United States Department of the Interior
U.S. GEOLOGICAL SURVEY
Reston, Virginia 20192

In Reply Refer To:
Mail Stop 415

June 13, 2013

OFFICE OF SURFACE WATER TECHNICAL MEMORANDUM 2013.03

OFFICE OF WATER QUALITY TECHNICAL MEMORANDUM 2013.02

SUBJECT: Guidelines for FISP Bag Sampler Intake Efficiency Tests and Operational Velocities

Policy

This memorandum directs USGS users of Federal Interagency Sedimentation Project (FISP) collapsible-bag samplers to:

- Perform field tests of bag-sampler intake efficiency before each set of samples is collected during site visits;
- Store the required data (five parameters) from these tests in the National Water Information System (NWIS) with associated environmental samples; and
- Incorporate the revised, temperature-indexed minimum stream velocities (Table 1) for bag samplers into data-collection practices where suspended sediment may include a significant percentage of material larger than silt size (≥0.062 mm).

This memorandum supplements the FISP reports and operation manuals for the FISP US-series DH-2, D-96, D-96A1, and D-99 bag-samplers (Davis 2001, 2005a,b; McGregor, 2006) and information in memorandum OWQ 99.02/OSW 99.01—Guidance for Collecting Discharge-Weighted Samples in Surface Water Using an Isokinetic Sampler (October 28, 1998). This memorandum does not, however, replace the extensive guidance in these previous reports provided for proper use of FISP samplers.

Background

Answers for many critical water-related questions require solid-phase water-quality data that are representative, accurate, and consistent. Collection of representative water-sediment samples for subsequent analyses of solid-phase constituents requires use of appropriate isokinetic samplers (Davis, 2005a) and deployment techniques (Edwards and Glysson, 1999; Nolan et al., 2005; Gray et al., 2008). Recent review of field and laboratory data indicates that the FISP bag samplers may not perform isokinetically under some conditions.

Suspended-sediment concentration (SSC) and sediment-associated water-quality constituent concentrations can be highly variable in stream cross sections, particularly when sand-size particles (0.062 to 2 mm, Guy, 1970) are suspended in appreciable quantities. Consequently, samples representative of the flow throughout the cross section must be collected using depth- and width-integrated methods and isokinetic samplers. Isokinetic sampling means that water enters the nozzle of a sampler without accelerating or decelerating relative to streamflow velocity at the sampler nozzle (ambient velocity). The measure of isokinetic sampling is the intake efficiency (IE) defined as the ratio of the velocity through the nozzle entrance (Vn) to the ambient stream velocity (V); IE = Vn/V, where Vn and V are averaged over the sample time and depth for each specific sample. The IE of every FISP bag sampler is confirmed in flume tests at the Hydrologic Instrumentation Facility to be within 0.9 and 1.1 at velocities of 3–4 feet per second (ft/s) at laboratory temperature before the sampler is released for field use.

The importance of isokinetic sampler performance on derived sediment concentrations is illustrated in figure 1 (Gray et al., 2008; adapted from FISP Report No. 5). If flow decelerates as it enters the nozzle (IE < 1, sub-isokinetic), the sample SSC will tend to be biased high; and if flow accelerates as it enters the nozzle (IE>1, super-efficient), the sample SSC will be biased low. The bias error in SSC for the coarsest grade of sand (0.45mm) shown in Figure 1 is about +10% for IE=0.75, at a velocity of 5 ft/s. Significant bias in derived sand-sized SSC is likely if samples are obtained under conditions where IE <0.75 or IE>1.25. Under some field and deployment conditions it may not be possible to collect a sample with 0.75 < IE < 1.25, in which case it is particularly important to document the IE so that potential bias in sand concentrations can be considered by users of the analyzed data.

For particle sizes finer than sand (< 0.062 mm) the bias error is less than 10 percent, even at extreme non-isokinetic conditions (see purple- and blue-dashed lines in figure 1). Thus, it is acceptable to sample under non-isokinetic conditions if the sand percentage of SSC has been shown to be negligible in prior analyses of samples collected at that site under similar flow conditions. In any case, IE should be tested and the IE-test data recorded with each environmental sampling effort.

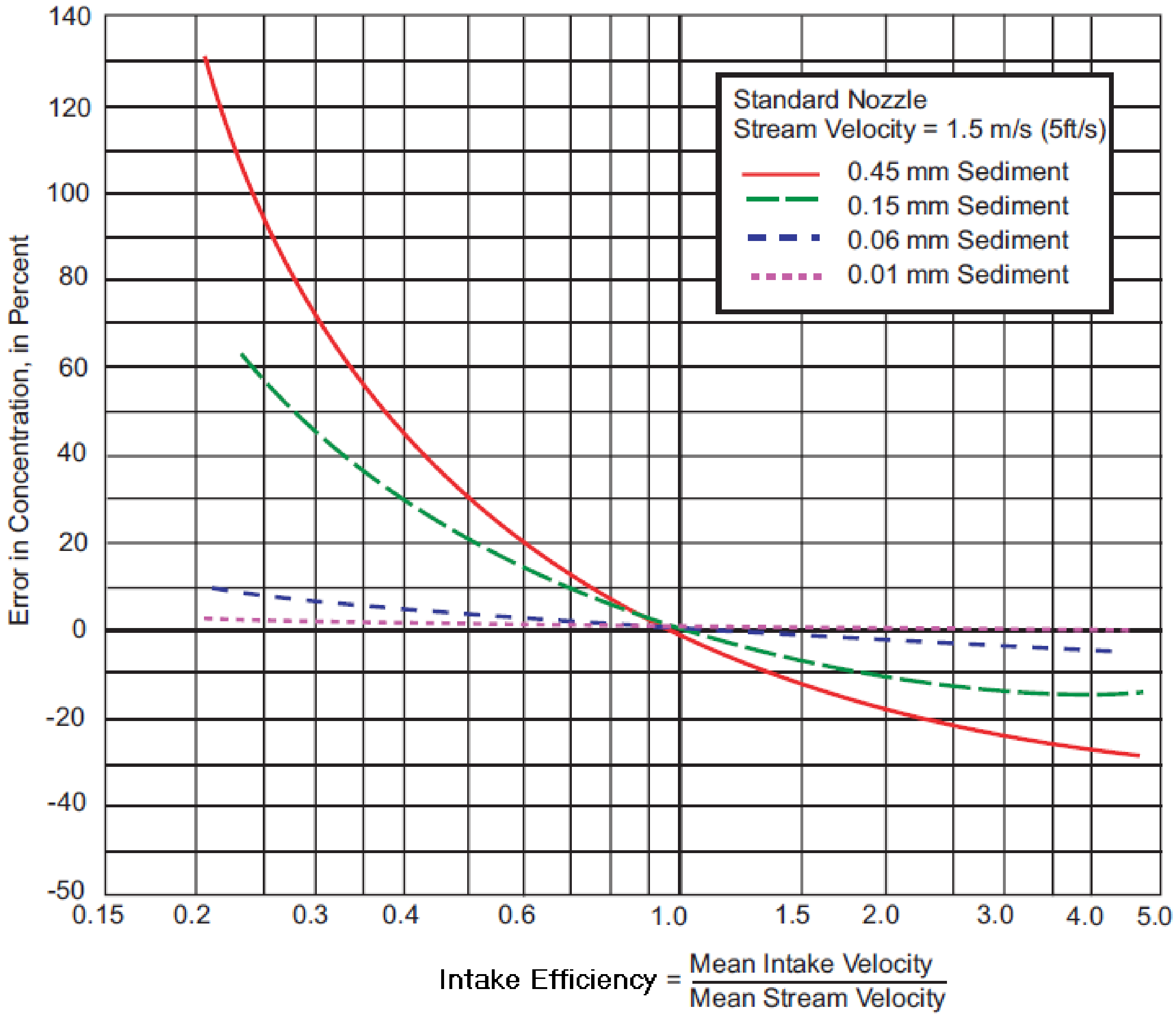

Figure 1. Errors in SSC for variable non-isokinetic sampling conditions for four sediment sizes, for flow velocity of 5 ft/s. Figure from Gray et al. (2008), based on data from FISP Report 5 (1941).

Factors that affect the IE of isokinetic samplers include sampler type and nozzle design, stream velocity, water temperature, sampler orientation relative to the flow, and the sample volume relative to that of the sample container. IE tends to decrease rapidly as stream velocities decrease from about 4 ft/s to 2 ft/s, depending on the type of sampler, nozzle size, and stream temperature. At low velocities, however, substantial concentrations of sand are unlikely, thus non-isokinetic sampling has limited influence on the accuracy of SSCs and sediment-associated water-quality constituent concentrations.

Decreasing stream temperatures tend to cause decreasing sampler IEs, because friction losses increase through the sampler nozzle as fluid viscosity increases. This is particularly true for lower velocities as shown in Figure 2 (from data in Davis, 2001). Tests of FISP samplers are typically conducted at water temperatures between about 24ºC–29ºC (75º–85ºF) in the warmer range of most field sampling conditions. Cold-water tests indicate that the US D-96 performs sub-isokinetically (IE < 0.9) at temperatures less than about 10ºC (50˚F) at velocities less than about 3.7 ft/s for all nozzle sizes (Davis, 2001).

A detailed theoretical and empirical evaluation of temperature effects also was conducted by Sabol and Topping (2012) for US D-96 bag samplers deployed in the Colorado River in Arizona and Utah. These data (Sabol and Topping, 2012) and subsequent review of FISP bag-sampler calibration data prompted revision of previous, temperature-indexed minimum operational velocity limits; the revised limits are shown in Table 1.

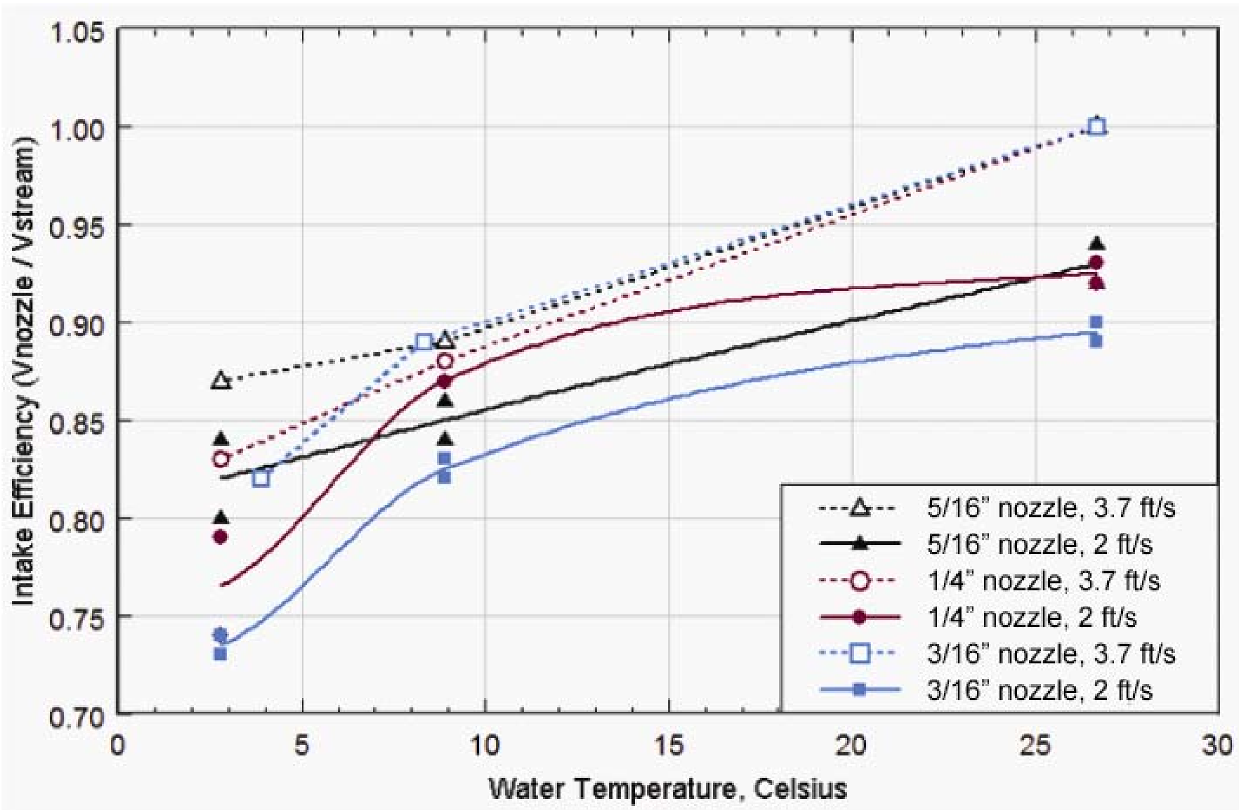

Figure 2. Changes in IE (intake efficiency) with temperature for FISP US D-96 sampler for three temperatures and nozzle sizes at two velocities. Data are from Davis, 2001.

Sample volumes should not exceed maximum sample container capacities or IE will decline rapidly as described by Szalona (1982) and Davis (2001). Sampling up to full-bag capacity did not affect IE in tests conducted in extensive laboratory tests at warm temperatures and in limited field tests in larger rivers. However, Sabol and Topping (2012) reported that sample volume also can affect IE before reaching container capacity, in the turbulent riverine environment of their tests. Additional data are being collected to further evaluate this issue.

Revised Guidance on Bag-Sampler Intake Efficiency Tests for Each Sampling Event

This memorandum directs USGS users of FISP bag samplers to perform field tests of sampler IE before each set of samples is collected as part of all site visits, as originally recommended in memorandum OWQ 99.02/OSW 99.01. It also requires the resulting data to be stored in the NWIS. A FISP Sampler Efficiency Template (Excel file) is available to aid in IE-test computations and data handling. Three IE tests should be performed per site visit, if safe and practical, to obtain an average IE value. The IE test must be made at least once before each sampling effort.

Method to determine IE values:

Intake efficiency tests require knowledge of the intake-nozzle inner diameter, and measurements of:

a. duration of time the sampler nozzle is submerged;
b. sample volume; and
c. average stream velocity at the sampler intake during the sample collection.

A large graduated pitcher or cylinder is needed to measure sample volume (one can be requested from the FISP at a minimal cost). Maximizing the accuracy of each of these measurements is highly important because the computed intake efficiency requires accurate values from each of these measurements.

The method to perform an intake-efficiency test follows:

1. Select the location of the IE-test vertical from one of the planned sampling stations. Preferably the IE-test vertical will have velocity characteristics similar to those of the majority of sampling stations; alternately one may use the deepest, fastest section where one may opt to test for maximum isokinetic transit rate. Note the IE-test vertical location. (The USGS EDI program can help with this if an ADCP is used.)
2. Record the water temperature and time.
3. Prepare the bag sampler as described in the sampler manual, and deploy through the IE-test vertical as for a regular depth-integrated sample, as described in TWRI 3C2 (Edwards and Glysson, p. 39-41).
4. Record the duration of sampler nozzle submergence (the duration that the IE-test sample is being collected) to the nearest second.
5. Remove the bag and measure the IE-test sample volume by decanting to a graduated cylinder. The IE-test sample subsequently can be discarded. Laboratory analysis of the IE-test sample is not required, however, visual examination of the IE-test sample for the presence of sand is recommended.
6. Measure the velocity in or near the IE-test vertical, and at or near the IE-test time (could be measured during step 3). Measure the velocity using a standard cup-meter or an ADCP deployed from the sampling vessel or suspended in the sampling streamline. The mean velocity at the IE-test vertical also could be derived from an ADCP moving-boat transect (particularly for steady flow conditions) using manufacturer software or the USGS EDI program (ver. 3.3). The velocity should be the average for the depth over which the IE test was performed.
7. Repeat steps 3–7 twice (a total of three measurements) at the same location if safe and practical. Repeating velocity measurement (step 6) is preferred, but if velocity is steady and without notable turbulence, a single velocity measurement for the three tests is adequate. The individual velocity measurements should be recorded.
8. Compute the IE for each test using the FISP Sampler Efficiency Template or equivalent method such as a calculator (see equation below). Compute the average of the three measured IE values.

The IE is computed as:

$$IE = K \times \frac{(Volume\ in\ ml)/(Duration\ in\ sec)}{\left(Stream\ Velocity\ in\ \frac{ft}{sec}\right)},$$

where K(indexed to nozzle diameter)= [0.1841 for $\frac{3}{16}$"; 0.1036 for $\frac{1}{4}$"; 0.0663 for $\frac{5}{16}$"]

9. If the average IE is within 0.75<IE<1.25 and each individual IE measurement is within 0.7<IE<1.3, then proceed with collecting the environmental sample(s).
10. If the average IE is not within 0.75<IE<1.25 and (or) each individual IE measurement is not within 0.7<IE<1.3 then:
    a. if suspended sand has been shown to be negligible in prior analyses of samples collected at the site under similar conditions, then clearly note this information and proceed with collecting the environmental sample(s);
    b. if appreciable suspended sand may be present in the SSC, then consider replacing the sampler nozzle (a larger nozzle may perform better) and (or) sampler and repeat steps 3-8;
    c. if the average IE is not within 0.75<IE<1.25 then still collect the environmental sample(s); note the IE; document the site and equipment conditions; document why alternative equipment could not be used; and reconsider the operational approach to sampling at the site.

Storing Intake Efficiency Data in the NWIS:

IE-test data are to be recorded in the USGS NWIS database. These data are to be stored in NWIS QWDATA with the record(s) for the associated environmental sample(s) (representative composites or discrete) for this site visit. The required parameters for the IE-test data are in addition to those required for entry in policy memorandum SW10.03/QW10.05. The IE-test data set does not require a separate water-temperature measurement. The water temperature for the environmental sample is adequate for the IE-test. At the time of this memorandum some of these parameters are not available in SedLOGIN or PCFF or other field data entry programs and will require separate entry to NWIS through QWDATA (QW-TipSheet 5.3). The three-measurement IE-tests at a vertical constitute a single average IE measurement. Thus, the average value of the (typically three) IE test measurements should be determined (where the values change) for each of these parameters and the average value should be entered into NWIS with the associated environmental sample(s). A remark code of “A” can be used with the values to indicate that what is stored in QWDATA is an average value. (See QWDATA user manual, Appendix A, table 6 http://nwis.usgs.gov/currentdocs/qw/QW-AppxA.pdf.)

These are the 5 parameters for the IE test that need to be quantified and stored with the environmental sample.

72217 Duration sampler collected water, seconds

72218 Sample volume to compute isokinetic transit rate, milliliters

72196 Velocity to compute isokinetic transit rate, feet per second (include method code)

72219 Sampler nozzle material, [code: Plastic=2, TFE=3]

72220 Sampler nozzle diameter, code [3/16”=3, 1/4”=4, 5/16”=5]

Revised Minimum Velocity for Bag Samplers where Sand may be in Suspension

Revised minimum operational velocities for FISP bag samplers where ≥0.062 mm size material may be in suspension are shown in Table 1. The new minimum velocity guidance is indexed to water temperature for specific nozzle sizes. The minimum-velocity requirement remains unchanged for temperatures greater than 27ºC (80°F) for all nozzle sizes, and for temperatures greater than 10ºC (50°F) for 1/4 and 5/16 inch nozzle sizes. Field tests of IE are particularly important when sampling near these operational limits.

Table 1. Characteristics and operational ranges for FISP bag samplers.

FISP Sampler Designation	Container type and capacity	Weight, lbs	Mode of Suspension	Un-samp-led Zone, in	Max-imum Velo-city[1], ft/s	Nozzle Inner Diameter[2], in	Maxi-mum Depth[3], ft	Minimum Isokinetic Velocity[4], ft/s for Temperature (T) °C		
								T<10°	10<T<27°	T>27°
US DH-2	Flexible 1-Liter (L) bag	30	Handline or Cable Reel	3.5	6	3/16	35	3.7	3.7	2
US DH-2						1/4	20	3.7	2	2
US DH-2						5/16	13	3.7	2	2
US D-96	Flexible 3-L bag	132	Cable Reel	4.0	12	3/16	110	3.7	3.7	2
US D-96						1/4	60	3.7	2	2
US D-96						5/16	39	3.7	2	2
US D-96-A1	Flexible 3-L bag	80			6	3/16	110	3.7	3.7	2
US D-96-A1						1/4	60	3.7	2	2
US D-96-A1						5/16	39	3.7	2	2
US D-99	Flexible 3-L or 6-L bag	285	Cable Reel, Custom Crane	9.5	15	3/16	220	4	4	4
US D-99						1/4	120	3.7	3	3
US D-99						5/16	78	3.7	3	3

[1]The maximum recommended velocity for bag sampler deployment is based on maximum drift angle of suspension cable (25–30 degrees). Actual maximum should be determined based on this maximum drift angle and field safety considerations.

[2] The 3/16- inch nozzle is more sensitive to velocity and temperature effects and should only be used when necessary to sample maximum depths.

[3] The maximum theoretical depth is based on maximum transit rate of 0.4 times the mean flow velocity in the sampled vertical and the sample bag capacity (6 L for the US D-99 sampler).

[4]Test results are not available for temperatures <10ºC (50°F). In colder water it is particularly important to test and record intake efficiency with each sample data set.

References

FISP Sampler Efficiency Template, available at: http://water.usgs.gov/fisp/FISP_Sampler_Efficiency_Template.xlsx.

Davis, B.E., 2001, The US D-96: An isokinetic suspended-sediment/water-quality collapsible bag sampler: Federal Interagency Sedimentation Project Report PP, 37 p. (http://water.usgs.gov/fisp/docs/Report_PP,_US_D-96_011114_.pdf).

Davis, B.E., 2005a, A guide to the proper selection and use of Federally approved sediment and water-quality samplers: U. S. Geological Survey Open-File Report 2005-1087, 20 pp. (http://pubs.usgs.gov/of/2005/1087/)

Davis, B.E., 2005b, The US DH-2: A one-liter hand-line isokinetic suspended-sediment/water-quality collapsible bag sampler: Federal Interagency Sedimentation Project Report SS, 19 p. (http://water.usgs.gov/fisp/docs/Report_SS_050720_DH-2_.pdf).

Edwards, T.K., and Glysson, G.D., 1999, Field methods for measurement of fluvial sediment: Techniques of Water-Resources Investigations of the U.S. Geological Survey, Book 3, Chapter C2, 89 p. (http://pubs.usgs.gov/twri/twri3-c2/pdf/TWRI_3-C2.pdf).

Federal Interagency Sedimentation Project, 1941, Laboratory investigation of suspended-sediment samplers: Iowa City, Iowa University Hydraulics Laboratory, Interagency Report No. 5, 99 p. (http://water.usgs.gov/fisp/docs/Report_5.pdf).

Federal Interagency Sedimentation Project, 1952, The design of improved types of suspended-sediment samplers: Minneapolis, Minnesota, St. Anthony Falls Hydraulics Laboratory, Interagency Report No. 6, 103 p. (http://water.usgs.gov/fisp/docs/Report_6.pdf).

Gray, J., Glysson, J.D., and Edwards, D.T., 2008, Suspended-sediment samplers and sampling methods, *in* Garcia, M., ed., Sedimentation Engineering, Processes, Measurements, Modeling, and Practice: ASCE Manuals and Reports on Engineering Practice No. 110, p. 320-339.

Guy, H.P., 1970, Fluvial sediment concepts: Techniques of Water-Resources Investigations of the U.S. Geological Survey, Book 3, Chapter C1, 55 pp. (http://pubs.usgs.gov/twri/twri3-c1/pdf/TWRI_3-C1.pdf).

McGregor, J., 2006, The US D-99: An isokinetic depth-integrating collapsible-bag suspended-sediment sampler: Federal Interagency Sedimentation Project Report RR, 19 p. (http://water.usgs.gov/fisp/docs/Report_RR.pdf).

Nolan, K. M., Gray, J.R., and Glysson, G.D., 2005, Introduction to suspended-sediment sampling: U.S. Geological Survey Scientific Investigations Report, 2005-5077 (http://pubs.er.usgs.gov/pubs/sir/sir20055077).

Sabol, T.A., Topping, D.J., and Griffiths, R.E., 2010, Field evaluation of sediment-concentration errors arising from non-isokinetic intake efficiency in depth-integrating suspended-sediment bag samplers: Ninth Federal Interagency Sedimentation Conference, Las Vegas, NV, 12 p. (http://acwi.gov/sos/pubs/2ndJFIC/Contents/P23_SABOL_02_23_10.pdf).

Sabol, T.A., and Topping, D.J., 2012, Evaluation of intake efficiencies and associated sediment-concentration errors in US D-77 bag-type and US D-96-type depth-integrating suspended-sediment samplers: U.S. Geological Survey Scientific Investigations Report 2012-5208, 111 p.

Szalona, J.J., 1982, Development of a bag-type suspended-sediment sampler, A study of methods used in measurement and analysis of sediment loads in streams: FISP Report Y, Minneapolis, Minnesota, Federal Interagency Sedimentation Project, St. Anthony Falls Hydraulic Laboratory, 32 p. (http://water.usgs.gov/fisp/docs/Report_Y.pdf).

U.S. Geological Survey, Office of Surface Water (OSW) Technical Memorandum 99.01, 1998, Guidance for Collecting Discharge-Weighted Samples in Surface Water Using an Isokinetic Sampler: 41 p. (http://water.usgs.gov/admin/memo/SW/sw99.01.pdf).

U.S. Geological Survey, Office of Water Quality (OWQ) Technical Memorandum 2002.09, 2002, Water-Quality Field Methods phaseout of US D-77 and frame-type samplers: 1 p. (http://water.usgs.gov/admin/memo/QW/qw02.09.html).

Robert R. Mason, Jr.
Deputy Chief, Office of Surface Water

Donna Myers
Chief, Office of Water Quality

Distribution: GS-W All