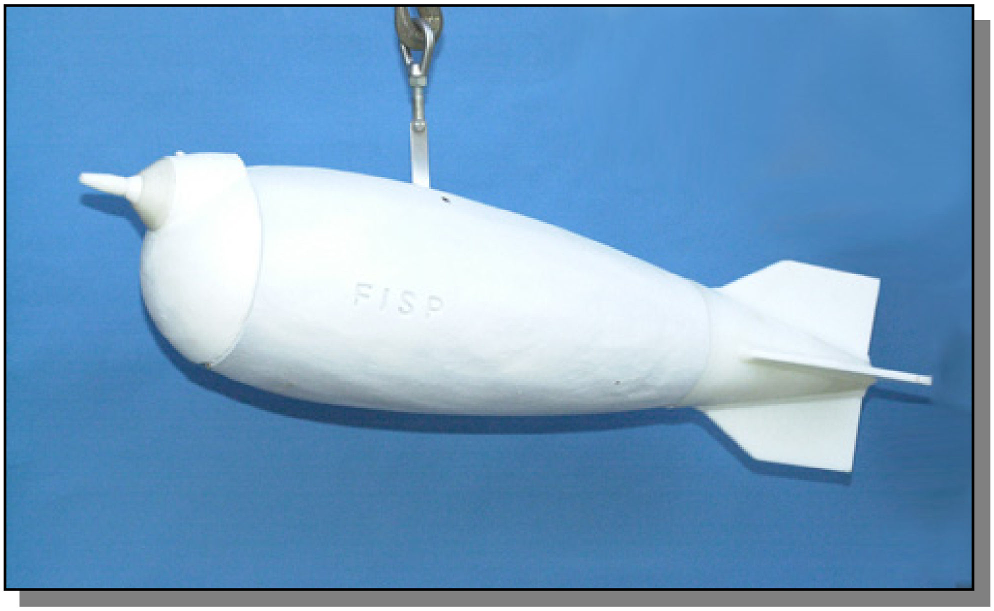
Report RR

THE US D-99: AN ISOKINETIC DEPTH-INTEGRATING COLLAPSIBLE-BAG SUSPENDED-SEDIMENT SAMPLER



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August 2006

Published by

FEDERAL INTERAGENCY SEDIMENTATION PROJECT
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Sponsored by:

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FACTORS FOR CONVERTING INCH/POUND UNITS TO SI METRIC UNITS

Multiply	by	To Obtain
inches	25.4	millimeters
inches	2.54	centimeters
quarts, liquid	0.9464	liters

ABSTRACT

The Federal Interagency Sedimentation Project(FISP) developed the US D-99 suspended-sediment sampler, a depth-integrating instrument for use in deep swift rivers requiring the collection of a large volume sample. The sampler weighs 285 pounds and has a streamlined body. The bronze body casting is coated with plastic to reduce the potential for contamination when used for trace element sampling. The tail section is constructed from plastic. The sampler is designed to use 3-liter or 6-liter perfluoroalkoxy(PFA) or polyethylene bags. Nozzles with intake diameters of 3/16, 1/4, and 5/16 inch(in) constructed of tetrafluoroethylene(TFE) or plastic are available for use with the sampler. Plastic nozzles and polyethylene bags are used for sediment sampling, and TFE nozzles and PFA bags meet the U.S. Geological Survey's (USGS) Office of Water Quality's (Wilde 1998) requirements for collecting non-contaminated water-quality samples for trace-element analysis. Using the 6-liter bag, the sampler is capable of sampling to a depth of 220 feet(ft) with a 3/16-in intake diameter nozzle, 120 ft with a 1/4-in intake diameter nozzle, and 78 ft with a 5/16-in intake diameter nozzle. The unsampled zone, the distance between the centerline of the nozzle and the streambed, is 7.4 in when the bottom of the sampler touches the streambed

Tests to determine the inflow efficiency of the sampler were conducted in a re-circulating flume and by towing the sampler with a boat in a lake. The inflow efficiency also was determined during raising and lowering of the sampler while towed by a boat in a lake to simulate a transit in a stream vertical. The sampler collected samples at acceptable inflow efficiencies in flow velocities of 2 to 4 feet per second (ft/sec) using a 3-liter bag and 3 to 15 ft/sec using a 6-liter bag. Drift angle tests documented the drift angle of the sampler at various depths and stream velocities. Underwater video documented the stability of the sampler while towing. A prototype was field tested by a U.S. Geological Survey Water Science Center.

INTRODUCTION

Various investigators including Gluschkoff and the Rhine Works Authority (FISP 1940), Stevens (1980), and Szalona (1982) have documented research on the use of a collapsible-bag suspended-sediment sampler. Results were encouraging, but the proposed samplers were not able to collect isokinetic samples at all stream velocities typically encountered in natural streams. In 1996 the FISP began research and development of an isokinetic collapsible-bag suspended-sediment/water-quality depth-integrating sampler. A collapsible-bag sampler has several advantages over traditional rigid-container samplers. A primary advantage is sampling depth. Rigid-container samplers are limited to a maximum depth of 15 ft. A bag container is flexible and contains essentially no air. As a result, sampling depth is not limited because of air compressibility, meaning the depth to which the sampler can be used is limited only by the intake diameter of the nozzle and the volume of the bag. It also means the maximum transit rate is limited only by the apparent approach angle of the nozzle facing into the stream flow as the sampler makes its vertical traverse, which is 0.4 times (FISP 1941) the mean stream velocity. The minimum transit rate is limited by the volume of the collapsible bag. Another advantage is cost savings in the use of collapsible bags as opposed to a rigid container or bottle.

The initial development effort beginning in 1996 resulted in a 3-liter sampler, designated the US D-96. The sampler was designed, tested, and approved for use by the FISP Technical Committee (Davis 2001). The US D-96 sampler weighs 130 lbs. In 2003 an 80-lb version of the US D-96, designated the US D-96-A1, was designed, tested, and approved by the FISP Technical Committee (Davis 2003). A 29 lb hand-line collapsible-bag sampler that collects a 1-liter sample was also designed, tested and approved by the FISP Technical Committee. The sampler is designated the US DH-2 and is described by Davis (2005). These samplers are in wide-spread use throughout the United States, and other countries.

The wide-spread use of the US D-96 led to the discovery that even at 130 lbs, the sampler encountered a severe down-stream drift in deep swift reaches such as those encountered on the lower Mississippi River. As a result, the FISP Technical Committee tasked the FISP with the design, fabrication, and testing of a heavy, large volume collapsible-bag sampler. The US D-99, a sampler that meets these criteria, has been developed and tested by the FISP. This report describes the development and testing of the US D-99.

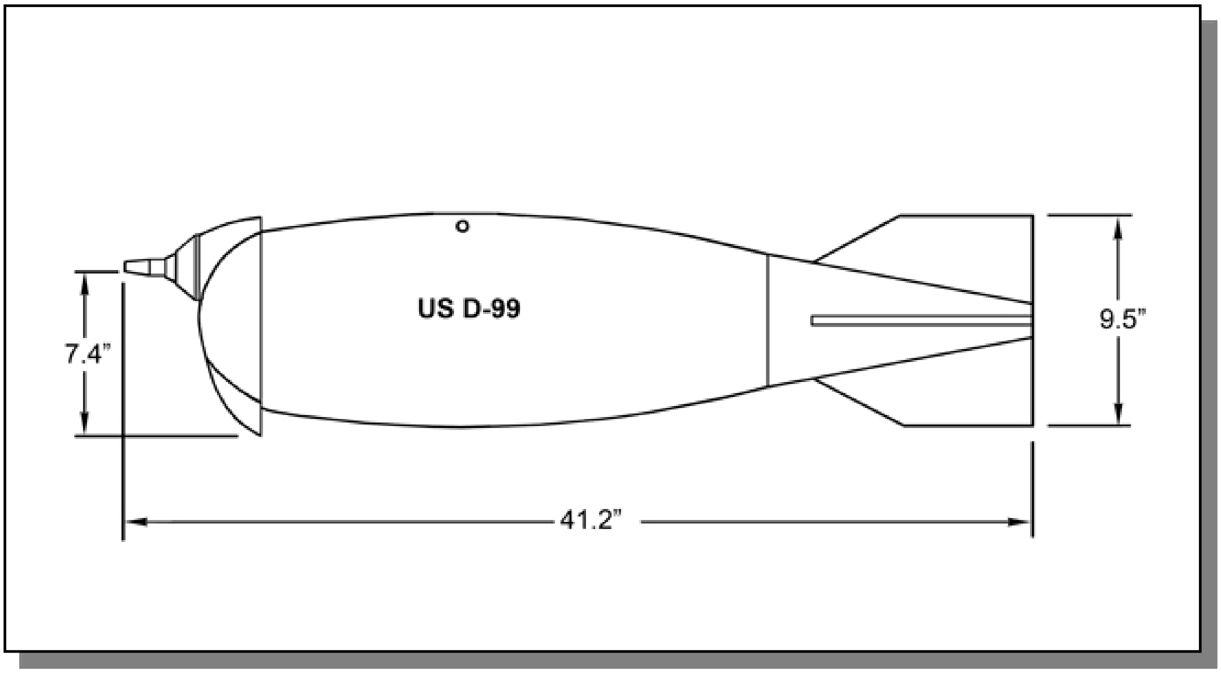

Figure 1-- Schematic of US D-99

DESIGN AND DESCRIPTION OF THE US D-99

The US D-99 sampler was designed and developed by FISP at the U.S. Army Corp of Engineer's Engineer Research and Development Center (ERDC), Vicksburg, Mississippi. FISP developed a configuration drawing and presented it to the FISP Technical Committee for review and comment. The FISP staff, USACE staff and USGS volunteers also reviewed the configuration drawing and general design criteria for the US D-99. Figure 1 shows a schematic of the US D-99. The sampler is 41.2 in long, approximately 9.5 in in diameter at its largest point, and weighs 285 lbs.

FISP developed the construction drawings used to fabricate the plastic resin casting patterns for the silicon bronze castings of the body and head of the sampler. These drawings were also used to carry out the machining processes for the body and head of the sampler. The cast body of the sampler is 23 in long and has a 5.5-in diameter hollow cavity. The tail sections fits 4 in inside the rear of the body cavity, leaving a 5.5-in diameter cavity 19 in long for the collapsible bag. The body of the sampler has a 1-in diameter hole drilled in the bottom near the front of the body, and 1-in diameter hole drilled in the top near the rear of the body. The holes aid in quick evacuation of air in the cavity when the sampler is submerged, and in removal of water from the cavity as the collapsible bag fills with sample.

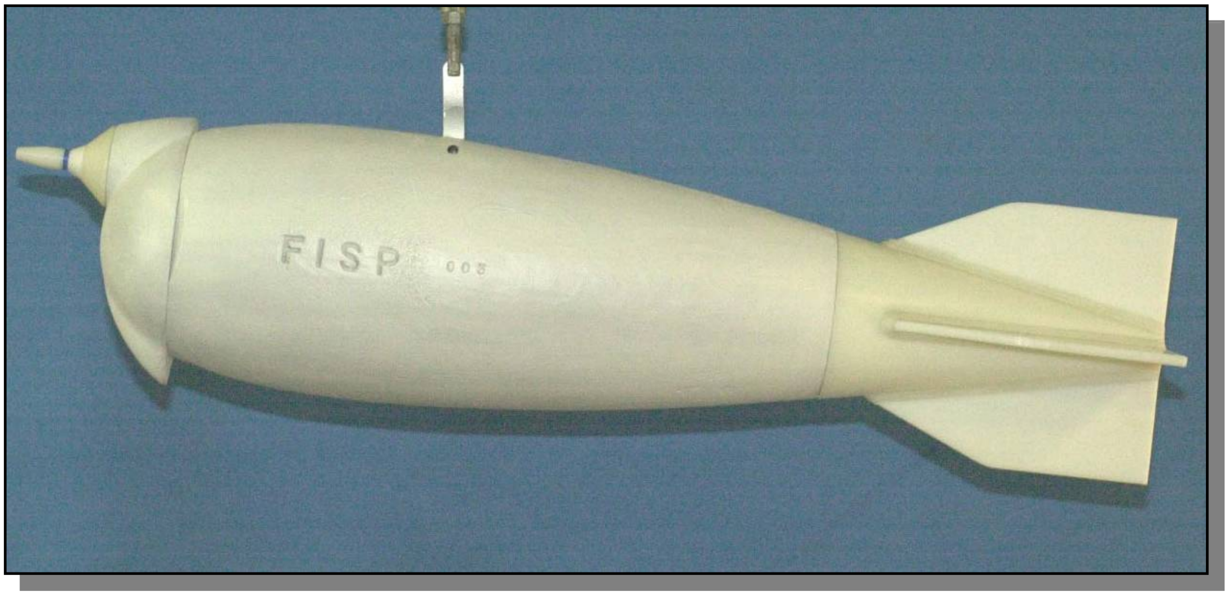

Figure 2-- Photograph of US D-99

The head of the sampler is hinged to the body of the sampler by a lug that is part of the casting on the right side of the head. It has an integral deflector at the bottom that protrudes below the bottom edge of the sampler in front of the hole in the bottom of the body cavity. The deflector aids in the quick evacuation of air in the cavity when the sampler is submerged. The head swings open to the right to allow placement of the bag into the sampler cavity. The head is machined to accept a plastic nose-piece that holds a nozzle holder with nozzle. When closed, the head is held in place by a magnet in the body and steel insert in the head. The bronze castings are coated with plastic to reduce the potential of trace element contamination.

A separate construction drawing was developed for the tail section of the sampler. It is designed to fit inside the cavity at the rear of the sampler body. The tail section is machined from a plastic polymer, High Density Polyethylene (HDPE). HDPE was chosen for its strength, malleability, buoyancy, and resistance to water absorption and to reduce the number of metal parts that might cause contamination during water quality sampling. HDPE can be welded, which allows the tail vanes to be replaced if damaged or broken. Tail sections are interchangeable, which negates the return the sampler for repair. The neutrally buoyancy of HDPE allows the sampler to be balanced around the center of the bronze casting. The balance point is approximately one third the total length of the sampler from the leading edge of the sampler body. When attached to a suspension line the sampler will assume a tail down attitude in air ensuring that the sampler will align the nozzle into the stream flow when lowered into the stream. Once the sampler is submerged, the neutrally buoyant tail causes the sampler to balance horizontally with the nozzle pointing into the stream flow. The sampler connection point accepts the standard hanger bar and pin configuration used on most suspended-sediment samplers or a typical sounding-weight hanger bar and pin. Figure 2 is a picture of the sampler.

A plastic nose insert (figure 3) mates to a hole near the top of the sampler head. The nose insert is held in place with a plastic coated brass screw. A nozzle holder (figure 4), is fabricated from either plastic or TFE, and mates the nozzle with the collapsible bag. The bag is secured by a hook and loop strap between the two lugs on the rear of the nozzle holder. The nozzle holder fits into the nose-piece with a locking-lug to hold it in place. The nozzle holder has a 0.0625-in diameter pressure equalization hole to insure equal pressure inside and outside of the bag, which facilitates isokinetic sampling. The nozzle holder and nose insert have colored index marks to insure that the pressure equalization hole is correctly positioned. Six and 3-liter polyethylene and PFA bags are used with the sampler. The 6-liter bags are 5.75-in diameter by 30-in long, 0.002-in wall thickness. The 3-liter bags are 4.61-in diameter by 22 in long, 0.002-in wall thickness. Nozzles with intake diameters of 3/16, 1/4, and 5/16 in were designed and fabricated from TFE and plastic for testing with the sampler. Each nozzle (figure 5) is stamped with the diameter. Plastic nozzles are color coded with a

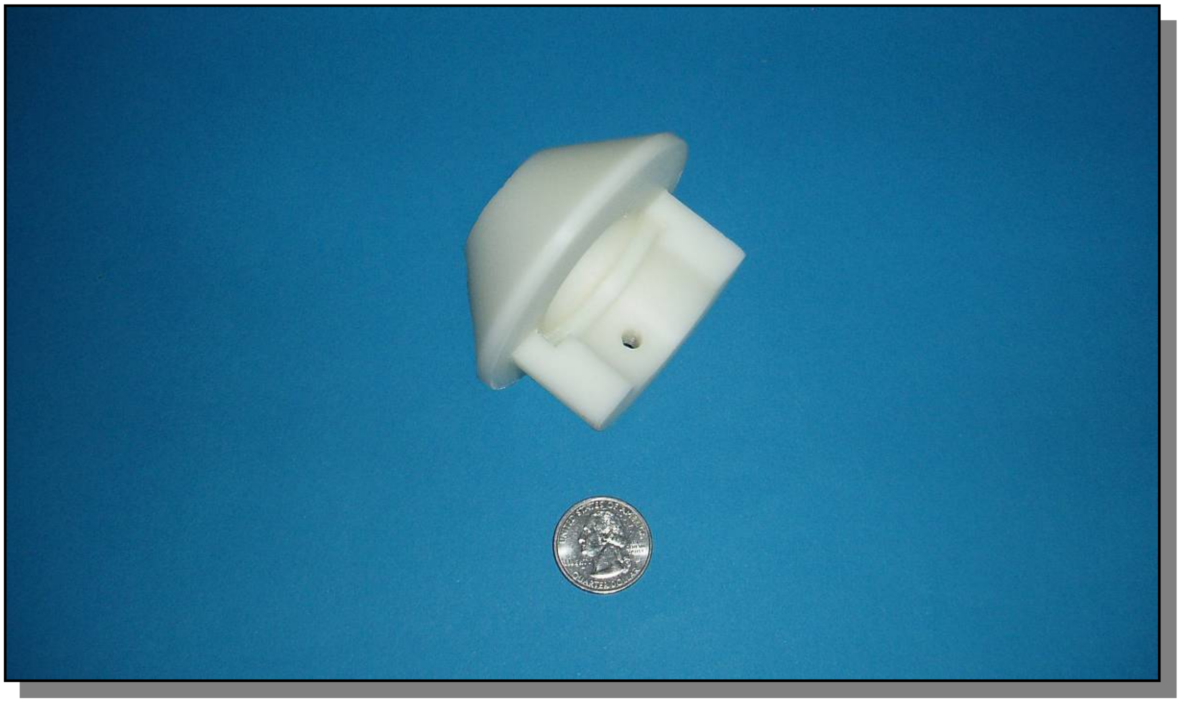

Figure 3-- Nose insert

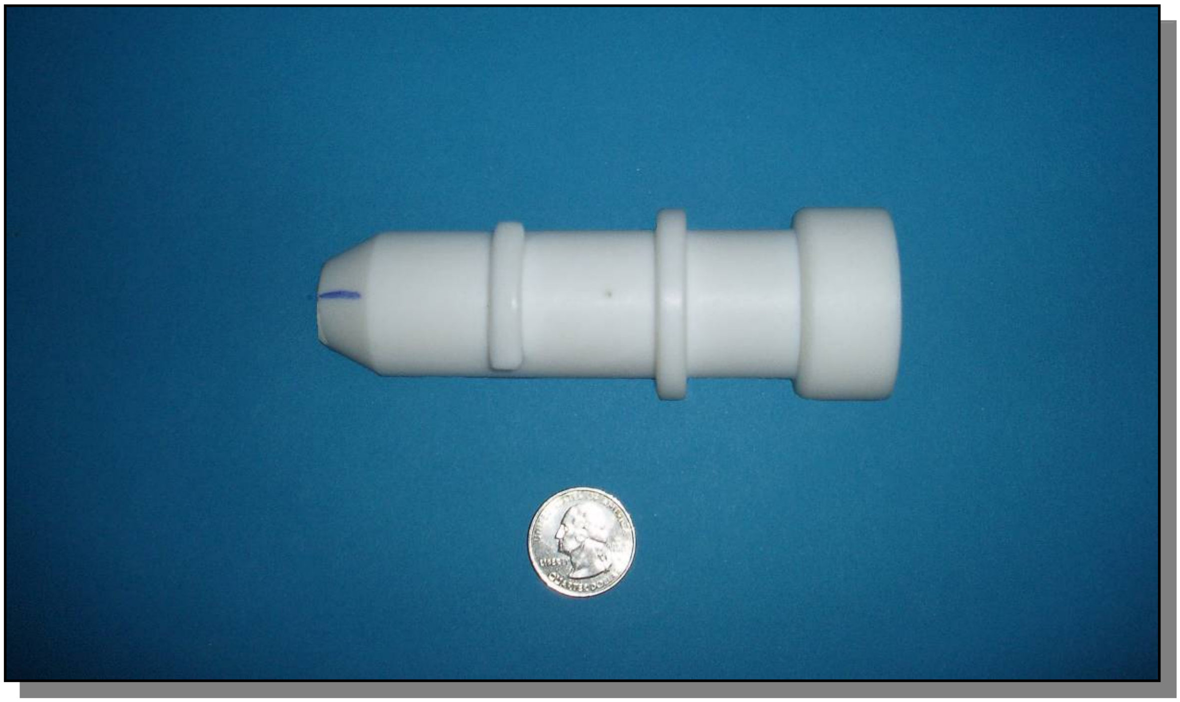

Figure 4-- Nozzle holder

Figure 5-- Nozzle

a blue band to provide a quick material identification. TFE nozzles do not have a colored band. Plastic parts should not be acid rinsed, only TFE parts should be used when an acid rinse is required as part of the sampling protocol. Figure 6 shows the nozzle holder with a nozzle and bag attached.

Figure 6-- Nozzle holder with nozzle and bag attached

TESTING

Preliminary Tests

Preliminary tests conducted at ERDC in the 3-ft wide FISP flume consisted of visual checks of the sampler to verify the correct suspension point, orientation when entering the water, and alignment with the flow when submerged. The sampler's balance point was correct; it entered the flow as designed, and maintained its alignment with the flow. Additional tests were conducted in a lake. The sampler was towed in the lake at velocities up to approximately 12 ft/sec to determine if it would remain stable at high velocities. A remote camera lens mounted on a sounding weight was used to view the sampler. A video camera equipped with a digital display was used to observe and record that the inflow nozzle was directed into the flow. The sampler was stable throughout the range tested.

Inflow Efficiency

A second series of tests was conducted to determine the effects of the US D-99 sampler design on the inflow efficiency. Inflow efficiency is the ratio of the nozzle inflow velocity to the ambient velocity. An inflow efficiency of 1.0 is defined as isokinetic. Information on the effects of inflow efficiencies on sediment concentrations can be found in Laboratory Investigation of Suspended Sediment Samplers, FISP Report 5, 1941. Previous research has shown that the parameters that affect inflow efficiency of collapsible-bag samplers are bag length, presence and location of vent holes in the body, presence/absence of deflectors, and depth of taper of the nozzle outlet (Davis 2001).

Initial tests were conducted using a flume flow velocity of 3.7 ft/sec. This velocity was used because it is the approximate mid-range of useable velocities for the majority of FISP samplers. It is also the velocity at which most FISP samplers are calibrated. Various combinations of vent holes location and the addition of a deflector were tested to determine their effect on inflow efficiency. The combination that gave optimum results was a 1-in diameter hole in the top of the sampler body near the rear of the sampler cavity, and a 1-in diameter hole in the bottom of the sampler body near the front of the sampler cavity. A deflector in front of the front hole aided in the quick evacuation of air when the sampler was submerged, and the evacuation of water from the sampler cavity as the sample bag filled with sample. Sample volume collected during all testing

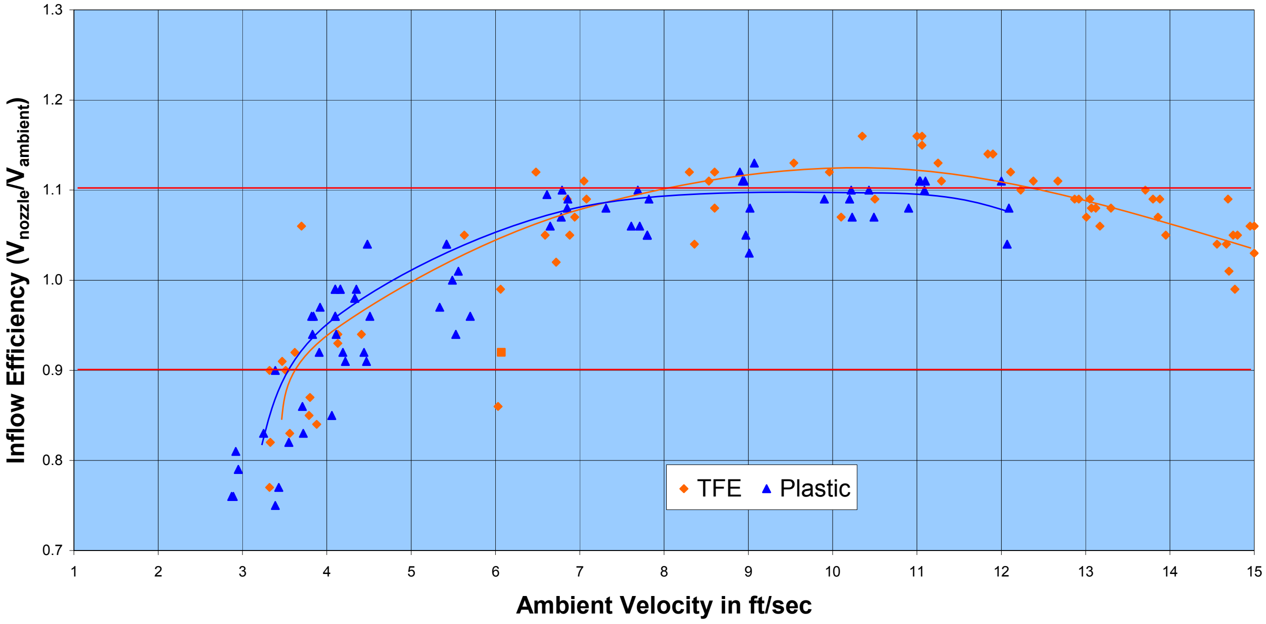

Figure 7-- Inflow efficiency test results for 3/16-in intake diameter nozzles

was near 6 liters, and usually slightly over 6 liters.

Three plastic nozzles with intake diameters of 3/16, 1/4, and 5/16 in were used in initial flume tests. The rear of the nozzles were taper reamed with a 1/4 in-per-ft reamer in increments until an inflow efficiency near 1.0 was obtained at 3.7 ft/sec flume flow velocity. Subsequent inflow efficiency tests were conducted by towing the sampler in a lake with a boat. The sampler was tested at velocities up to 15 ft/sec. All velocities were measured using a Price AA current meter attached to a sounding weight suspended from the boat. TFE nozzles taper reamed to the same depth as the plastic nozzles were also tested by towing the sampler with a boat. The final taper depth for the 3/16-in intake diameter nozzles was 2.25 in, 2.5 in for the 1/4-in intake diameter nozzles, and 2.3 in for the 5/16-in intake diameter nozzles.

Figure 7 shows the results for the 3/16-in intake diameter nozzles. The lines drawn at 0.9 and 1.1 inflow efficiencies represent the acceptable upper and lower limits for FISP samplers. Figure 7 shows that acceptable inflow efficiencies were obtained with the TFE nozzle from approximately 4 to 15 ft/sec flow velocity. The inflow efficiency was slightly high in the 10 to 12 ft/sec velocity range, but the slight increase should not adversely effect the sediment concentration of samples (FISP 1941). The plastic nozzle produced acceptable inflow efficiencies from 4 to 12 ft/sec flow velocity, however data was

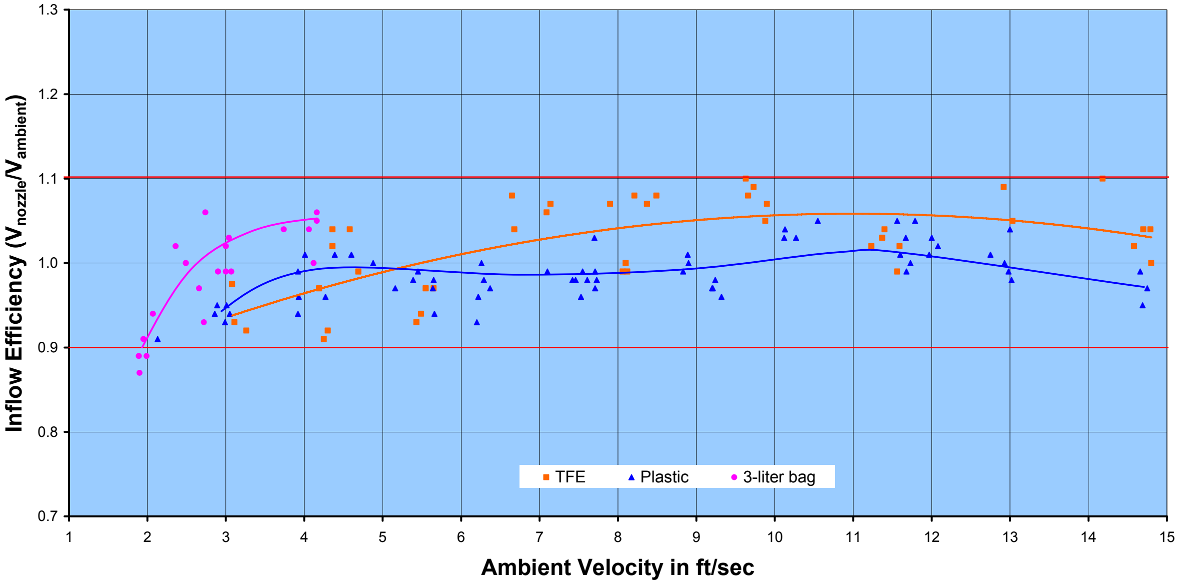

Figure 8-- Inflow efficiency results for 1/4-in intake diameter nozzles

not collected above 12 ft/sec flow velocity. The trend of the curve indicates that it would produce acceptable efficiencies up to 15 ft/sec flow velocity. The sampler did not collect samples at an acceptable inflow efficiency at the lower velocity range of 2 to 4 ft/sec. However, it should be recognized that a 3/16-in intake diameter nozzle would only be used in extremely deep and swift rivers since the sampler can be used to a depth of 120 ft with the larger 1/4-in intake diameter nozzle.

Figure 8 shows the results for the 1/4-in intake diameter nozzles. Both the TFE and plastic nozzle produced acceptable inflow efficiencies from approximately 3 to 15 ft/sec flow velocity. The efficiencies obtained with the TFE nozzle at the mid-range flow velocities of 7 to 10 ft/sec flow velocity were slightly higher than obtained with the plastic nozzle, but were within the acceptable range.

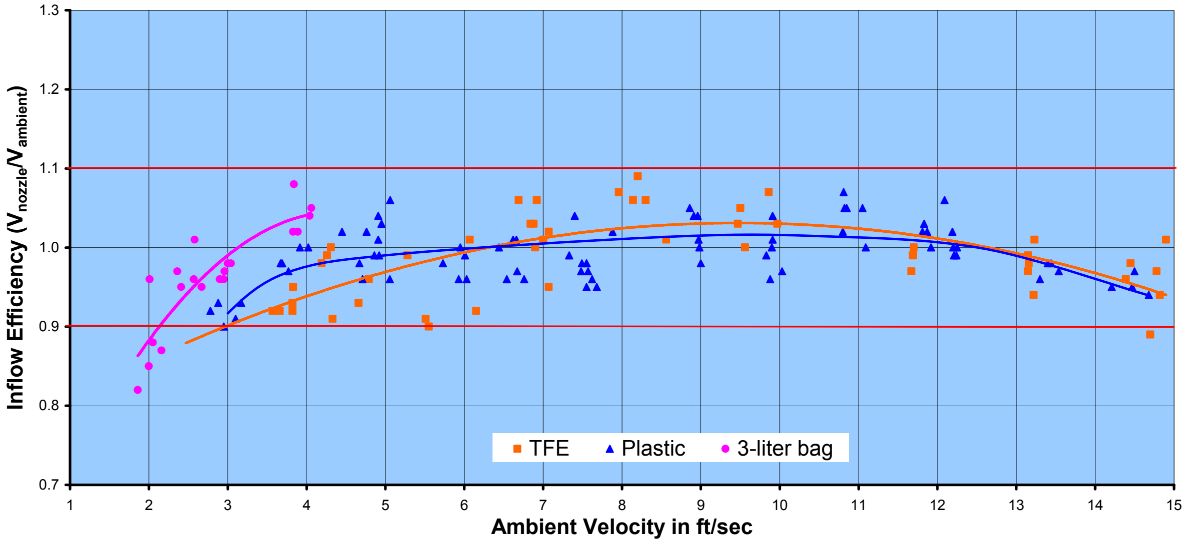

Figure 9-- Inflow efficiency test results for 5/16-in intake diameter nozzles

Figure 9 shows the results for the 5/16-in intake diameter nozzles. The TFE and plastic nozzles produced similar results with acceptable inflow efficiencies from 3 to 15 ft/sec flow velocity.

Figures 7-9 indicate that the US D-99 sampler used with any of the three intake diameter nozzles and a 6-liter bag would meet the application for which it was designed, i.e., deep swift rivers. However, additional tests were conducted to extend the useable range of the sampler to include lower velocity conditions. The tests consisted of using 1/4- and 5/16-in intake diameter nozzles and a 3-liter bag designed for the US D-96 sampler. Figures 8 and 9 show the results. The sampler collected samples at acceptable inflow efficiencies in the 2 to 4 ft/sec flow velocity range. Tests using a 3/16-in intake diameter were not conducted because the larger nozzles met the goal of extending the useful velocity range of the sampler. In summary, the US D-99 will perform acceptably in a velocity range of 2.0 to 15 ft/sec, depending on the nozzle intake diameter and bag size used. Although tests indicated the sampler would sample isokinetically above 15 ft/sec, tests at higher velocities were not performed due to safety concerns. Inflow efficiencies were also determined while raising and lowering the sampler while being towed by a boat to simulate a depth integrated transit. Results were comparable to the previously described inflow efficiency tests.

Drift Angle Tests

The US D-99 sampler was field tested to determine the drift angle that could be expected during depth-integrating operations. The drift angle is the angle between the vertical and the suspension cable as the sampler drifts downstream due to stream current. The sampler was suspended from the boat crane which had been fitted with a bridge crane protractor. The suspension point on the boat crane was 8 ft above the water surface. A diagram of the test configuration and an example of the effect of drift angle are provided in figure 10.

Figure 11 shows the expected drift angle for the US D-99 under different velocities and depths using the configuration shown in figure 10. Additional information on the effect of drift angle are discussed in Beverage (1987), Buchanan and Somers (1969), and in S. E. Rantz and others (1982).

Field Tests

With the testing of the US D-99 suspended-sediment sampler completed at FISP, a prototype of the sampler was shipped to the USGS Louisiana Water Science Center (WSC). FISP requested the WSC to use the sampler in their normal field operations and provide FISP with comments and suggestions for any modifications needed before final production. Operating instructions were supplied with the sampler. The evaluation of the prototype sampler was positive, with only a couple of minor suggestions for improvement. One suggestion was for improvements to the shipping container. The improvements were incorporated in the production shipping container.

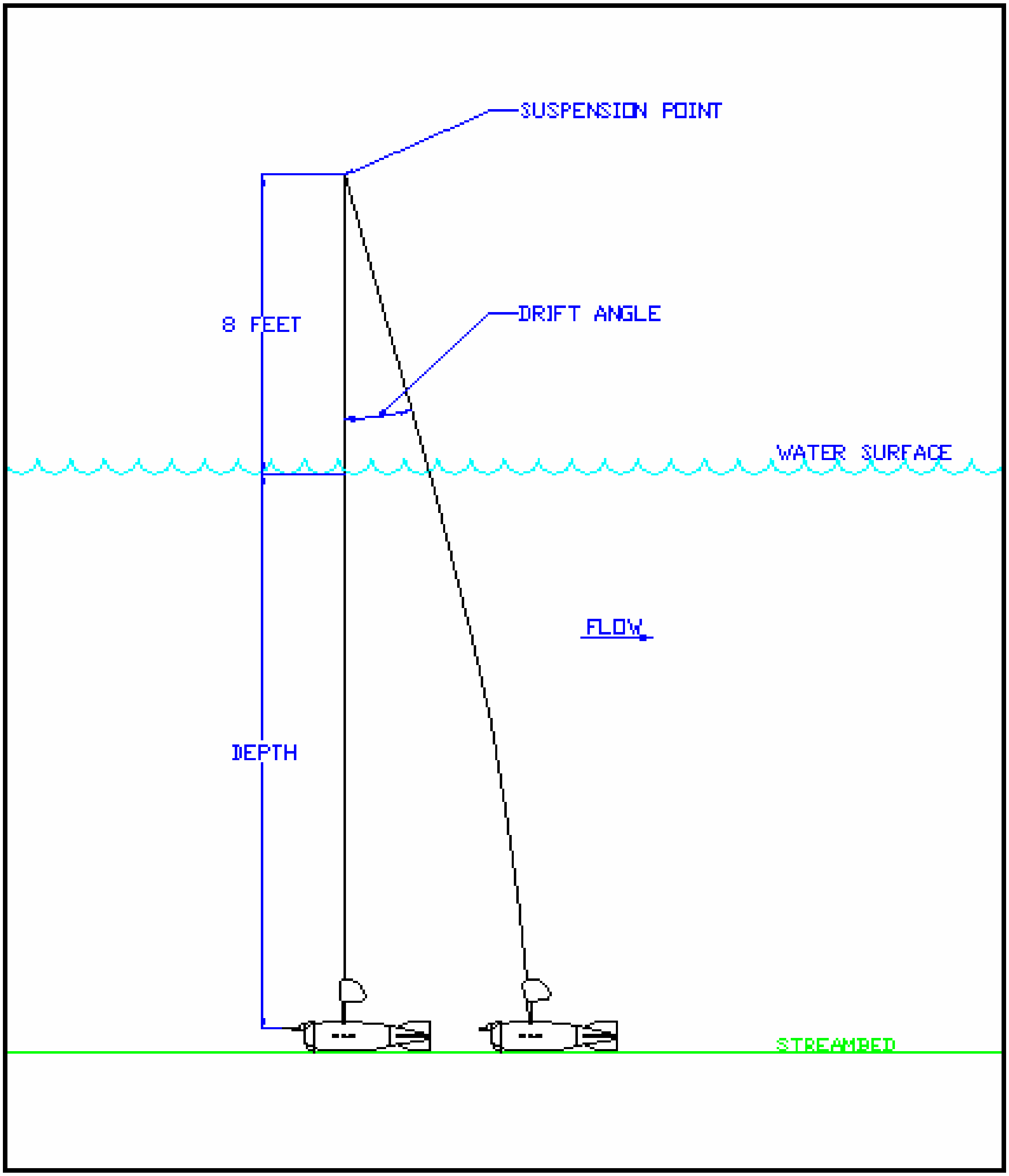

Figure 10-- Drag induced drift angle diagram *(not to scale)*

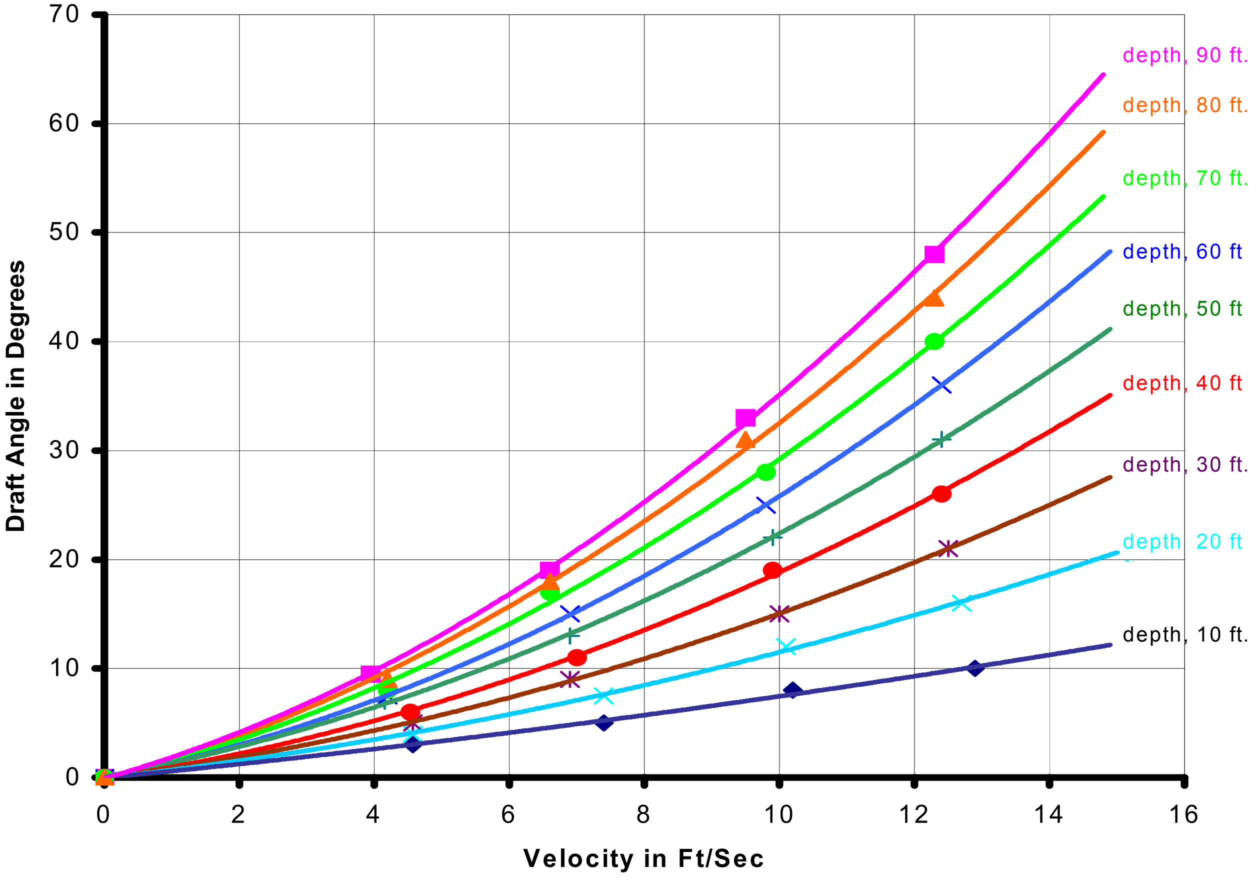

Figure 11-- Drag induced drift angle chart

SAMPLER OPERATION

The US D-99 is simple to use when the following steps are followed:

1. Based on the maximum stream depth and velocity select the appropriate nozzle for the stream cross-section. In general the largest intake diameter nozzle possible should be used. The larger the nozzle, the smaller the chance of excluding large sand particles which may be in suspension. Screw the nozzle into the nozzle holder. Place the nozzle holder in the center of the bag opening as shown in figure 12.

2. "Gather" the open end of the bag around the rear of the nozzle holder between the two lugs. Secure the bag by cinching it down between the two rear lugs with a hook-and-loop strap as shown in figure 13.

Figure 12-- Nozzle holder placed in center of bag opening

3. Lay the bag and nozzle holder combination on a flat surface. The top of the shipping box makes an excellent work platform. Fold the bag in half, lengthwise, as shown in figure 14. Starting at the rear of the bag, use one hand to hold the bag, and the other hand to flatten and push all the air out of the bag.

4. Slide the folded bag into the sampler cavity. Insert the nozzle and nozzle holder through the nose insert in the head as shown in figure 15 and rotate the nozzle holder 180 degrees. It will only go in the nose insert one way. The small diameter air exhaust hole in the nozzle holder should be pointed up and not covered by the bag. Index marks on the nozzle holder and head insert insure proper alignment of the exhaust hole.

5. Once the sample is collected, remove the nozzle holder, and remove the bag containing the sample.

Figure 13-- Bag "gathered" around nozzle holder

Figure 14-- Bag folded and pressed to remove air

Further information on collection of suspended-sediment samples can be found in Edwards and Glysson's Field Methods for Measurement of Fluvial Sediment: U.S. Geological Survey Techniques of Water-Resources Investigations, book 3, chap. 2 (1999).

Figure 15-- Sampler with nozzle holder and bag inserted

Limitations for Operation

Volume

It is possible to collect more than the rated volume in the 3-liter and 6-liter bags used in the US D-99 sampler. However, it is recommended that the sample volume collected not exceed approximately 3 liters or 6 liters because the inflow efficiency degrades rapidly above the rated volume.

The table shows the filling times to collect 3-liter and 6-liter samples using the 3/16-, 1/4-, and 5/16-in intake diameter nozzles. The filling time represents the total time to traverse the stream vertically in both directions. Use of this table will provide acceptable sample volumes and permit minor variations in total submerged time without invalidating the sample.

Table-- Filling times for US D-99 sampler

		3/16" NOZZLE		1/4" NOZZLE	5/16" NOZZLE
VELOCITY	VOLUME	TIME IN		TIME IN	TIME IN
FT/SEC	IN ML	SECONDS		SECONDS	SECONDS
2.0	3000	N/R	*	156	99
2.2	3000	N/R		141	90
2.4	3000	N/R		130	83
2.6	3000	N/R		120	76
2.8	3000	N/R		111	71
3.0	3000	N/R		104	66
3.2	3000	N/R		97	62
3.4	3000	N/R		91	58
3.6	3000	N/R		86	55
3.8	3000	N/R		82	52
4.0	3000	N/R		78	50
3.0	6000	368		207	133
3.2	6000	345		194	124
3.4	6000	325		185	117
3.6	6000	307		174	111
3.8	6000	291		165	105
4.0	6000	276		157	99
4.2	6000	263		149	95
4.4	6000	251		143	90
4.6	6000	240		136	86
4.8	6000	230		131	83
5.0	6000	221		126	80
5.5	6000	201		113	72
6.0	6000	184		104	66
6.5	6000	170		97	61
7.0	6000	158		89	57
7.5	6000	147		83	53
8.0	6000	138		78	50
8.5	6000	130		73	47
9.0	6000	123		69	44
9.5	6000	116		65	42
10.0	6000	110		62	40
10.5	6000	105		59	38
11.0	6000	100		57	36
11.5	6000	96		54	35
12.0	6000	92		52	33
12.5	6000	88		50	32
13.0	6000	85		48	31
13.5	6000	82		46	29
14.0	6000	79		44	28
14.5	6000	76		43	27
15.0	6000	74		41	26

* Not Recommended

Depth

The maximum depth the US D-99 can be used with a 3-liter bag is 60 ft with a 1/4-in intake diameter nozzle and 39 ft with a 5/16-in intake diameter nozzle. The maximum depth using the 6-liter bag is 220 ft with a 3/16-in intake diameter nozzle, 120 ft with a 1/4-in intake diameter nozzle and 78 ft with the 5/16-in intake diameter nozzle.

Velocity

The theoretical stream velocity limitation of the US D-99 is 2 to 4 ft/sec using a 3-liter bag and 3 to 15 ft/sec using a 6-liter bag. However, safety should always be the controlling factor when sampling in high stream velocity situations.

Unsampled Zone

The unsampled zone, the distance between the centerline of the nozzle and the streambed, is 7.4 in when the bottom of the sampler touches the streambed. Extreme care should be taken when allowing a sampler to touch the streambed. Disturbance of the streambed could result in the biasing of suspended-sediment samples.

CONCLUSION

Based on the success of the previously developed FISP collapsible-bag samplers, a need for a heavy version was identified. A FISP concept has evolved through the design, fabrication, testing, and evaluation of a 285-lb, 6-liter collapsible-bag sampler. The sampler is designated the US D-99 and can be used in streams up to 220 ft deep and at stream velocities ranging from 2 to 15 ft/sec.

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