Federal Interagency Sedimentation Project (FISP)
Memorandum 2013.01

May 6, 2013

Subject: Best Practices for FISP Bag Sampler Intake Efficiency Tests and Operational Velocities

This memorandum recommends that users of Federal Interagency Sedimentation Project (FISP) collapsible-bag samplers:

- Perform quality-assurance field tests of bag-sampler intake efficiency before each set of samples is collected during site visits; 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 sand-sized material.

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). 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 issues 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 (larger than 0.062 mm) 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 U.S. Geological Survey Hydrologic Instrumentation Facility to be within $0.9<IE<1.1$ 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 SSCs 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, 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 (larger than 0.062 mm) SSC is likely if samples are obtained under conditions where IE is <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 SSCs can be considered by users of the analyzed data.

For particles finer than sand size (< 0.062 mm) the bias error is less than 10%, 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 conditions. In any case, IE should be tested and the IE-test data recorded with each environmental sampling effort.

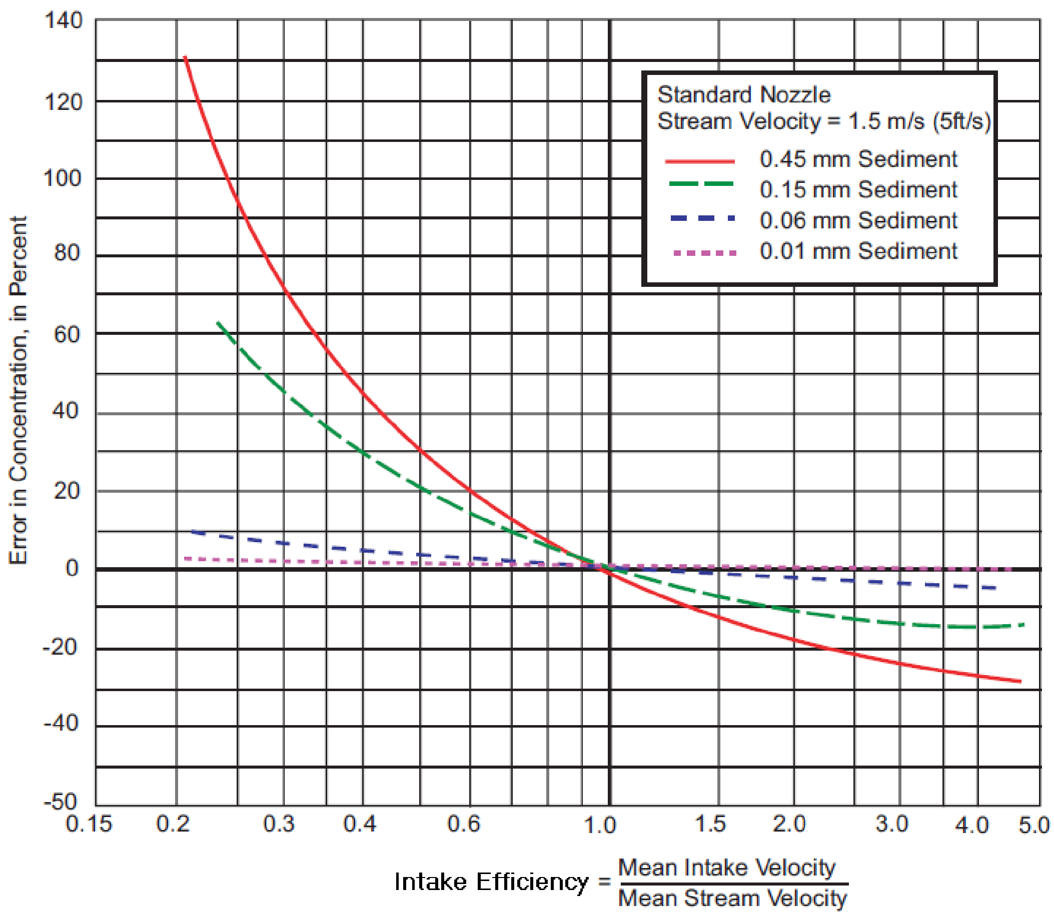

Figure 1—Errors in SSC for variable non-isokinetic sampling conditions for four sediment sizes, for flow velocity of 5 ft/s. Figure from Gray et al. (2008), based on data from FISP Report 5 (1941).

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 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 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.

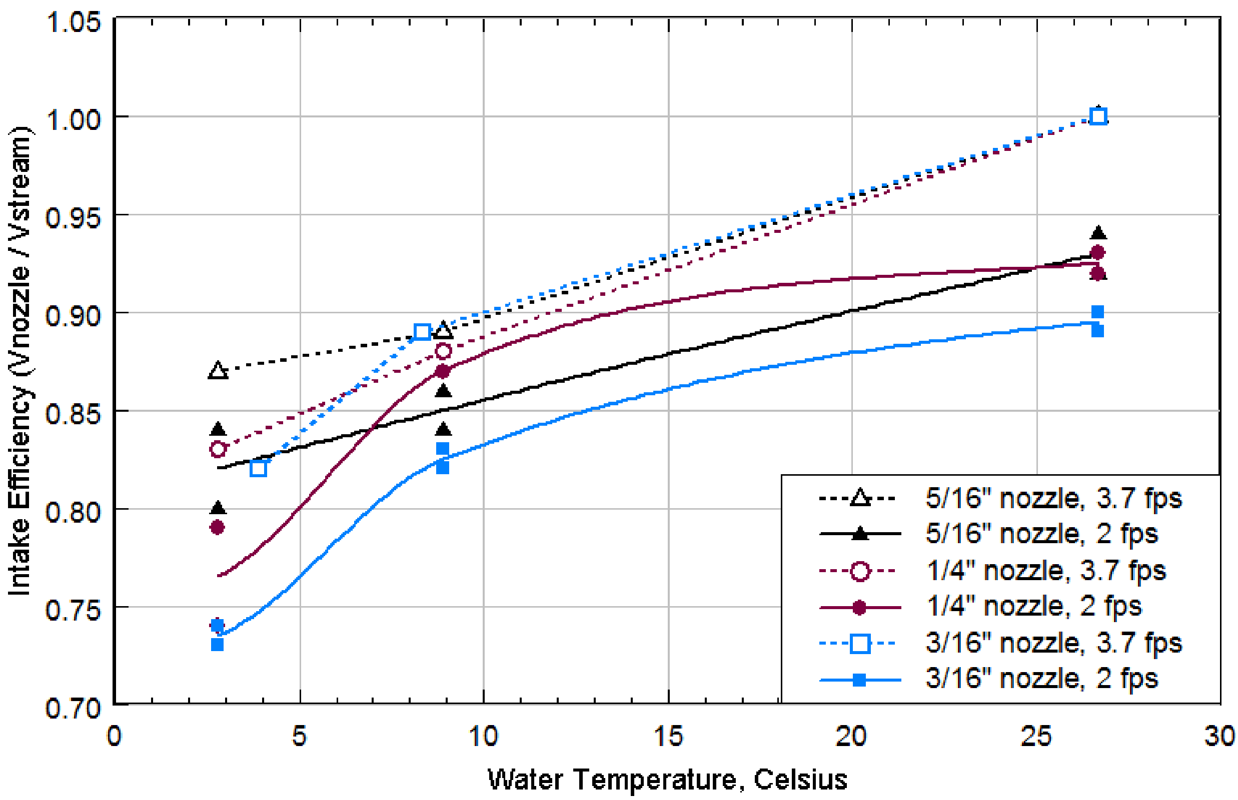

Figure 2—Changes in IE (intake efficiency) with temperature for FISP US D-96 sampler for three water temperatures and nozzle sizes at two velocities, from data in Davis, 2001.

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.

Recommended Bag-Sampler Intake Efficiency Tests for Each Sampling Event

This memorandum recommends 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, and recording IE-test results as quality assurance data. A FISP Sampler Efficiency Template (Excel file) is available to aid in IE-test computations and data handling. Three IE test should be performed per site visit, if safe and practical, to obtain an average IE value. The IE test should 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 the intake-efficiency test follows:

1. Select the location of the IE-test vertical from one of the planned sampling verticals. 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.
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 in a graduated cylinder. The IE-test sample 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 velocity at the IE-test vertical also could be taken from an ADCP moving–boat transect (particularly for steady flow conditions) using manufacturer software. 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.
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 3 measured IE values.
   The IE is computed as:

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

$$\text{where } K = \left[0.1841 \text{ for } \tfrac{3}{16}''; 0.1036 \text{ for } \tfrac{1}{4}''; 0.0663 \text{ for } \tfrac{5}{16}''\right]$$

9. If the average IE is <u>within</u> $0.75<IE<1.25$ 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 <u>not</u> <u>within</u> $0.75<IE<1.25$ <u>and (or)</u> each individual IE measurement is <u>not within</u> $0.7<IE<1.3$ 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 <u>not within</u> $0.75<IE<1.25$ then still collect the environmental sample(s); note the IE; document the site and equipment conditions; explain why alternative equipment could not be used; and reconsider the operational approach to sampling at the site.

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

Revised minimum operational velocities for FISP bag samplers where sand-size (≥0.062 mm) 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 ¼- 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-sampled Zone, in	Maximum Velocity [1], ft/s	Nozzle Inner Diameter [2], in	Maximum 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-L bag	30	Handline or Cable Reel	3.5	6	3/16	35	3.7	3.7	2
US DH-2						¼	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						¼	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						¼	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						¼	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

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