGS—TWRI Book 6, Chapter A6, 1996. 125 pages.

Book 7. Automated Data Processing and Computations

Section C. Computer Programs

7–C1.Finite difference model for aquifer simulation in two dimensions with results of numerical experiments, by P.C. Trescott, G.F. Pinder, and S.P. Larson: USGS—TWRI Book 7, Chapter C1. 1976. 116 pages.

7–C2.Computer model of two-dimensional solute transport and dispersion in ground water, by L.F. Konikow and J.D. Bredehoeft: USGS—TWRI Book 7, Chapter C2. 1978. 90 pages.

7–C3.A model for simulation of flow in singular and interconnected channels, by R.W. Schaffranek, R.A. Baltzer, and D.E. Goldberg: USGS—TWRI Book 7, Chapter C3. 1981. 110 pages.

Book 8. Instrumentation

Section A. Instruments for Measurement of Water Level

8–A1.Methods of measuring water levels in deep wells, by M.S. Garber and F.C. Koopman: USGS—TWRI Book 8, Chapter A1. 1968. 23 pages.

8–A2.Installation and service manual for U.S. Geological Survey manometers, by J.D. Craig: USGS—TWRI Book 8, Chapter A2. 1983. 57 pages.

Section B. Instruments for Measurement of Discharge

8–B2.Calibration and maintenance of vertical-axis type current meters, by G.F. Smoot and C.E. Novak: USGS—TWRI Book 8, Chapter B2. 1968. 15 pages.

Book 9. Handbooks for Water-Resources Investigations

Section A. National Field Manual for the Collection of Water-Quality Data

9–A1.Preparations for water sampling, by F.D. Wilde, D.B. Radtke, Jacob Gibs, and R.T. Iwatsubo: USGS—TWRI Book 9, Chapter A1. 1998. Variously paged.

9–A2.Selection of equipment for water sampling, by F.D. Wilde, D.B. Radtke, Jacob Gibs, and R.T. Iwatsubo, editors: USGS—TWRI Book 9, Chapter A2. 1998. Variously paged.

9–A6.Field measurements, by F.D. Wilde and D.B. Radtke, editors: USGS—TWRI Book 9, Chapter A6. 1998. Variously paged.

9–A7.Biological indicators, by D.N. Myers and F.D. Wilde, editors: USGS—TWRI Book 9, Chapter A7. 1997. Variously paged.

9–A8.Bottom-material samples, by D.B. Radtke: USGS—TWRI Book 9, Chapter A8. 1998. Variously paged.

9–A9.Safety in field activities, by S.L. Lane and R.G. Fay: USGS—TWRI Book 9, Chapter A9. 1998. Variously paged.