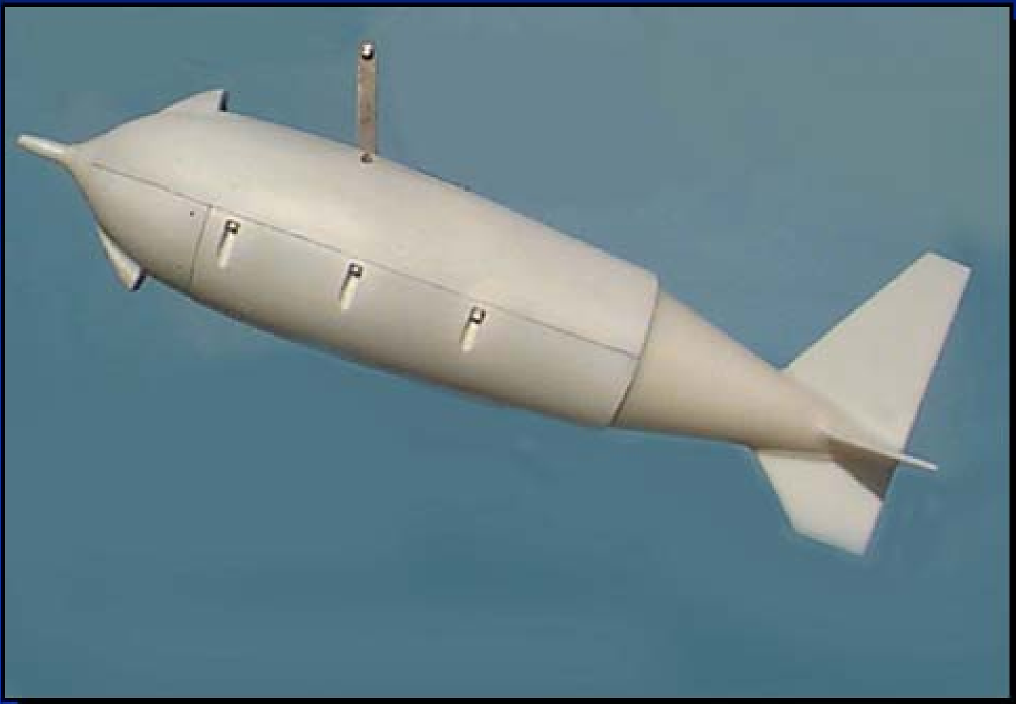
FISP™ *Federal Interagency Sedimentation Project*



Report PP
The US D-96: An Isokinetic Suspended-Sediment/ Water-Quality Collapsible-Bag Sampler
April 2001

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REPORT PP

THE US D-96: AN ISOKINETIC SUSPENDED-SEDIMENT/WATER-QUALITY COLLAPSIBLE-BAG SAMPLER

April 2001

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U.S. GEOLOGICAL SURVEY

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TABLES (Continued)

FACTORS FOR CONVERTING INCH/POUND UNITS TO SI METRIC UNITS

Multiply	By	To Obtain
Inch (in)	2.54	centimeter (cm)
pint, liquid (pt)	0.4732	Liter (L)
quart, liquid (qt)	0.9464	Liter (L)
gallon (gal)	3.785	Liter (L)
pound, avoirdupois (lb)	0.4545	kilogram (kg)
feet per second (ft/sec)	0.3048	meter per second (m/sec)
^{o}F	5/9(^{o}F – 32)	^{o}C

Superscripted numbers refer to references listed at the end of the report.

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ABSTRACT

The Federal Interagency Sedimentation Project (FISP) has designed, fabricated, and tested a collapsible-bag sampler that will collect a depth-integrated isokinetic water-sediment/water-quality sample. The sampler will collect a 3-liter (L) sample at stream velocities as low as 2 feet per second (ft/sec) and as high as 15 ft/sec. Nozzles with intake diameters of 3/16, 1/4, and 5/16 inch (in) give the sampler the capability to sample to depths of 110, 60, and 39 feet (ft), respectively. Testing to determine the inflow efficiency of the sampler was conducted in a re-circulating flume and by towing the sampler in a lake with a boat. The inflow efficiency also was determined during raising and lowering of the sampler while towed in a lake by a boat to simulate a transit in a stream vertical. Tests in water at 37° F indicated the low water temperatures that could be encountered in stream environments did not affect the flexibility of the collapsible bag. Drift angle tests showed the sampler had a smaller drift angle than a US P-61 A1. Underwater video documented the stability of the sampler while towing. Other tests indicated that no problems were encountered with sediment adhering to the inside of the bag when the sample was removed from the bag. Results from an equipment-blank test showed the sampler met the U.S. Geological Survey (USGS) protocol as a “clean” sampler for water-quality sample collection.

The sampler has been designated by FISP as the US D-96. It is 35 in long, fabricated from bronze, aluminum and plastic parts, and weighs 132 pounds (lbs). All metal parts are plastic-coated. Nozzles are fabricated from plastic and tetrafluoroethylene (TFE). The collapsible bag used with the sampler is made of perfluroalkozy (PFA).

A U.S. patent was granted on the US D-96 sampler (U.S. Patent No. 6,216,549 B1).

INTRODUCTION

FISP History

In early fluvial-sediment investigations, each investigator or agency concerned with sediment developed methods and equipment individually as needed. As sampling progressed, managers realized the accuracy of sediment data was affected by a lack of standardization in methodology and equipment. In 1939, Mr. G.A. Hathaway of the Corps of Engineers and Dr. E.W. Lane of the Iowa Institute of Hydraulic Research (IIHR) proposed that a project be established for standardization. Representatives of the U.S. Geological Survey, Department of Agriculture, Bureau of Reclamation, Office of Indian Affairs, and the Tennessee Valley Authority endorsed this proposal. The project was established at the IIHR in Iowa City, IA. In 1946, the interdepartmental committee that had oversight for the project became known as the Subcommittee on Sedimentation of the Federal Inter-Agency River Basin Committee. In 1948, the subcommittee moved the project to the test facility at St. Anthony Falls Hydraulic Laboratory at the University of Minnesota, in Minneapolis, MN. The Subcommittee reorganized the project in 1956 to its current structure as the Federal Interagency Sedimentation Project (FISP).[1] In 1992, FISP was moved to its current location at the U.S. Army Corps of Engineers Engineering and Research Development Center in Vicksburg, MS. Representatives from seven agencies currently compose the Technical Committee, which has oversight for FISP projects and priorities. The agencies are: U.S. Army Corps of Engineers, U.S. Geological Survey, U.S.D.A. Agricultural Research Service, U.S. Bureau of Reclamation, U.S.D.A. Forest Service, U.S. Bureau of Land Management, and U.S. Environmental Protection Agency. The Technical Committee operates under the guidance of the Subcommittee on Sedimentation.

Since its initiation in 1939, the FISP has published over 60 reports dealing with nearly all aspects of measurement and analysis of fluvial sediment movement. FISP also has established the following criteria for the design and construction of suspended-sediment samplers:

- To allow a water-sediment mixture to enter the nozzle isokinetically. In isokinetic sampling, water-sediment mixture approaching the nozzle of the sampler undergoes no change in speed or direction as it enters the orifice.
- To permit the sampler nozzle to reach a point as close to the streambed as physically possible.
- To minimize disturbance to the flow pattern of the stream, especially at the nozzle.
- To be adaptable to suspension equipment already in use for streamflow measurement.
- To be as simple and maintenance-free as possible.
- To accommodate a standard bottle size: 1-pint (pt) glass; 1-quart (qt) glass; 1-L plastic; or 3-L plastic.

Integrating Sediment Samplers

Isokinetic sediment samplers are divided into two categories according to how they sample: depth-integrating and point-integrating. Depth-integrating samplers are further divided into two general categories, those that use a rigid bottle for sample collection and those that use a collapsible bag. A depth-integrating sampler fills as it is being lowered from the water surface to the streambed and as it is raised to the surface again. The sampler is designed to collect a water-sediment sample from the stream vertical at a rate such that the velocity in the intake nozzle is equal to the incident stream velocity while transiting the vertical at a uniform rate.[2] The water-sediment sample collected will be proportional to the instantaneous stream velocity at the locus of the intake nozzle and, therefore, will be representative of the sediment load in the vertical.

At any instant during the operation of a rigid-bottle depth-integrating sampler, the volume of air contained in the bottle is a function of the hydrostatic head and the volume of water-sediment collected. As the sampler is lowered into a stream, sufficient water-sediment sample must enter the bottle to compress the air so that its pressure balances the external hydrostatic head according to Boyle's law. For the water-sediment inflow in the nozzle to be equal to the ambient stream velocity at the nozzle, the rate of air-volume contraction due to increasing hydrostatic pressure must not exceed the volume rate of water-sediment inflow. For this reason, the sampler must be lowered in the water column at a rate such that these two factors are balanced to avoid the water-sediment mixture being forced into the sampler at a velocity greater than the ambient stream velocity. The sampler also must be raised at a rate such that the expanding air can vent at a rate equal to the inflow of the water-sediment sample. Depth-integrating samplers have a vent designed for this purpose. However, if the sampler is raised too fast the expanding air cannot vent fast enough and will cause the inflow of water-sediment sample to be less than the ambient stream velocity. The rate of raising and lowering the sampler is known as the transit rate and can be calculated using Boyle's law. Calculation of the transit rate for rigid-bottle samplers shows for low stream velocities (< 3 ft/sec) the transit rate can become extremely slow, especially for samplers with a large volume bottle such as the 3-L US D-77.[1] The transit rate for this bottle can be less than 0.1 ft/sec, making it difficult to deploy properly. Other studies have shown that the maximum transit rate cannot exceed 0.4 times the stream velocity due to the apparent approach angle of the nozzle facing into the stream as the sampler makes its vertical descent and ascent.[2]

Other studies of the filling characteristics of rigid-bottle samplers have shown that the maximum distance the sampler can travel through the water column and still sample isokinetically is approximately 34 ft at sea level.[2] Because the depth-integrating sampler collects water-sediment from the instant it enters the stream, the maximum theoretical stream depth that can be sampled is half this distance (approximately 17 ft). This maximum sampling depth decreases as altitude increases. General field practice limits the use of rigid-bottle depth-integrating samplers to 15 ft.[1]

FISP has designed rigid-bottle depth-integrating samplers that have been in use since the 1940's. These are designated as the US DH-48, a 1-pt hand-held sampler; the US DH-59, a 1-pt hand-line sampler; the US D-74, a 1-qt cable-suspended sampler; the US DH-76, a 1-qt hand-line sampler; the US D-77, a 3-L cable-suspended sampler; the US DH-81, a hand-held sampler that accepts any size bottle with mason jar threads. Recently designed rigid-bottle depth-integrating samplers include the US D-95, a 1-L cable-suspended sampler and the US DH-95, a 1-L hand line sampler, both of which can also be used for water-quality sampling.

A point-integrating sampler uses an electrically activated valve to open and close the intake and exhaust passages.[3] Point-integrating samplers are more versatile than the simpler depth-integrating types. They can be used to collect a suspended-sediment sample at any point from the surface of a stream to within approximately 4-6 in of the bed, as well as to integrate over a range in depth. These samplers were designed for depth integration of streams too deep to be sampled in a continuous round-trip integration (15 ft). When depth integrating, sampling can begin at any depth and proceed either upward or downward from that initial point through a maximum vertical distance of 30 ft. The increased effective depth to which a point-integrating sampler can be used is made possible by a pressure-equalizing chamber (diving-bell principle) enclosed in the sampler body. This chamber equalizes the air pressure in the sample container with the external hydrostatic head near the intake nozzle at all depths alleviating the in-rush of sample water that would otherwise result when the intake and air exhaust are opened at depth.[1] The three most widely used FISP point-integrating samplers are the US P-61-A1, US P-63, and US P-72. The US P-61-A1 and US P-63 are made of bronze and weigh 105 and 200 lbs, respectively. The US P-72 is made of aluminum and weighs 41 lbs. The US P-61-A1 and US P-63 are capable of sampling to a depth of 180 ft with a pint sample container; the US P-72 is capable of sampling to a depth of 72 ft with a pint sample container.

There are some disadvantages to the use of point-integrating samplers. To delineate a sediment profile using a point-integrating sampler, multiple points in the vertical must be sampled. A typical sampling procedure would be as follows: lower the sampler to depth and take a timed sample; raise the sampler to the surface; remove the sample container; place an empty container in the sampler; lower the sampler to the next depth. This procedure has to be repeated until multiple points in the vertical have been sampled. The described procedure can require a considerable amount of time, leading to the possibility of temporal changes in sediment concentration from the beginning to the end of sampling. When a point-integrating sampler is used to take depth-integrated samples, it can only sample a vertical distance of 30 ft. Hence, for streams deeper than 30 ft, the sampler has to be raised and lowered more than one time, again leading to the possibility of temporal sediment concentration changes. In addition, when the point-integrating sampler is used as a depth-integrating sampler, it usually is traversed only in one direction. At high stream velocities this could mean that the downward path of the sampler in the vertical may not be the same as the upward traverse due to downstream drift of the sampler and the tension on the suspension cable.[4] If the sample is taken in the downward traverse, the water-sediment velocity in the sampler nozzle is less than the stream velocity. If it is taken in an upward traverse, the velocity in the sampler nozzle is greater than the stream velocity.[5] A depth-integrating sampler would of course experience the same phenomenon, but would see both the apparent increased and decreased velocities which would tend to balance. Another disadvantage of point-integrating samplers is that they contain metal parts that come in contact with the sample and therefore cannot be used for some types of water-quality samples.

Collapsible-Bag Sampler Capabilities

A sampler specifically designed to use a collapsible bag has advantages over rigid-bottle depth-integrating samplers and point-integrating samplers. The bag container is flexible and contains essentially no air. Therefore there is no limitation because of air compressibility, meaning the depth to which the sampler could be used is limited only by the intake diameter of the nozzle and the volume of the bag. It also means that the maximum transit rate is limited only by the apparent approach angle of the nozzle facing into the stream velocity as it makes its vertical traverse, which is 0.4 times the stream velocity. The minimum transit rate is limited by the volume of the collapsible bag. There also is a cost savings in the use of a collapsible bag as opposed to a rigid bottle, especially when used for water-quality samples. A collapsible-bag depth-integrating sampler is not subject to the same temporal changes in the vertical as a point-integrating sampler, or possible errors associated with sampling in one direction when the point sampler is used as a depth-integrating sampler. The US D-96 currently is the only FISP approved collapsible-bag sampler.

Previous Investigations

Suspended-sediment samplers utilizing a collapsible bag have been proposed as an improvement over the previously described US series of depth-integrating samplers. Various investigators have researched collapsible bag samplers. Two early models were developed by Gluschkoff and by the Rhine Works Authority.[6] The Gluschoff sampler, developed in Russia, consisted of several balloon-shaped bags, each fitted with a nozzle. The nozzles were mounted on a vertical staff and were oriented horizontally in the same direction. When sampling, the staff was inserted into the stream with the nozzles facing downstream and with the bags devoid of air. The staff then was twisted so the nozzles faced upstream. The bags simultaneously collected point-integrated samples at pre-selected depths. The staff again was twisted so the nozzles faced downstream, pinching off any further inflow. The staff was lifted carefully out of the water and the samples removed. The major problem with this sampler was that the bags were unprotected and had to be handled very carefully to prevent damage to the bags and loss of sample.

The Rhine Works Authority[6] sampler consisted of a latex balloon, a nozzle, and a metal frame with a tail fin. A pinch clamp located at the neck of the balloon and operated by an auxiliary line initiated sample collection into the balloon. The sampler was not streamlined. The sampler was of limited use because of this limitation and the necessity of having an auxiliary line.

Stevens and others[7] fabricated 1-gal and 2-gal samplers with plastic bags. These samplers consisted of a wide-mouth, perforated, rigid container enclosed in a cage-like metal frame attached above a sounding weight. The head of the frame supported a plastic intake nozzle and swung open to permit the plastic container to be removed. When the head was closed, the end of the nozzle extended slightly into the mouth of the container and the container sealed against a gasket. An adjustable rubber stop at the rear of the sampler held the container in place. The perforations in the container were 0.75-in diameter holes arranged in three partial rings of six holes each on the underside of the container at different heights. In addition, there was a large opening in the side of the container just below its neck. During sampling, this opening was covered with a loose fitting plastic sleeve. For sampling, a collapsed, pre-shaped, flexible plastic bag was placed inside the rigid container. The neck of the flexible bag was stretched over the neck of the rigid container and the whole unit placed into the metal frame. The sampler was of limited use at stream velocities above 3 ft/sec, was cumbersome to operate, had an unsampled zone of approximately 18 in, and not streamlined.

In FISP Report Y, Szalona[8] describes an investigation of a bag sampler. His approach was to modify the US D-77 rigid-bottle sampler. The sampler was equipped with a 3-L plastic bottle, nozzle cap and nozzle, and utilized a commercially available food storage bag. Holes were drilled at various locations on the bottle to enable quick flooding. Various combinations of vents and deflectors were added to the US D-77 sampler to facilitate isokinetic sampling. The sampler has limited use at stream velocities from 3 to 8 ft/sec and its sampling capacity is limited to approximately 2.5 L. It is difficult to remove the filled bag through the small opening of the bottle mouth. Additional testing by FISP and experience by field personnel have shown that if the collapsible bag is not placed correctly inside the container, no water-sediment sample will be collected at all. The sampler is unstable above 8 ft/sec stream velocity due to its large frontal area and short length.

In his recent study of contaminants in the Mississippi River, Robert Meade[9] used an 8-L frame-type bag sampler similar to that described by Stevens and others.[7] The sampler consisted of a perforated 8-L plastic container fitted with a US D-77 sampler cap and nozzle. The container was secured inside a metal frame suspended above a sounding weight. A collapsed 8-L PFA bag was placed inside the plastic container. A review of the sampling data showed that some difficulty maintaining isokinetic sampling efficiencies was encountered.[10,11,12]

US D-96 SAMPLER DESCRIPTION

For several years those involved in sediment and water-quality studies have expressed a need for a new collapsible-bag sediment/water-quality sampler. This need was identified in the USGS's National Stream Quality Accounting Network (NASQAN) and was increased by the implementation of the USGS's National Water-Quality Assessment Program (NAWQA). As a result of these needs, the FISP was tasked by the Technical Committee to design a new sampler

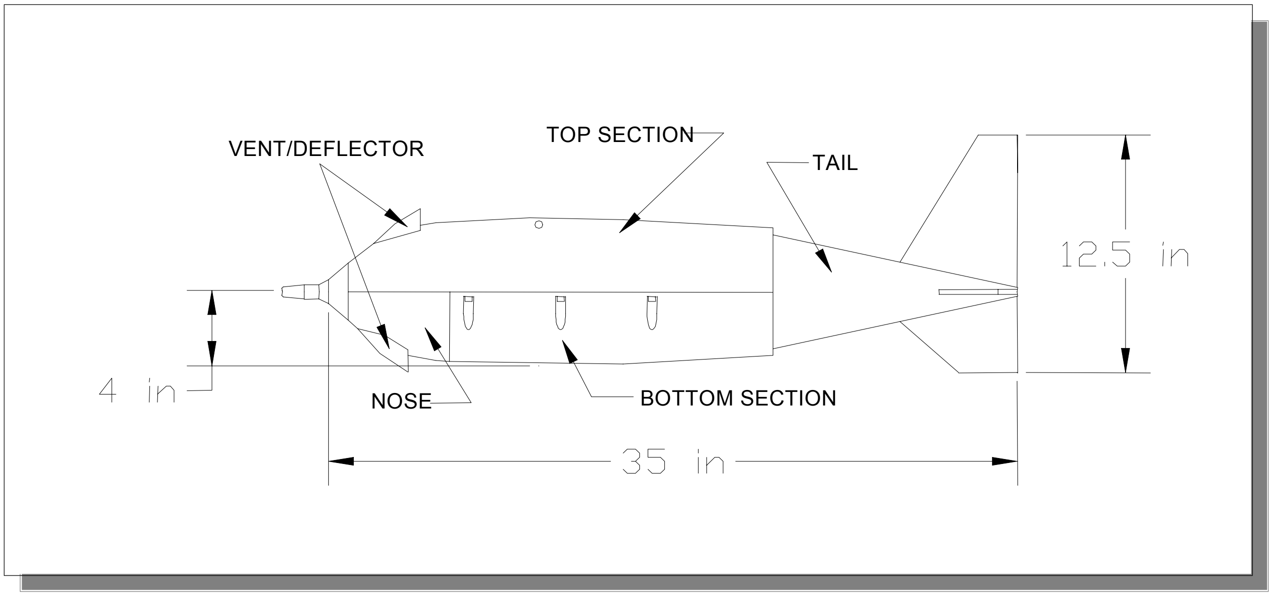

Figure 1-- US D-96 schematic

that would overcome the limitations and disadvantages of the current samplers as discussed previously. FISP's goals for the sampler were that it would:

- Be designed specifically for a collapsible bag.
- Sample isokinetically at stream velocities as low as 2 ft/sec.
- Remain stable at high velocities approaching 10 ft/sec.
- Minimize the unsampled zone.
- Collect as much as a 3-L sample.
- Facilitate the use of PFA and TFE parts for water-quality sampling.
- Be simple to use.
- Minimize cost by use of castings and common materials.

FISP's concept was that a streamlined sampler body could be designed with a cavity inside to contain the bag. A holder could be designed so a nozzle could be attached to one end and the bag to the other end. Vent holes in the sampler body would ensure that the pressure inside and outside the bag always would be equal. Because the hydrostatic pressure outside the sampler and inside the sampler cavity always would be equal, the only acting force would be the velocity head due to the stream velocity. As a result, the sampler would collect an isokinetic water-sediment sample at a wide range of stream velocities. This velocity head, coupled with vents in the sampler body to induce a venturi effect, would be sufficient to allow the bag to open as it collected a water-sediment sample. The vent holes also would serve to quickly evacuate the air in the cavity and flood it with water, then allow the water in the cavity to be evacuated as the bag filled with water-sediment.

A sampler that would meet the goals described above, the US D-96, has been developed and tested. A U.S. patent was granted on the US D-96 (U.S. Patent No. 6,216,549 B1). A schematic of the sampler is shown in figure 1. The US D-96 is 35 in long, 8 in diameter at its widest point, and weighs 132 lbs. The nozzle is located at the centerline of the sampler resulting in an unsampled zone of 4 in. The sampler is composed of various parts including a top section, bottom section, tail section, nose section with tray, nozzle holder, and nose insert. The top section is made of cast bronze and weighs 108 lbs. A slot is cast into the front to accept the nose insert. A 1-in diameter hole is drilled toward the front of the top section to aid in air and water evacuation from the sampler cavity. The hole is drilled under a deflector that is part of the casting. A 0.625-in diameter hole is drilled through the back of the deflector to intersect the 1-in diameter hole. This deflector creates a venturi effect that aids in allowing the bag to open, as well as in the evacuation of air and water from the sampler cavity. A 6-in diameter half-cylinder shaped cavity 6 in deep is cast into the rear of the top section to facilitate attachment of the tail section. The bottom of the top section is covered with plastic.

The bottom section is a cast aluminum shell that mates with the top section to form the cavity inside the sampler. The bottom section is fastened to the top section with stainless-steel socket head machine screws. The top section is drilled and tapped to accept the machine screws. The inside of the bottom section is lined with plastic.

The nose section is cast aluminum and has a slot machined in the front that matches the slot in the top section for the nose insert. The nose section is also fitted with a plastic tray that is fabricated from 6-in diameter clear plastic tube. The tube is halved lengthwise and machined to fit the nose section. The tray slides into the cavity formed by the bottom section and is designed to support the bag. The tray is secured to the nose section with stainless-steel screws. The nose section also is vented with a 1-in diameter hole and deflector that is similar to the one in the top section. All metal parts are plastic coated with Plasti-Dip, a commercially available product, to minimize the possibility of contamination of samples for trace-metal analyses. The nose insert is fabricated from plastic, is machined to fit in the slot in the nose section, and is secured to the nose section with a machine screw. It has a 1.25-in diameter hole machined in it to accept the nozzle holder. The nose insert is shown in figure 2.

The nozzle holder is fabricated from either plastic or TFE, and mates with the nose insert. The nozzle holder is shown in figure 3. It has a 0.0625-in diameter pressure equalization hole drilled in it. This hole ensures that the pressure is equal both inside and outside the bag which facilitates isokinetic sampling. The bag is secured with a hook-and-loop strap between two lugs on the outside of the rear of the nozzle holder. The nozzle holder with a nozzle and bag attached is shown in figure 4.

The tail section is fabricated from high-density polyethylene plastic (HDPE). The tail has a 6-in long, 6-in diameter half-cylinder section that fits inside the cast hole in the top section for attachment. Horizontal and vertical fins fabricated from 0.25-in thick HDPE sheet are welded to the tail-section body. The tail section is attached to the top section with stainless-steel machine screws. HDPE is neutrally buoyant in water, which allows the suspension point of the sampler to be located such that in air, the sampler maintains a tail-down attitude allowing it to orient itself

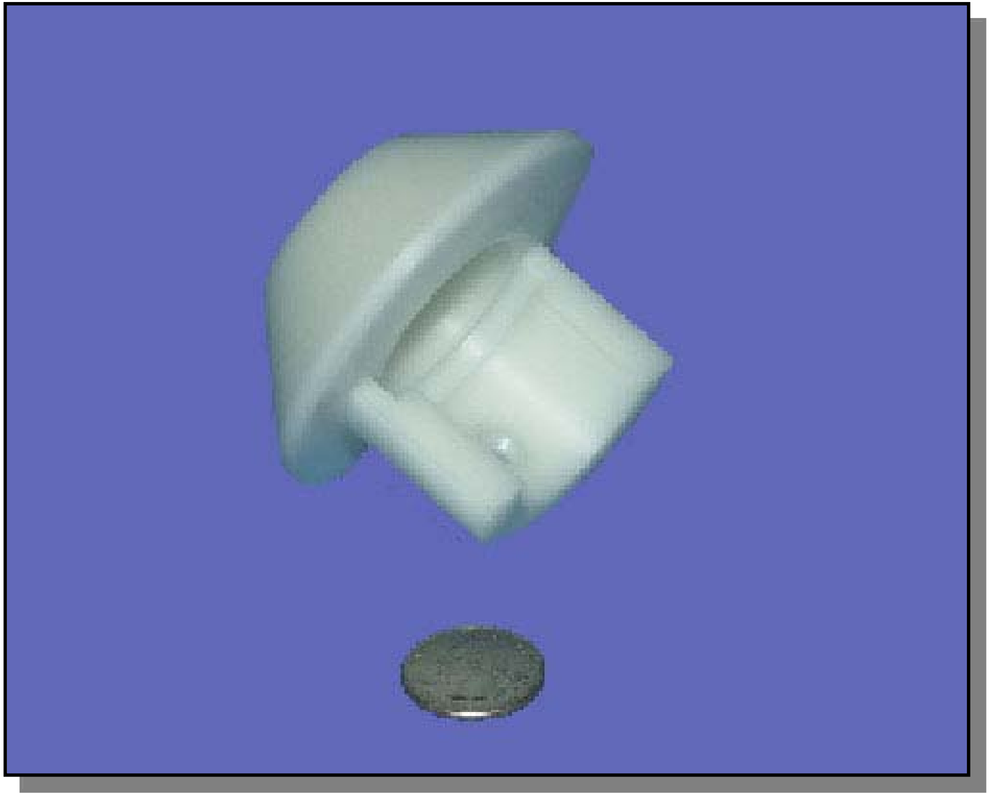

Figure 2-- Nose insert

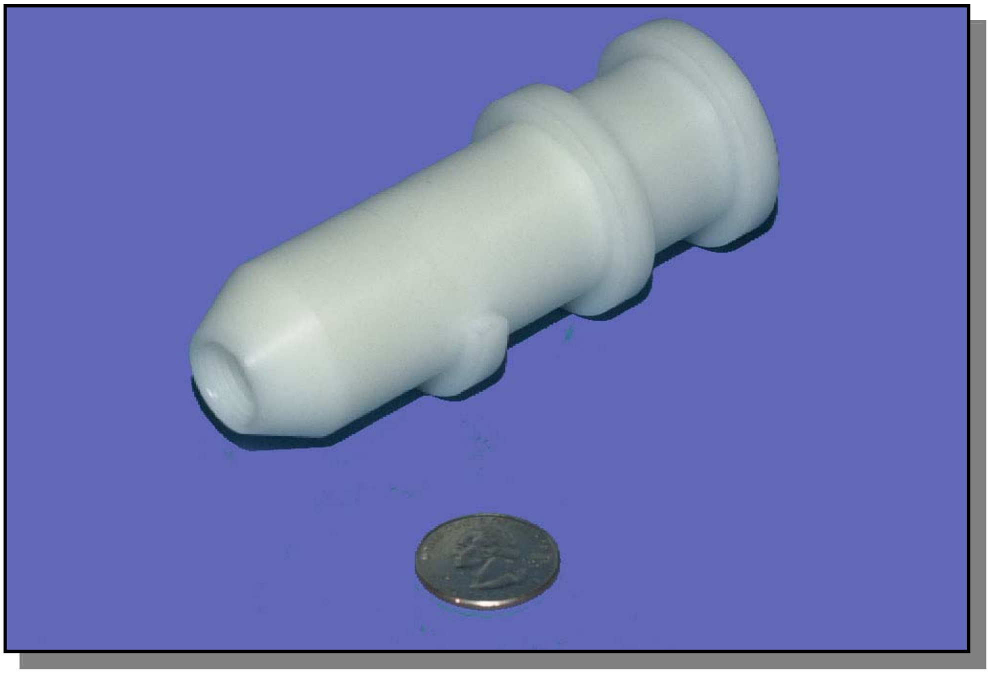

Figure 3-- Nozzle holder

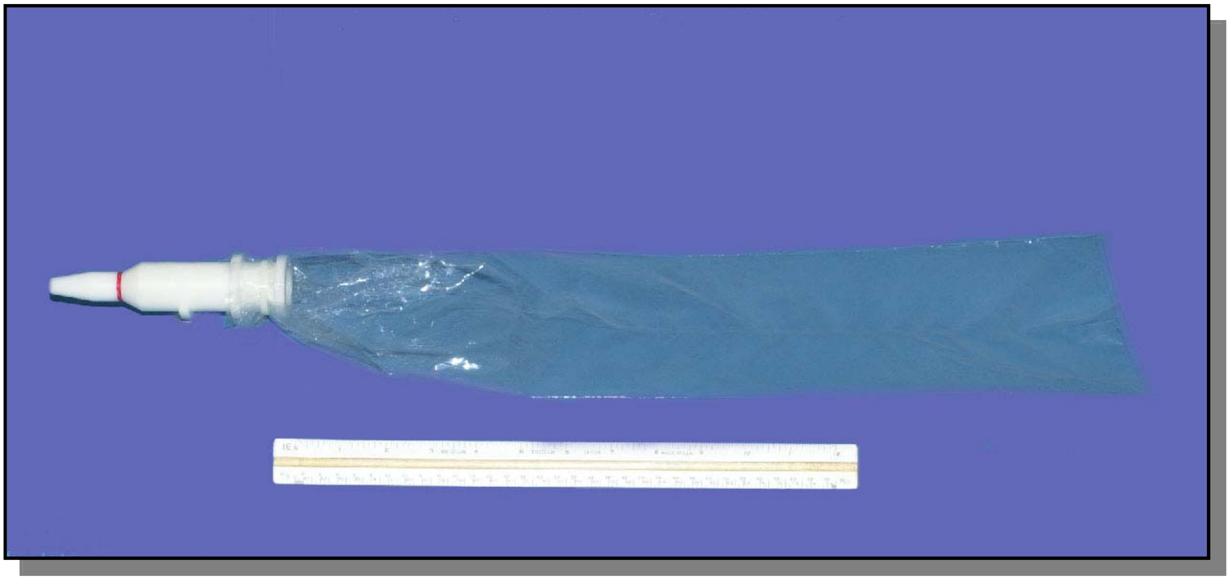

Figure 4-- Nozzle holder with nozzle and bag attached

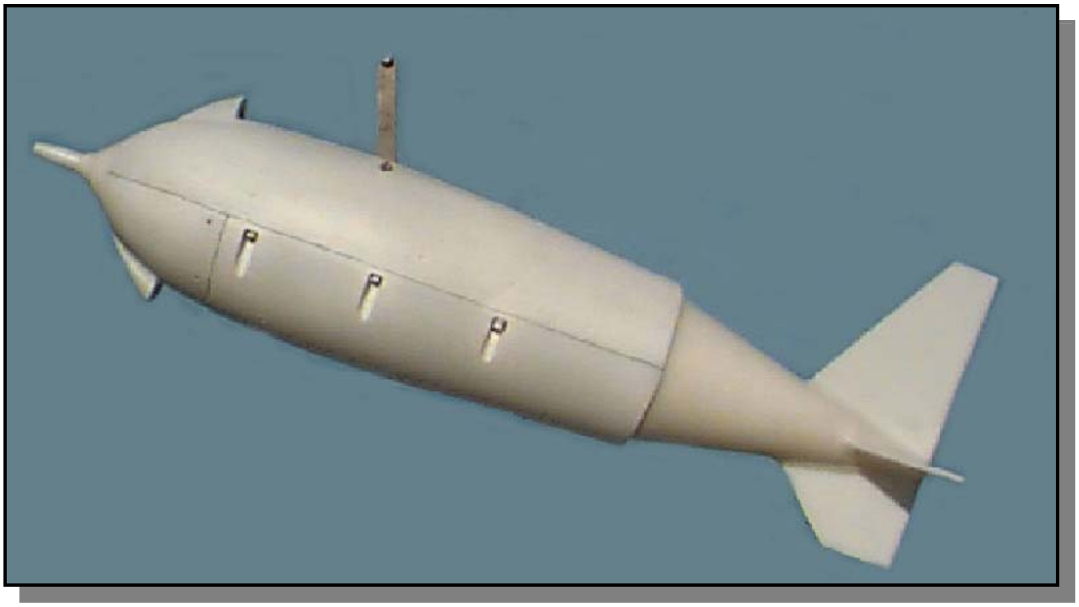

Figure 5-- US D-96 sampler suspended in air

facing into the stream-flow. Once submerged, the sampler assumes a horizontal position. A photograph of the assembled US D-96 sampler suspended in air is shown in figure 5.

The bag used with the sampler is a cylindrical PFA bag 4.61-in diameter by 24-in long by 0.002-in thick. The bag is secured to the nozzle holder with a hook-and-loop strap.

Nozzles with intake diameters of 3/16 in, 1/4 in, and 5/16 in were used in testing the US D-96 sampler. At a maximum transit rate of 0.4 times the stream velocity, the US D-96 is capable of sampling to a depth of 110 ft with the 3/16-in diameter nozzle, 60 ft with the 1/4-in diameter nozzle, and 39 ft with the 5/16-in diameter nozzle.

TESTING

Development Testing

A testing program was conducted to determine the effect of design configurations that led to the final design described in this report. Initial test work was conducted in a flume at the US Army Corps of Engineers Engineer and Research Development Center located in Vicksburg, MS. The flume has a cross-section 3-ft wide by 4-ft deep, and a straight section approximately 60-ft long. It has an adjustable tailgate to aid in control of water velocity. Water is supplied to the flume by two 25-cubic feet per second (cfs) pumps and one 10-cfs pump that may be operated in any combination. A small lake serves as the water reservoir and water from the flume is recirculated. For US D-96 testing, the flume could be operated at mean water velocities up to approximately 6 ft/sec. A Price type AA current meter with a Current Meter Digitizer model number CMD 1.7 was used to measure water velocity in the flume. The meter had been previously calibrated by

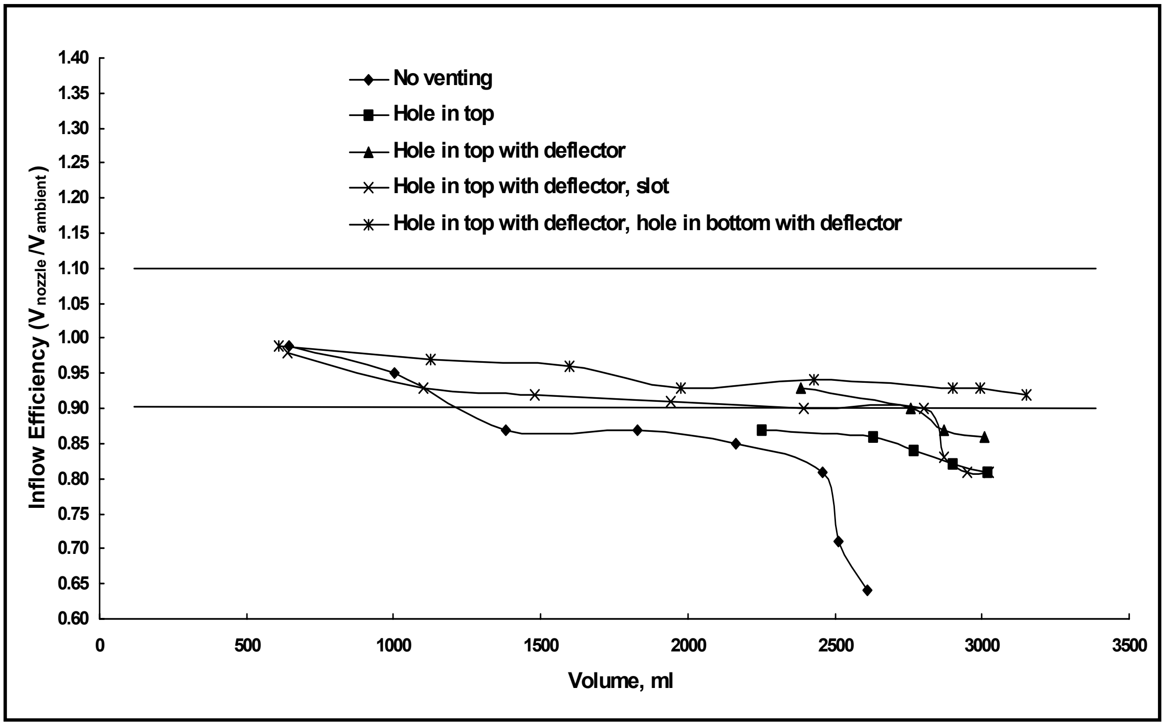

Figure 6-- Venting configuration effects

the USGS, Office of Surface Water Hydraulics Laboratory located at Stennis Space Center, Bay St. Louis, MS. A set of nozzles designed for use with a US D-77 rigid-bottle sampler was calibrated in a rigid-bottle sampler and modified to fit the US D-96 nozzle holder. These nozzles had intake diameters of 3/16 in, 1/4 in, and 5/16 in, and were used in flume, tow, and initial transit tests. This set of nozzles was used throughout most of the testing so changes in inflow efficiency could be attributed to changes in design configurations and not in different nozzle design. Nozzles damaged during testing were replaced with nozzles of the same design and calibration.

Initial tests were conducted with a 1/4-in diameter nozzle and a water velocity of approximately 5 ft/sec in the flume. The test procedure was as follows:

- Three velocity measurements were made in succession and averaged for the water velocity. The measurements were made near the point in the flume where the sampler nozzle would be located. This procedure was repeated after three samples were taken so that after every three observations the velocity was measured.
- As a minimum, three replicates (samples taken) were conducted at each of five to seven volume levels ranging from 500 to 3000 mL. This resulted in up to 21 measurements for each configuration.
- Raw data including sample volume, time of collection, water velocity, nozzle diameter, and water temperature were recorded and the inflow efficiency calculated for each measurement. The inflow efficiency was defined as the velocity of the water through the

nozzle divided by the ambient velocity in the flume incident to the nozzle. The water velocity through the nozzle was calculated based on the volume of water collected, the elapsed time of collection, and the cross-sectional area of the nozzle.

An inflow efficiency of 1.0 indicates that the sampler is sampling isokinetically. Tests conducted and reported in FISP Report 5[13] show that minimal error in sediment concentration for sediment up to 0.15-millimeter (mm) diameter is incurred as long as the inflow efficiency is 1.0 plus or minus 0.15. Szalona[8] also reports an acceptable inflow efficiency of 1.0 plus or minus 0.15. FISP currently calibrates samplers to sample at an inflow efficiency of 1.0 plus or minus 0.10.

Many design configurations were tested to determine the optimal design for a sampler that would collect 3 L at the prescribed range of stream velocities. The four major configurations were venting, nozzle placement, nozzle holder design, and bag dimensions. Venting configurations tested were no vents, one vent in the top, one vent in top and one in the bottom, two vents in the top and two vents in the bottom, vents with and without deflectors, and venting in the rear of the sampler. Some of the test results on venting effects with a 1/4-in diameter nozzle at 5 ft/sec flume flow velocity is shown in figure 6. The five conditions were no vents, vent hole in the top, vent hole in the top with deflector, vent hole in the top with deflector and interior vent slots, and hole in the top and bottom with deflectors. The case of no venting resulted in unacceptable inflow efficiencies at large volumes (figure 6). The sampler would collect no more than approximately 2600 mL of water with no venting. The configurations with a hole in the top, a hole in the top with a deflector, and a hole in the top with a deflector and interior vent slots resulted in inflow efficiencies that approached acceptable levels. A hole in the top with a deflector and a hole in the bottom with a deflector resulted in the collection of a sample of more than 3000 mL and an inflow efficiency from 0.92 to 0.99. The vent holes aided in rapid evacuation of air and influx of water into the sampler cavity around the outside of the collapsible bag when the sampler was submerged. This result was necessary to help balance the pressure outside the sampler and inside the sampler cavity so the only acting force was the velocity head created by the stream velocity. The deflector over the hole in the top section and nose section created a slight venturi effect that aided in removing the water in the sampler cavity around the outside of the bag when filling. This result allows the bag to expand unrestricted as it filled with water. The bag used in the sampler was sized to have a volume slightly more than the volume of the sampler cavity. The bag is made of PFA, cylindrical in shape (4.61-in diameter by 24-in long). Tests were conducted with bags that were shortened to 19-, 20-, 21-, 22- and 23-in long. Tests also were conducted with bags that were modified to have a neck shaped like a bottle with a 1.5-in diameter opening. Results showed no improvement over the standard-sized bag. Another configuration tested for effect was the placement of the nozzle. Placements tested were centerline, 0.5 in above centerline, and 2.5 in above centerline. In other tests the nozzle was extended 3, 5, and 7 in in front of the sampler. Test results showed that acceptable inflow efficiencies were obtained with the nozzle located at the centerline with no extension. No improvement in inflow efficiency was observed at the other nozzle placements.

Although all configurations described above had been optimized, isokinetic sampling was difficult to achieve at the low flume flow velocity of 2 ft/sec. This result is similar to the case

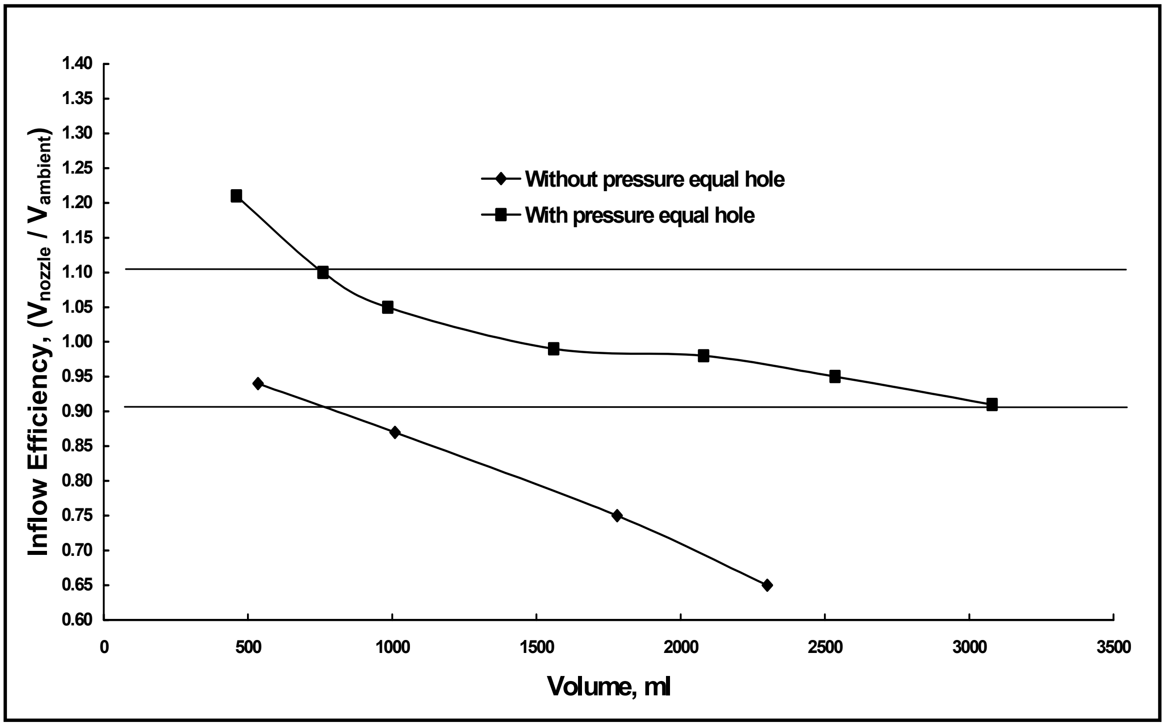

Figure 7-- Effect of pressure equalization hole

with previously tested bag samplers[6], as isokinetically sampling could not be obtained below 3 ft/sec flow velocity. For the sampler to perform isokinetically, the pressure inside and outside the bag in the sampler cavity, and the hydrostatic pressure outside the sampler must be equal so the only acting force is the velocity head produced by the stream. To ensure that these pressures were balanced, a small pressure equalization hole (0.0625-in diameter) was drilled in the nozzle holder slightly in front of the point at which the bag is attached to the holder. The effect on inflow efficiency of the pressure equalization hole with a 1/4-in diameter nozzle at 2 ft/sec flume flow velocity is shown in figure 7. The effect on inflow efficiency was appreciable. Without the hole, the inflow efficiency was not even close to acceptable, and the sampler would collect no more than approximately 2600 mL. With the hole, the sampler collected more than 3000 mL. The inflow efficiency over most of the volume range was within the acceptable range of 0.9 to 1.1.

Underwater Video

Concurrent with development testing, an underwater video system was assembled to observe and record the action of the sampler underwater while being towed by one of the FISP research boats. No FISP samplers had previously been filmed underwater to determine stability and horizontal orientation. A small black-and-white underwater camera lens was mounted on a specially designed hanger bar and attached to a sounding weight. The lens was connected remotely by a co-axial cable to a video camera equipped with a digital screen for observation and recording. The sampler was suspended from one boat and the camera system from another boat. After various attempts and refinement of the technique, it was possible to position the sounding

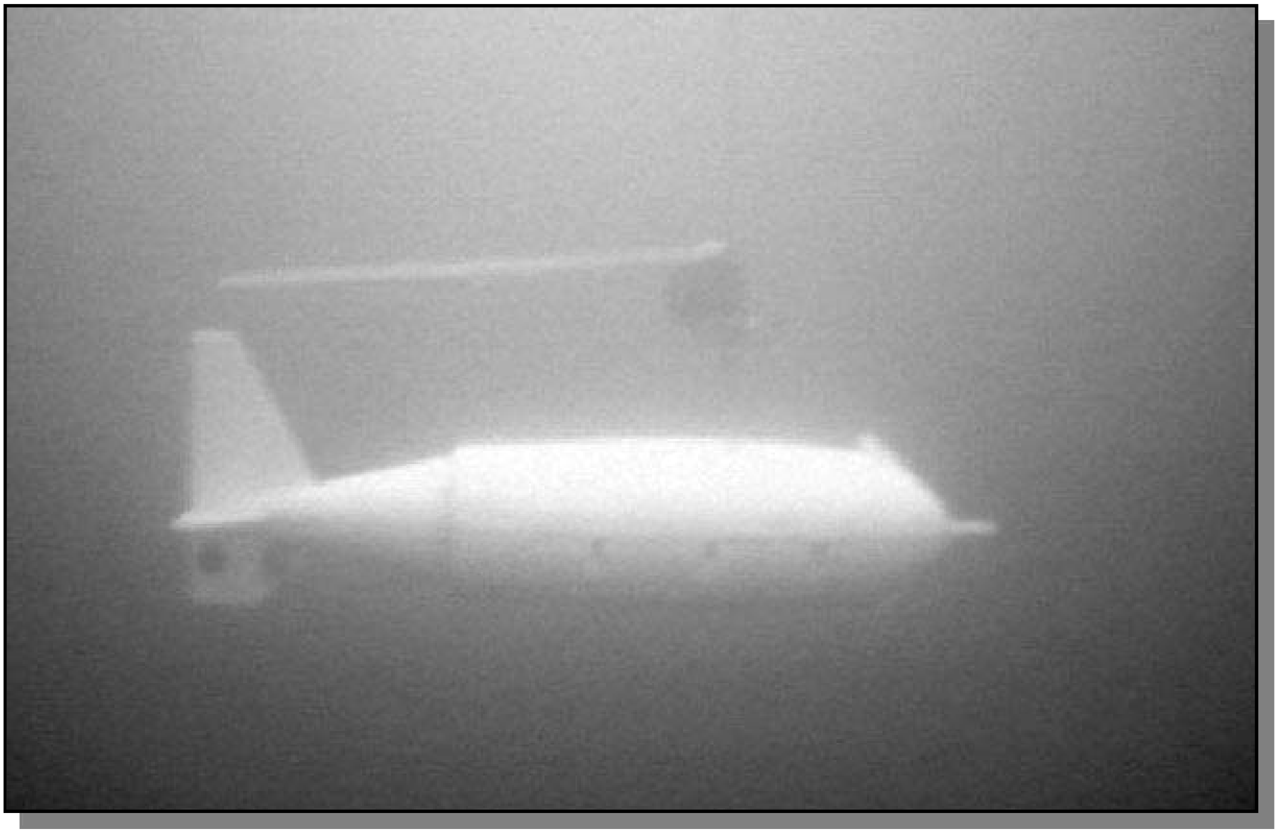

Figure 8-- Underwater video image of the US D-96 sampler

weight with camera lens so the sampler was in the field of view. A streamer was attached to the hanger bar above the sampler so the horizontal attitude of the sampler could be recorded. The towed sampler is shown in figure 8. The action of the sampler was recorded at velocities of 2 to 10 ft/sec at depths up to 26 ft. At greater depths and velocities it was impossible to keep the sampler in the field of view of the camera lens because of the camera cable drag. At all velocities observed and recorded, the sampler was very stable and remained horizontal throughout the velocity range. To determine sampler stability in a more turbulent environment, the sampler was video recorded at a depth of 2 ft behind a boat. The boat was propelled by twin jet pumps and the sampler was placed directly in the turbulent water caused by the jets. The sampler remained stable under these conditions.

Flume and Tow Testing

The final design of the sampler was tested with different internal diameter and material nozzles over a range of velocities. Nozzle diameters tested were 3/16 in, 1/4 in, and 5/16 in, and the materials tested were plastic and TFE. Tests at flow velocities of 2 to 6 ft/sec were conducted in the flume. Testing at velocities higher than 6 ft/sec was accomplished by towing the sampler in a lake with a FISP research boat. The test procedure was as follows:

- Three velocity measurements were made in succession and averaged for the flow velocity

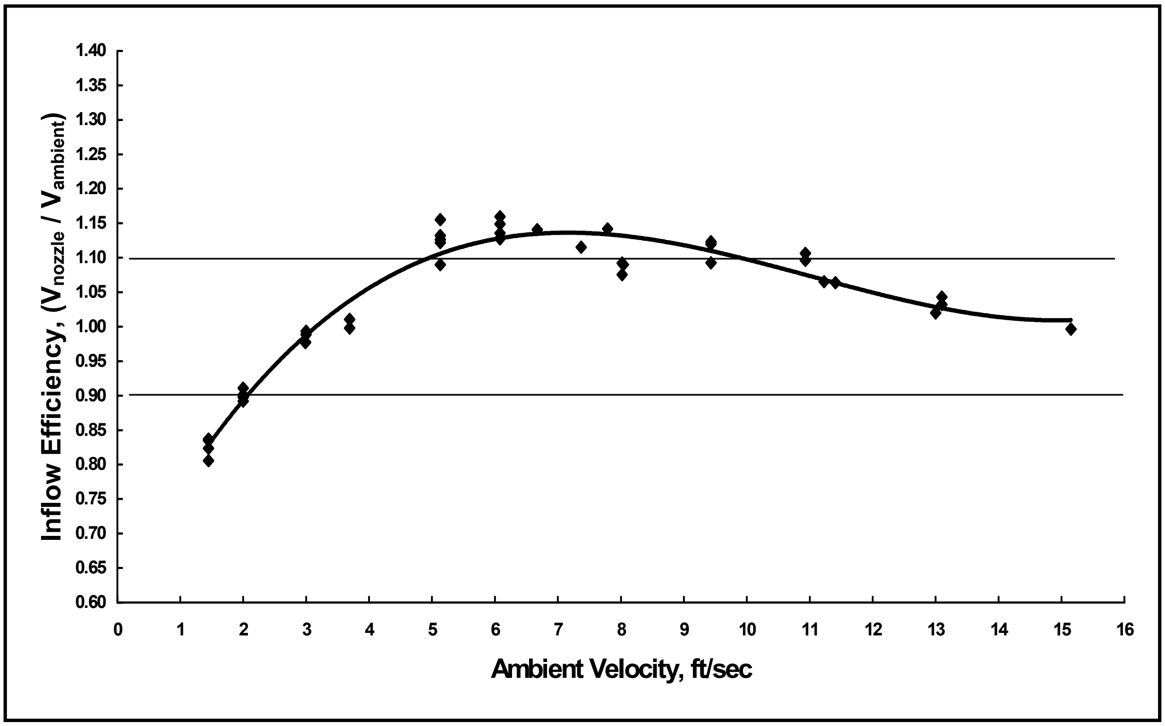

Figure 9-- Nozzle inflow efficiency for a 3/16-in diameter plastic nozzle in flume-tow tests

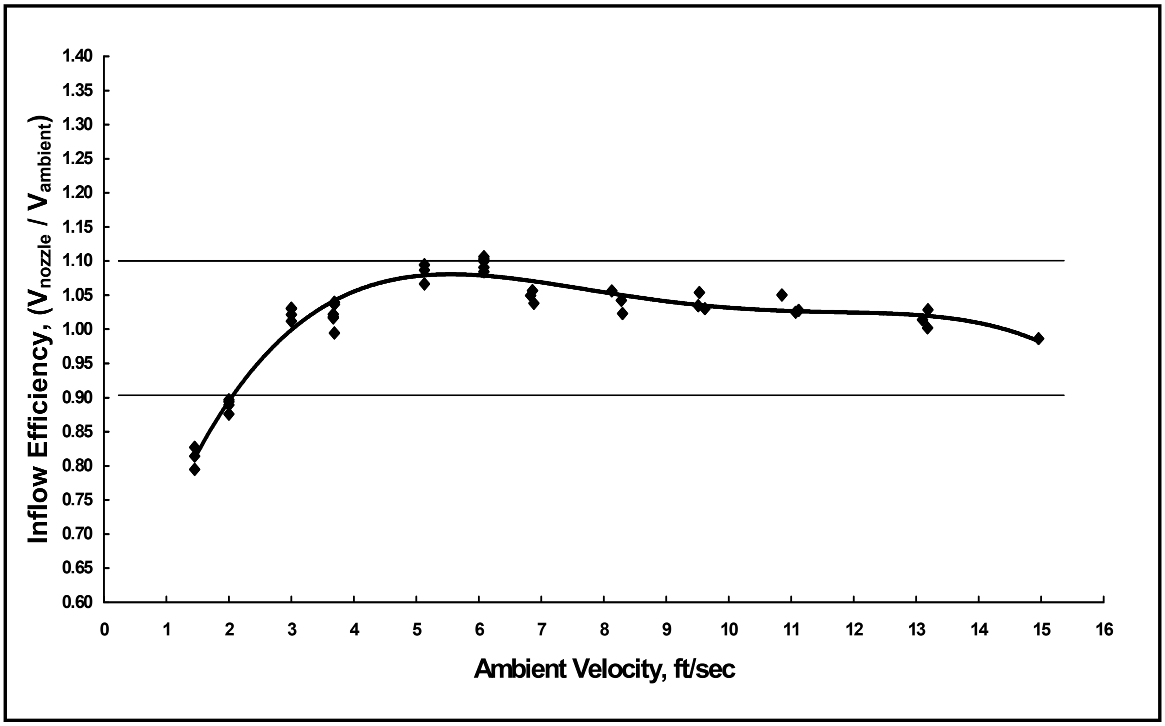

Figure 10-- Nozzle inflow efficiency for a 3/16-in diameter TFE nozzle in flume-tow tests

in the flume. The velocity was re-measured after every three observations.

- In tow testing with the boat, the boat velocity was measured during the sampling interval with a current meter affixed above a sounding weight.
- Sample volume collected was approximately 3 L.
- A minimum of three measurements was made for each velocity.
- Raw data were recorded and inflow efficiency for each observation calculated.

The results for the 3/16-in diameter plastic nozzle, and the results for the 3/16-in diameter TFE nozzle are presented in figures 9 and 10, respectively. The velocity range tested was from 2 to approximately 15 ft/sec. The plastic nozzle inflow efficiency for velocities between 2 and approximately 5 ft/sec and 9 to approximately 15 ft/sec were within 0.9 to 1.1. The inflow efficiency for the mid-range velocities of approximately 5 to 9 ft/sec was slightly above 1.1, but not over 1.15. The TFE nozzle efficiency was slightly under 0.9 at 2 ft/sec, but was from 0.9 to 1.1 throughout the rest of the velocity range tested, up to approximately 15 ft/sec.

The results for the 1/4-in diameter plastic and TFE nozzles are shown in figures 11 and 12, respectively. Both nozzles produced inflow efficiencies between 0.9 and 1.1 throughout the velocity range. The plastic and TFE nozzles were tested up to approximately 15 ft/sec and 13 ft/sec velocity, respectively.

The results for the 5/16-in diameter plastic and TFE nozzles are shown in figures 13 and 14, respectively. Both nozzles produced inflow efficiencies of between 0.9 and 1.1 throughout the

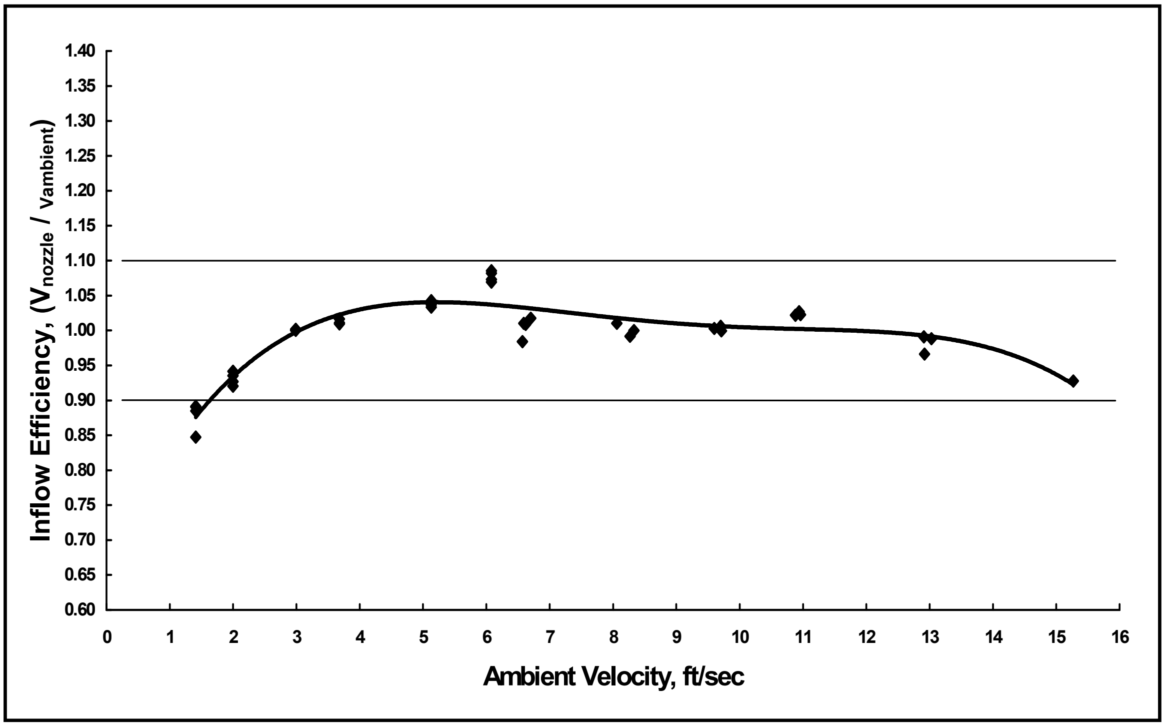

Figure 11-- Nozzle inflow efficiency for a 1/4-in diameter plastic nozzle in flume-tow tests

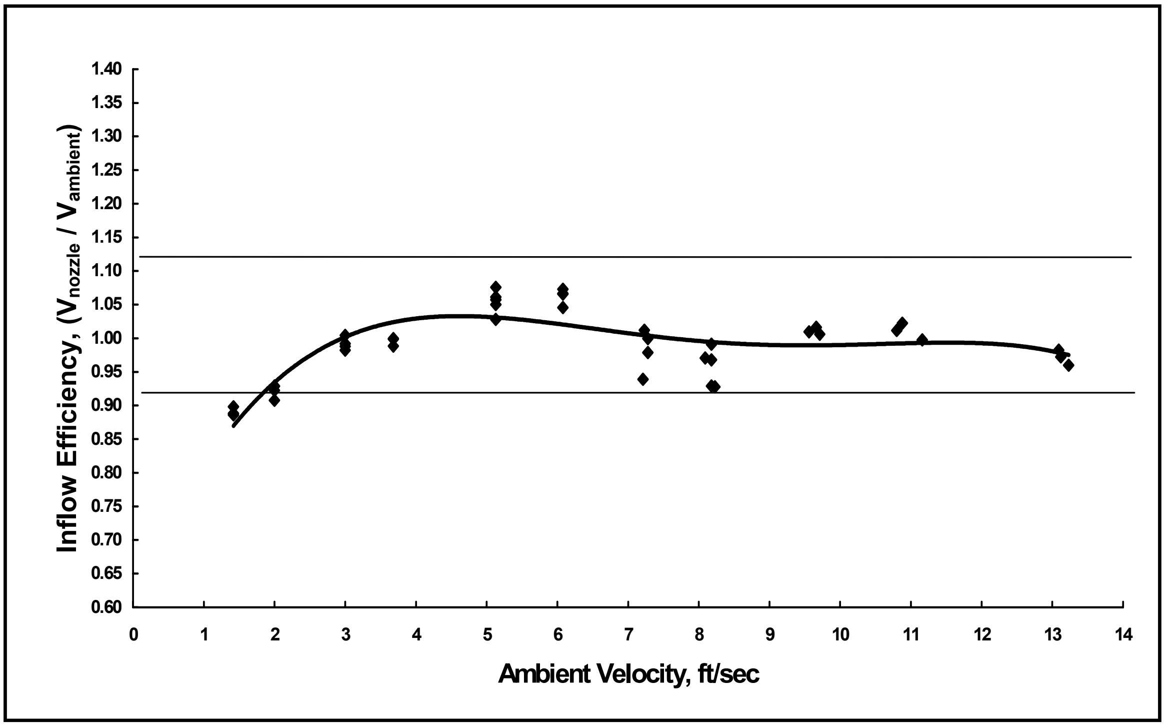

Figure 12-- Nozzle inflow efficiency for a 1/4-in diameter TFE nozzle in flume-tow tests

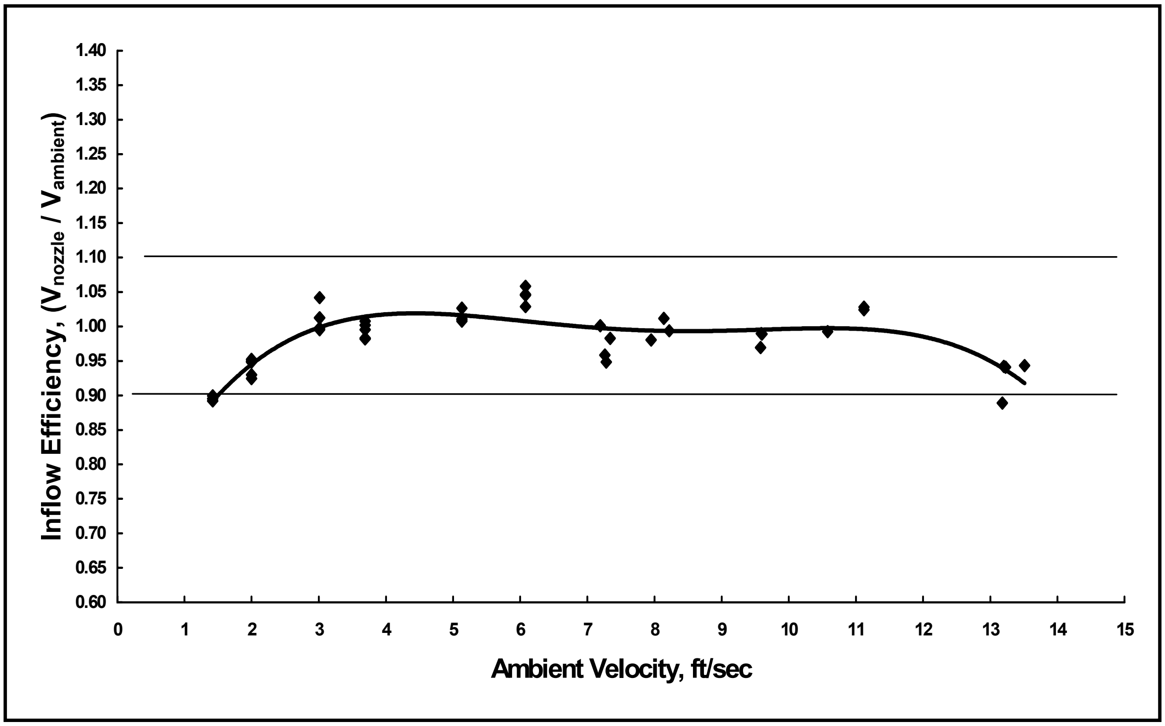

Figure 13-- Nozzle inflow efficiency for a 5/16-in diameter plastic nozzle in flume-tow tests

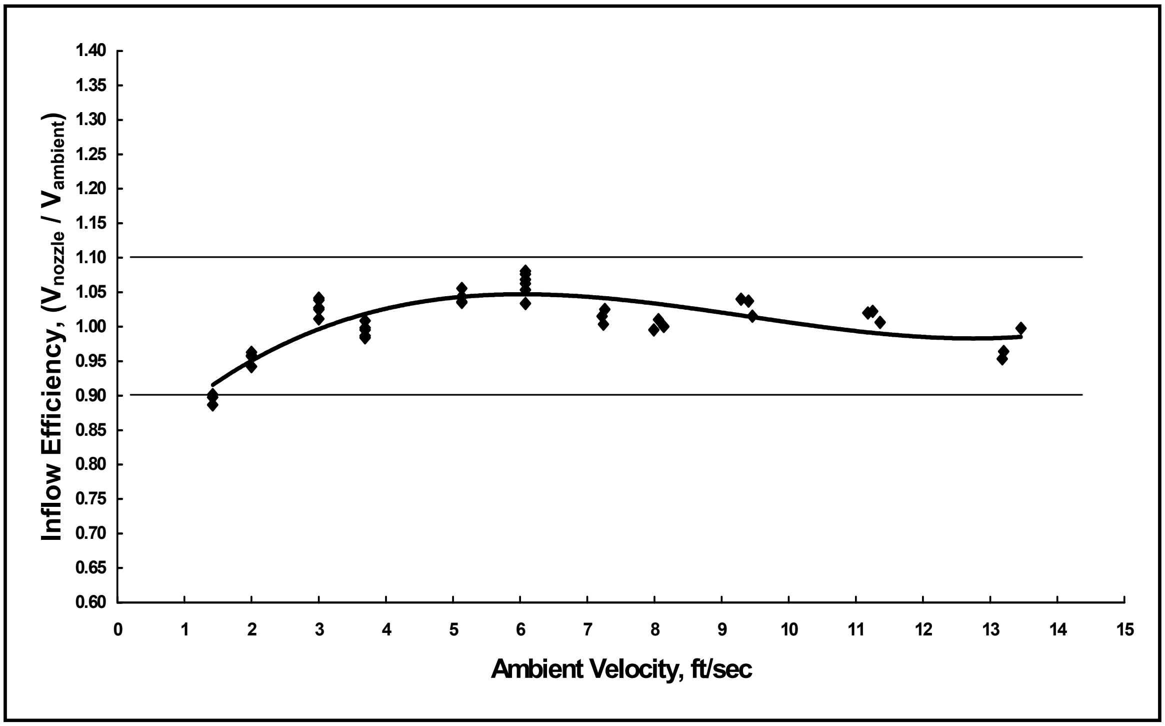

Figure 14-- Nozzle inflow efficiency for a 5/16-in diameter TFE nozzle in flume-tow tests

velocity range of 2 to approximately 13.5 ft/sec.

The results of the flume and tow tests confirmed that the US D-96 produced acceptable inflow efficiencies at a wide range of velocities. It was noted that the 3/16-in diameter plastic nozzle produced slightly higher inflow efficiency in mid-range velocities. During US D-96 testing, it was noted that sometimes a slight variation in inflow efficiency resulted among identically fabricated nozzles. This variation possibly could be attributed to two factors encountered in the machining process. The first is how close to the exact diameter the nozzle is machined. Differences of a few thousandths of an inch would result in several percentage points difference in the calculated inflow efficiency. The second factor is how smooth the inside bore is machined, the smoother the bore, the higher the inflow efficiency.

Transit Testing

As previously discussed, the theoretical depth limitation of a collapsible-bag sampler depends on the nozzle intake diameter and the volume of the bag. Based on a volume of 3 L and the maximum transit rate of 0.4 times the stream velocity, the 3/16-in diameter nozzle is capable of sampling to a depth of 110 ft, the 1/4-in diameter nozzle to a depth of 60 ft, and the 5/16-in diameter nozzle to a depth of 39 ft. A test scheme was devised to test the inflow efficiency of the US D-96 with the three size nozzles while transiting to the operational depth of each nozzle. A crane system with an E-reel and an electronically controlled DC regenerative type electric motor was designed and fabricated. The system was capable of very precise control of the transit rate of the sampler.

Testing was conducted on a lake that could be characterized as a highland reservoir built for a city water supply. The flooded area of the reservoir had been cleared of trees, bridges, dwellings, and other structures before filling. The sampler could be lowered to depth while being towed with a certain amount of confidence that it would not become entangled with any underwater obstacles. The test procedure was as follows:

- The boat velocity was set using the velocity reading from a current meter attached to a sounding weight.
- A transit rate of 0.4 times the boat velocity was calculated and set on the electronically controlled reel.
- The sampler was lowered to depth using the counter of the E-reel for the depth reading.
- At depth, the sampler immediately was reversed and the transit rate maintained.
- A minimum of three observations was made at each velocity and depth.
- The velocity, volume of sample, and sample time were recorded and inflow efficiency calculated.

Transit tests were conducted with the set of nozzles that was used in the development testing, including flume and tow testing. A set of nozzles calibrated in the US D-96 also was transit

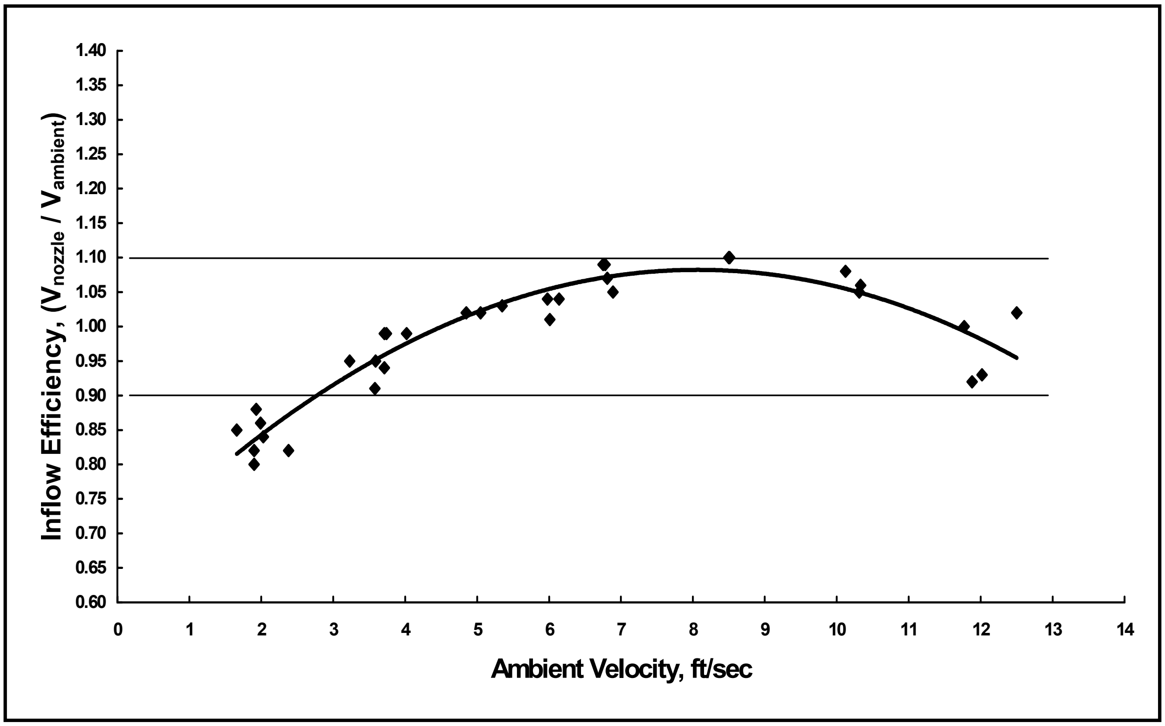

Figure 15-- Nozzle inflow efficiency for a 3/16-in diameter development nozzle in transit tests

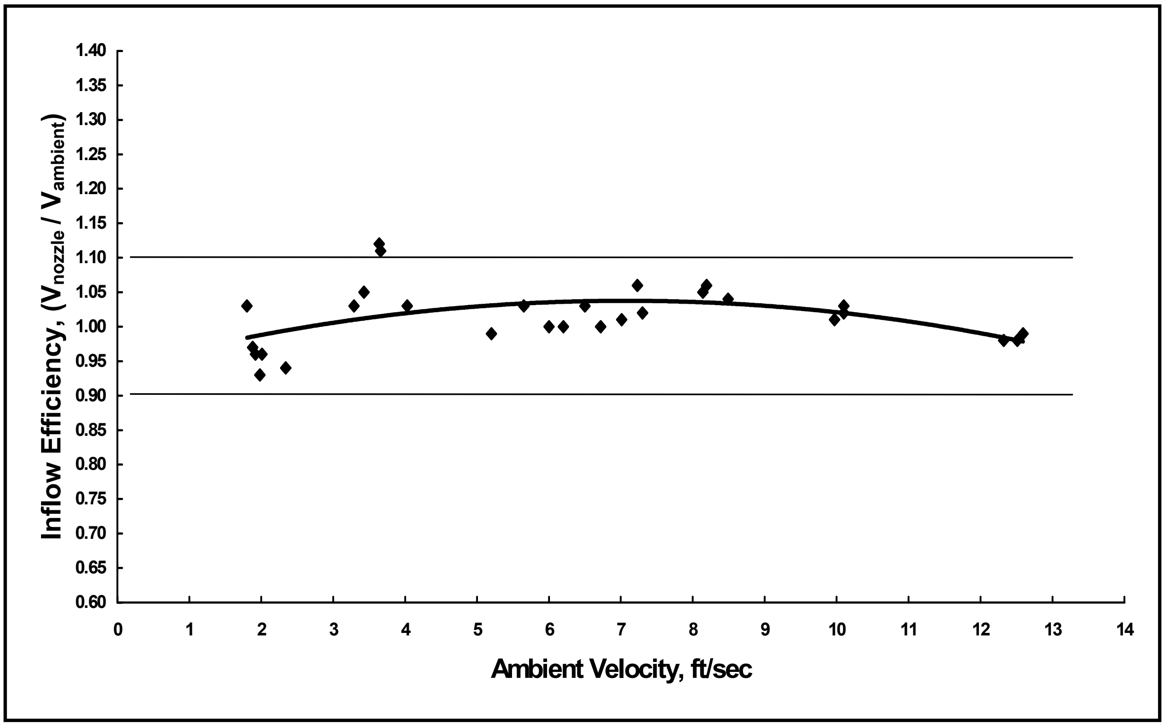

Figure 16-- Nozzle inflow efficiency for a 1/4-in diameter development nozzle in transit tests

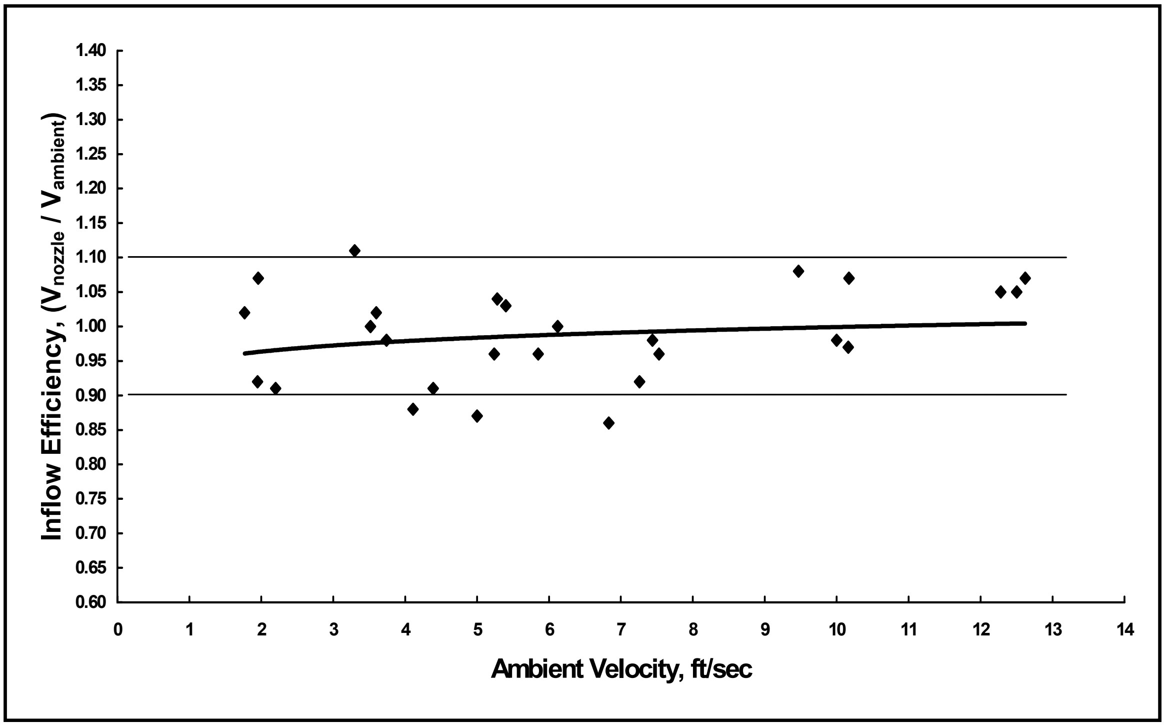

Figure 17-- Nozzle inflow efficiency for a 5/16-in diameter development nozzle in transit tests

tested. The nozzles were calibrated by adjusting the taper depth in the rear of the nozzle until the sampler collected 3 L of water at an inflow efficiency of 1.0 at 3.7 ft/sec flume flow velocity. The data were somewhat scattered as compared to those from the flume and tow test. This scatter was attributed to the difficulty of precise boat velocity control, coordination of personnel operating the crane, timing the sample, and measuring the sample volume on a moving boat. However, even with the data scatter, meaningful results were attained.

The results of the transit test for a 3/16-in diameter plastic development nozzle are shown in figure 15. Although the US D-96 is capable of sampling to a depth of 110 ft, the maximum depth for testing in the lake was 90 ft. The sampler was tested at velocities of 2 to 12.5 ft/sec. The inflow efficiency was slightly lower than other results at 2 ft/sec (0.85), but was between 0.9 and 1.1 when the velocity exceeded 3 ft/sec. The results for a 1/4-in diameter plastic development nozzle transited to a 60 ft depth are presented in figure 16. The inflow efficiency was between 0.9 and 1.1 throughout the velocity range of 2 to 12.5 ft/sec. The results for a 5/16-in diameter development nozzle transited to a depth of 39 ft are shown in figure 17. Environmental conditions including high wind and waves the day of the test made it difficult to maintain consistent sampling conditions. The result was a scattered data set. However, the inflow efficiency was still mostly between 0.9 and 1.1 throughout the velocity range of 2 to 12.5 ft/sec.

Additional transit tests were conducted using a set of nozzles that had been calibrated using the US D-96. The results attained using a 3/16-in diameter TFE nozzle are presented in figure 18. The sampler was tested to a depth of 90 ft and at velocities of 2 to 8.5 ft/sec. It can be seen that the inflow efficiency was between 0.9 and 1.1 in velocities up to approximately 5 ft/sec, and slightly over 1.1, but less than 1.15 above approximately 5 ft/sec. The results for a 1/4-in diameter plastic nozzle are shown in figure 19. The sampler was transited to a depth of 60 ft in the tests. Results were similar to the 3/16-in diameter nozzle in that the inflow efficiency was between 0.9 and 1.1 from 2 to approximately 5 ft/sec and slightly higher at approximately 6 ft/sec and above. The transit test results for the sampler using a 5/16-in diameter plastic nozzle are shown in figure 20. The sampler was transited to a depth of 39 ft in the tests. Again, the inflow efficiency was between 0.9 and 1.1 up to approximately 6 ft/sec and slightly above at the higher velocities.

There was a slight difference in the inflow efficiency curves between the development and calibrated nozzles, although both were mostly between 0.9 and 1.1. Nozzles for the US D-96, and other FISP samplers do not have a consistent intake diameter from front to rear. They are tapered at the rear of the nozzle. The nozzles are calibrated by varying the taper depth to produce an inflow efficiency of 1.0 at an ambient flume flow velocity of 3.7 ft/sec. The difference in the inflow efficiency curves between the two sets of nozzles is attributed to a slight difference in taper depths between the nozzles. A review of all the inflow efficiency data including flume, tow, and transit testing indicates that with the 3/16-in diameter nozzle, there always will be an approximately 0.2 range in inflow efficiency through the velocity range of the sampler. The 1/4- and 5/16-in diameter nozzles also will have a variation throughout the velocity range, but to a lesser extent than the 3/16-in diameter nozzle. As previously discussed, there can be inflow efficiency variations between nozzles due to machining. However, all these variations still are very near within the acceptable inflow efficiency range of 0.9 to 1.1.

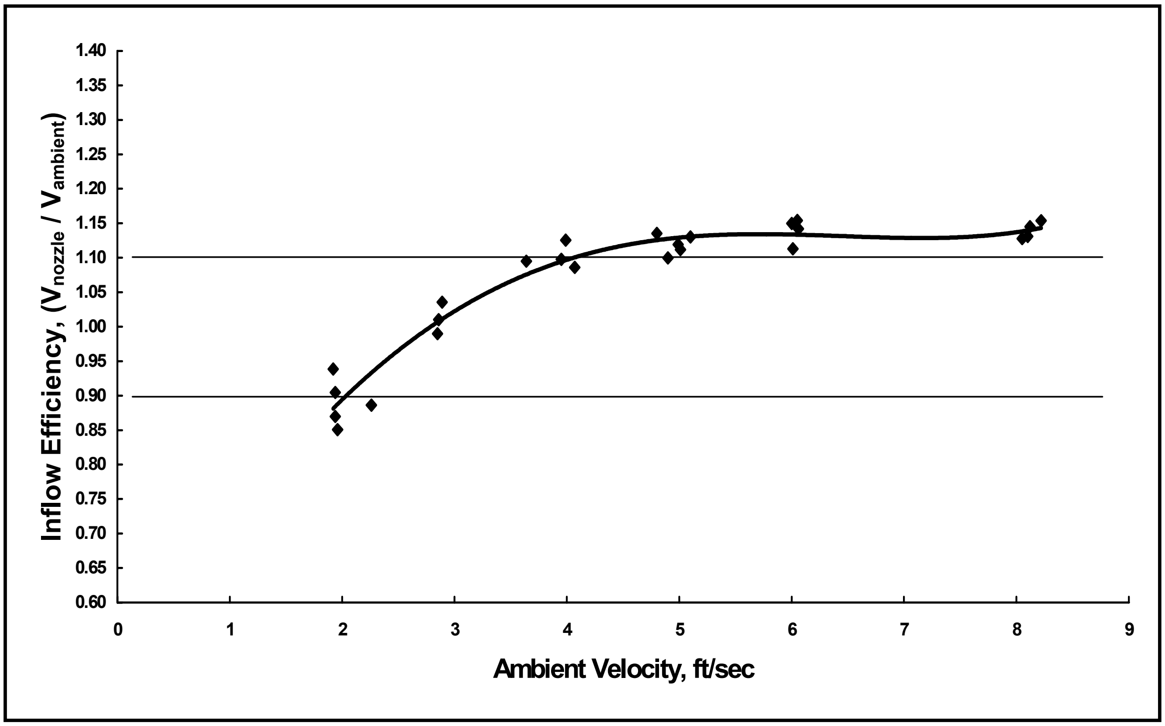

Figure 18-- Nozzle inflow efficiency for a 3/16-in diameter calibrated nozzle in transit tests

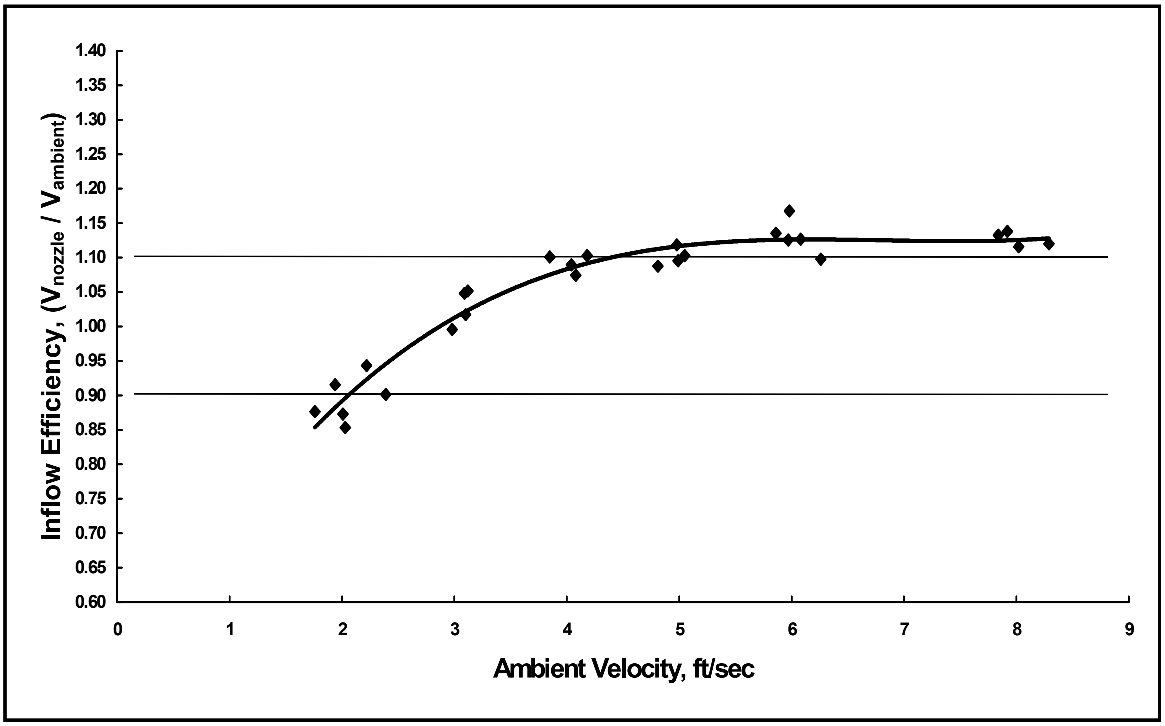

Figure 19-- Nozzle inflow efficiency for a 1/4-in diameter calibrated nozzle in transit tests

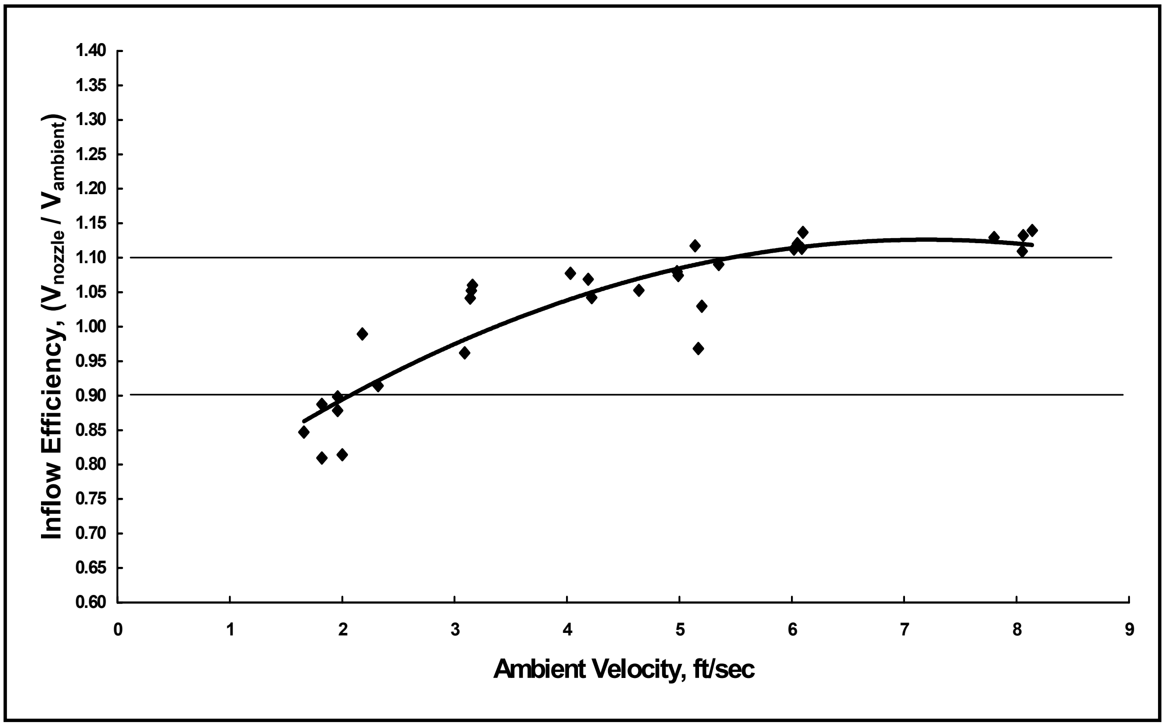

Figure 20-- Nozzle inflow efficiency for a 5/16-in diameter calibrated nozzle in transit tests

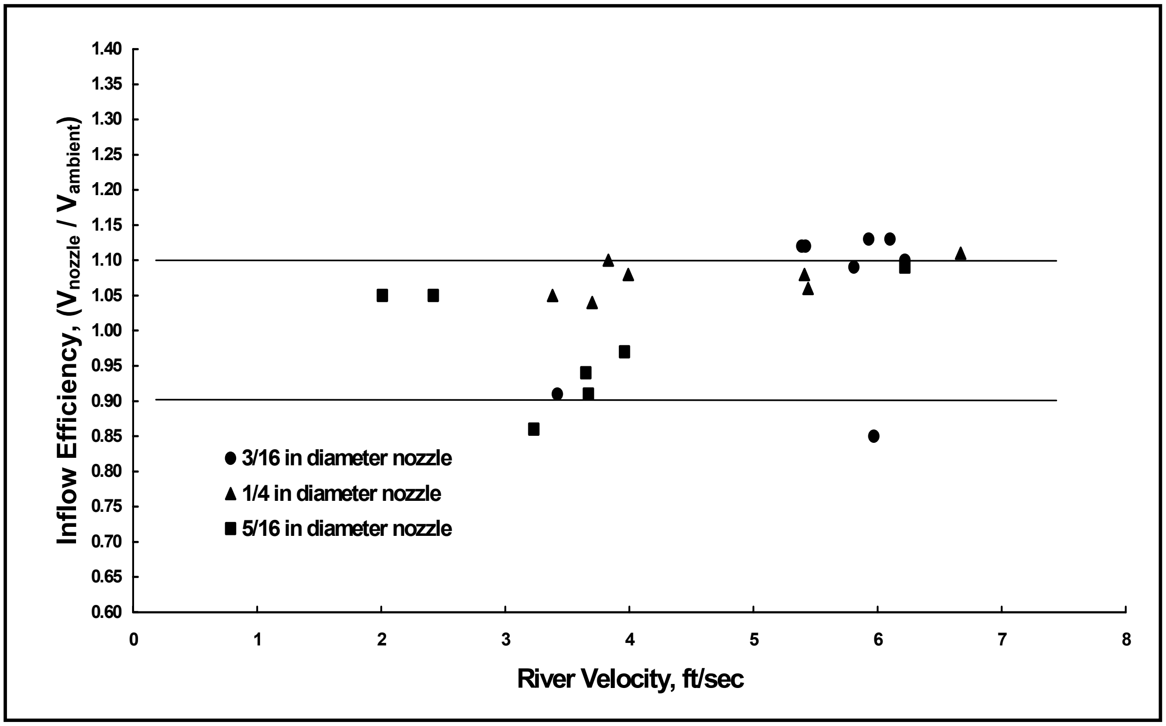

Figure 21-- Nozzle inflow efficiencies obtained in river tests

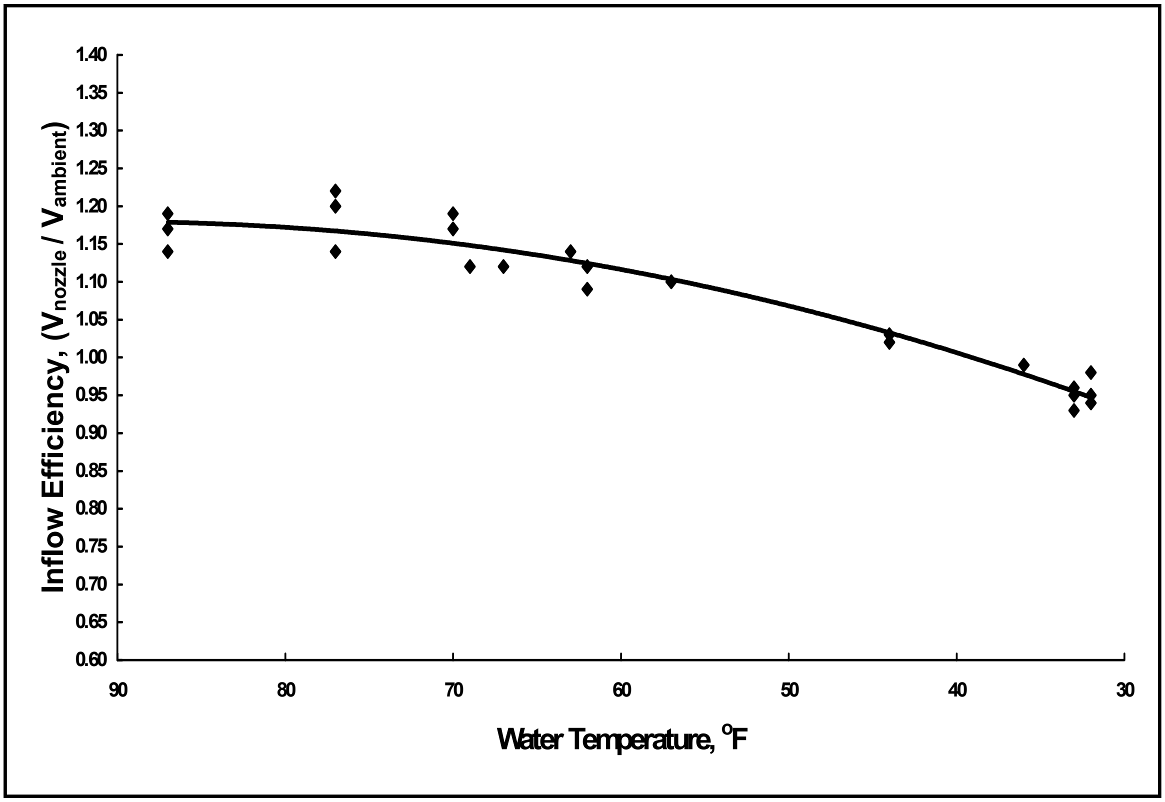

Figure 22-- Water temperature effect on nozzle inflow efficiency

River Testing

FISP collected samples at three sites on the Mississippi River near Vicksburg, MS, at velocities of 3 to 7 ft/sec at depths of 30, 39, and 70 ft. All three nozzle sizes were used. The results are shown in figure 21. Although the velocity range was not such that curves could be plotted, it can be seen that most of the inflow efficiencies were between 0.9 and 1.1 (figure 21). The exercise also showed that the sediment in the river water did not interfere with the operation of the sampler concerning the sliding tray that supports the collapsible bag.

Cold-Water Testing

Successful operation of a collapsible-bag sampler is dependant on the bag opening or expanding as the bag fills with water. Some previous investigations where plastic bags were used indicated that the flexibility of the bag was reduced at low temperatures and difficulty was encountered with the bag opening, especially at low velocities. Tests were conducted to determine the effect of cold water on the PFA bag used with the US D-96. However, before the tests were conducted, some inflow efficiency calculations were made based on previous research. Data in the literature supports that temperature affects the flow of water in small tubes.[14] For small smooth pipes the loss of head has been found to increase about 4 percent for each 10-degree fall in temperature from 70 degrees to 40 degrees Fahrenheit (°F). Other laboratory investigations

Table 1-- Cold-water test results at 2 ft/sec velocity

Nozzle diameter, inch	Nozzle material	Calculated inflow efficiency at 47 °F	Measured inflow efficiency at 47 °F	Calculated inflow efficiency at 37 °F	Measured inflow efficiency at 37 °F
3/16	Plastic	0.78	0.82	0.73	0.73
3/16	TFE	0.78	0.83	0.73	0.74
1/4	Plastic	0.78	0.87	0.73	0.79
1/4	TFE	0.78	0.87	0.73	0.74
5/16	Plastic	0.78	0.84	0.73	0.84
5/16	TFE	0.78	0.86	0.73	0.80

indicate that the velocity of water in small glass tubes may be increased as much as 20 pct when the temperature is increased from 32 to 77 °F.[15] FISP Report No. 6[2] presents results of tests conducted to determine the effect of water temperature on inflow efficiency. Tests were conducted with two US D-43 samplers with 1/8-, 3/16-, and 1/4-in diameter nozzles at temperatures from slightly above freezing to approximately 87 °F. A compilation of data from the two samplers tested with a 3/16-in diameter nozzle at 3.5 ft/sec flume flow velocity is presented in figure 22. The data show that there was an inflow efficiency drop of approximately 0.2 from 87 °F to 33 °F. The majority of the US D-96 testing has been in water temperatures of 75 to 85 °F. FISP samplers are calibrated at a flume flow velocity of 3.7 ft/sec. Based on the data in figure 22, a US D-96 with a 3/16-in intake diameter nozzle calibrated to an inflow efficiency of 1.0 at 80 °F would produce an inflow efficiency of approximately 0.8 at 33 °F. FISP was not able to conduct cold-water tests at a water temperature of 33 °F, but was able to conduct tests at 47 °F and 38 °F. At 47 °F, the calculated drop in inflow efficiency was approximately 0.12 (0.88 inflow efficiency), and at 38 °F, approximately 0.17 (0.83 inflow efficiency). Tests conducted at 47 °F and 3.7 ft/sec velocity resulted in inflow efficiencies of 0.89, 0.87, and 0.89, almost exactly as calculated. Tests conducted at 38 °F and 3.8 ft/sec velocity resulted in inflow efficiencies of 0.82, 0.83, and 0.87, again almost exactly as calculated. Tests conducted with the 1/4-in and 5/16-in diameter nozzles showed similar results.

Tests also were conducted at 47 °F and 37 °F at 2.0 ft/sec velocity. Although no data for tests conducted at 2.0 ft/sec is presented in Report 6[2], it states, “The effect of temperature shows up markedly at the lower velocities, but seems to decrease rapidly as the velocities increase.” Based on this conclusion, the temperature effect would be greater at 2.0 ft/sec as compared to 3.5 ft/sec. Test results presented in the Flume-Tow Testing section show that a 3/16-in diameter nozzle calibrated at 80 °F at 3.7 ft/sec has as inflow efficiency of approximately 0.9 at 2.0 ft/sec velocity. At 47 °F, the calculated drop in inflow efficiency would be a minimum of 0.12 resulting in a maximum inflow efficiency of 0.78. At 37 °F, the calculated minimum drop in inflow efficiency would be 0.17 resulting in a maximum inflow efficiency of 0.73. The test results at 2.0 ft/sec velocity using all three intake diameter plastic and TFE nozzles are shown in table 1. In all cases, the inflow efficiency was as calculated or higher.

The conclusion of the cold-water tests was that the decrease in inflow efficiency at low water temperatures is a function of the water temperature and not the flexibility of the PFA bag. Tests also were conducted where the bag was placed in a cooler filled with a mixture of crushed ice and water. The bag was left in the cooler approximately 10 minutes and then placed in the sampler with crushed ice placed in the sampler cavity around the bag. After a sample was collected, it was noted that there was still ice in the sampler cavity. Inflow efficiencies for tests conducted in this manner were the same as the other cold-water tests.

Drift Angle Testing

The drift angle is the angle between the vertical and the suspension cable as the sampler drifts downstream due to the stream current. Information is available for determining the drift angle, true depth, and wet-line correction for sounding weights in Buchanan and Somers[16], Rantz and others[17], and Coon and Futrell.[18] FISP Report F[5] discusses the water velocity in the sampler nozzle during its downward and upward transit in the stream vertical. During the downward transit, the water velocity in the nozzle is less than the actual stream velocity due to the downstream drift. During the upward transit, the velocity in the nozzle is greater than the actual stream velocity due to the sampler being pulled upstream. The error in sediment concentration due to the downstream drift was not determined in the study. Beverage[4] made theoretical estimates of sediment concentration error due to downstream drift for a US P-61 at a stream depth of 100 ft and velocities of 10, 12, and 14 ft/sec. The concentration errors were calculated to be less than 2 pct. However, he did not include the extra downstream drift of the sampler due to lift while it is being lowered and the decreased drift due to drag while it is being raised. Beverage further states, “There is reason to believe that errors due to the dynamic motion could be appreciable.” Beverage also addressed the issue of true depth, downstream drift, and drift

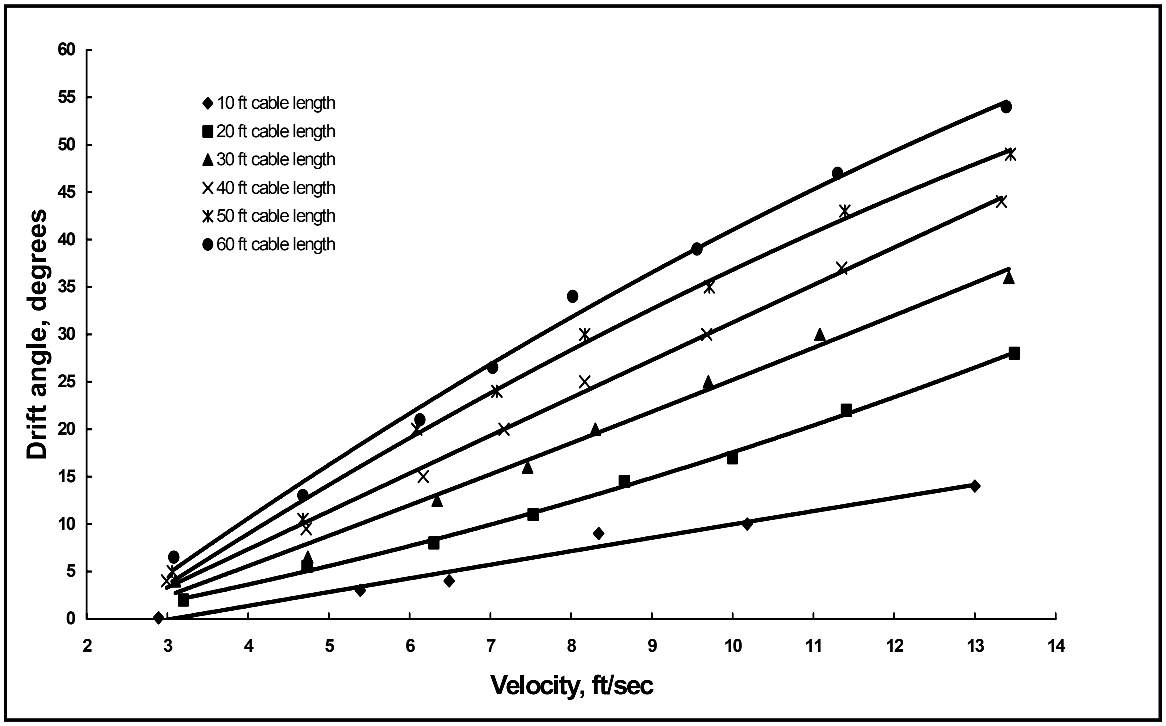

Figure 23-- Drift angle for various wetted cable lengths

angle in determining the characteristics of a proposed sampler for use in extremely deep and fast rivers such as the Amazon in South America, specifically 100 ft deep and 15 ft/sec stream velocity. He wrote a computer program that would calculate the downstream drift, cable length, and drift angle for a given stream depth and mean velocity. By adjusting the drag coefficient of the cable, Beverage was able to calculate values for sounding weights that were close to those given in the literature. He also used the program to calculate the same information for a US P-61 sampler. Substituting the US D-96 characteristics into the program indicated that it would have a smaller drift angle than the US P-61.

FISP conducted tests to determine the drift angle of the US D-96 while being towed by a boat. It is realized that the drift angle of a towed sampler is not exactly the same as that in a stream due to the velocity distribution in a stream vertical. When towed in a lake, the entire wetted cable and sampler are subjected to the same velocity force. In a stream vertical, the velocity force varies along the wetted cable based on the velocity distribution in the stream. However, the information derived from tow tests should give the user a good indication of the expected drift angle. The crane on the FISP research boat was modified to accept a bridge crane protractor. The sampler was towed at velocities from 3 to 13 ft/sec and cable lengths from 10 to 65 ft, measured from the water surface. Water depth limitations in the lake prevented testing longer cable lengths. The measured drift angles for cable lengths of 10, 20, 30, 40, 50, and 60 ft at velocities from 3 to 13 ft/sec are shown in figure 23. Because the maximum theoretical depth for a 5/16-in diameter nozzle is 39 ft, and for a 1/4-in diameter nozzle is 60 ft, results presented in figure 23 should give the user a good indication of the drift angle for most field situations. At

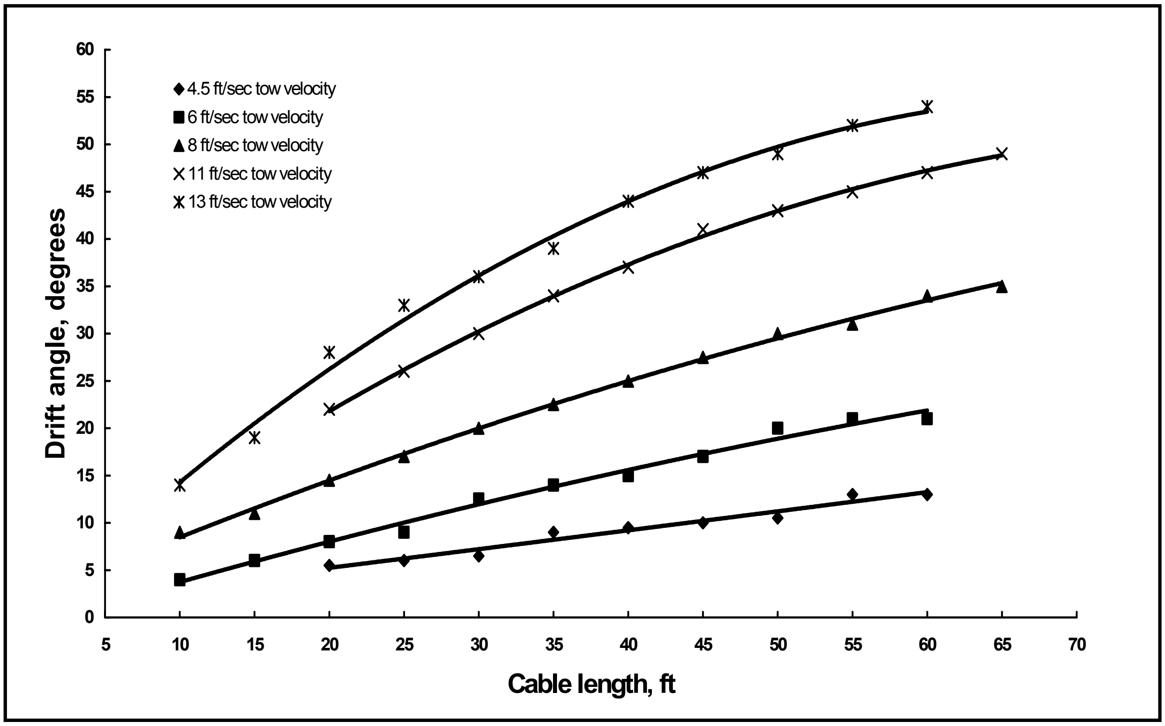

Figure 24-- Drift angle for various constant velocities

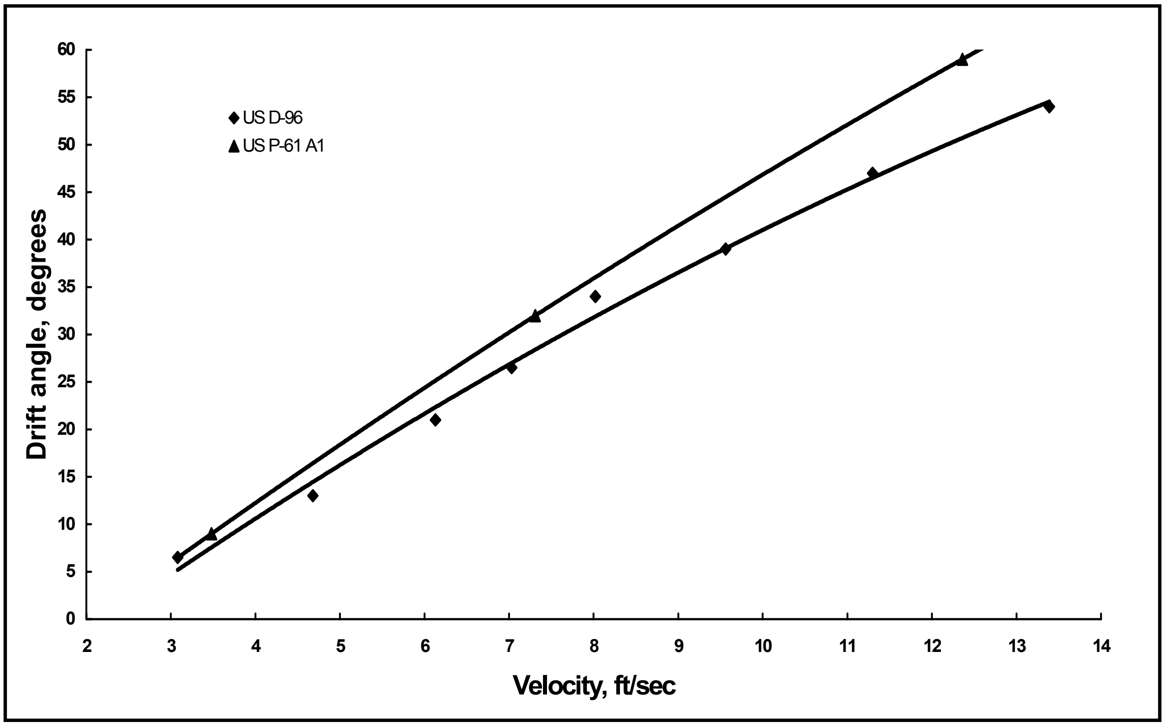

Figure 25-- Drift angle comparison between the US D-96 and a US P-61 A1

long cable lengths and high velocity, the drift angle was over 50 degrees. The drift angle varies with wetted cable length for constant velocities of approximately 4.5, 6, 8, 11, and 13 ft/sec (figure 24).

For comparison purposes, drift angles for a US P-61 A1 also were determined. It is similar in dimensions to the US D-96, but is lighter at 105 lbs compared to 132 lbs. The US P-61 A1 was towed at velocities of approximately 3, 8, and 12 ft/sec. The results are presented in figure 25. As Beverage's program calculated, the US D-96 had a smaller drift angle than the US P-61 A1. However, the program calculated much smaller drift angles than were measured for both samplers. The comparison should give those who have used a US P-61 A1 a good indication of how the US D-96 will perform with respect to drift angle in the field. The maximum acceptable drift angle will have to be determined by those designing a testing program. Determination of the error in sediment concentration due to the downstream drift of the US D-96 was beyond the scope of this study.

Sediment Retention Tests

Although the frame-type bag sampler and the modified US D-77 bag sampler are currently in limited use, very little could be found in the literature regarding how much sediment may be retained in the bag. Szalona[8] refers to sediment adhesion tests that he conducted for the plastic bag used with the modified D-77 bag sampler, but only stated, "Clay did not appear to present a problem, but beads of water remaining with the bag entrapped silt and fine sand sizes." However, he did not present any quantitative results. The main concern would be that sediment could be trapped in the corners or along the seam of the bag. The USGS Baton Rouge, LA, sediment laboratory conducted tests to obtain an indication of how much sediment was retained in the PFA bag used in the US D-96. Sediment samples were obtained from the USGS Branch of Quality Systems (BQS). Included instructions were to mix each sample with de-ionized water to a volume of 3 L, resulting in three suspended-sediment samples described by BQS as having medium, large, and x-large concentration. A sampling system using a cone splitter and a churn splitter was assembled for the study. The cone splitter was placed above the churn splitter with eight of the cone splitter outlets returning to the churn, and two outlets to a sample bottle for analysis. The test procedure was as follows:

- The 3 L suspended-sediment sample was placed in the churn splitter.
- The sample was mixed and 300 mL was removed for a beginning analysis.
- The bag was rinsed with de-ionized water.
- Approximately 1.5 L of sample was transferred from the churn to the bag.
- The sample in the bag was poured into the cone splitter, with eight sub-samples returning to the churn splitter and two to a bottle to supply 250 to 300 mL for analysis.
- The bag was rinsed with approximately 300 mL of de-ionized water and placed in a bottle for analysis.
- The procedure was repeated.
- A middle sample was taken for analysis.
- The procedure was repeated two more times.
- An end sample was taken for analysis.

The same procedure was followed for all three suspended-sediment concentrations. Visual inspection of the bag during testing indicated that there was no entrapment of sediment in the corners or seam of the bag. The concentration (in mg/L) of the suspended-sediment samples, concentration of the sample poured from the bag, and the concentration of the bag rinse for the three suspended-sediment concentrations are shown in table 2.

Table 2-- Sediment retention test results, mg/L

Sample ID	Medium concentration	Large concentration	X-large concentration
Beginning sample	1391	2881	5109
First sample	1288	2702	4733
First sample rinse	45	5	18
Second sample	1300	2628	4671
Second sample rinse	8	4	15
Middle sample	1353	2761	4709
Third sample	1282	2631	4544
Third sample rinse	8	7	7
Fourth sample	1309	2668	4577
Fourth sample rinse	no data	14	9
End sample	1319	2635	4626

A statistical analysis of the data showed there was a significant difference in the sediment concentration among all of the samples taken. However, more than likely the difference is attributed to sampling errors associated with the cone and churn splitters because the concentration in the blanks dropped by roughly 10 pct from the beginning to end of the test. Calculations of the dry weight percentage of the sediment retained in the bag were made. The weight of the sediment retained in the bag was determined directly because the whole rinse was analyzed. The weight of the sediment in the sample in the bag was determined from its concentration and volume of 1.5 L (table 3). In every case except the first sample of the medium concentration, less than 0.2 dry weight pct of the sediment was retained in the bag.

Table 3-- Dry weight percentage of sediment retained in bag, pct

Sample ID	Medium concentration	Large concentration	X-large concentration
First sample	0.80	0.03	0.08
Second sample	0.12	0.03	0.05
Third sample	0.17	0.05	0.03
Fourth sample	no data	0.08	0.04

Additional sediment retention tests were conducted on samples taken during a test on the Mississippi River. Twenty samples at St. Francisville, LA, and 20 samples at Tarbert Landing, LA, were collected with the US D-96 sampler. Bags were rinsed with de-ionized water prior to sampling. Sand-splits were performed in the field on half of the samples. After the suspended-sediment sample was poured from the bag, it was rinsed twice with 500 mL of de-ionized water, the two rinses combined, and saved for analysis. The volume of the suspended-sediment sample was recorded for the sand-split samples. The suspended-sediment concentration data for the samples and rinses are shown in table 4. Three conclusions were made after a review of the sediment retention test data. First, if the sample is transported to the laboratory in the bag, it can be rinsed and the rinse volume recorded in the same way that a sample in a bottle is handled. Second, with proper field technique, practically all the sediment can be removed from the bag. During testing, the open end of the bag was twisted and sealed with one hand, trapping air in the bag. Some pressure could be applied with the hand holding the loose end of the bag, causing the bag to become somewhat rigid. The bag could be shaken, agitating the water-sediment in the bag, and quickly dumped. The third conclusion is that the suspended-sediment concentration of the rinse was relatively constant, regardless of the concentration of the sample. This constant suspended-sediment concentration makes it important to pay close attention when pouring the sample from a bag when sampling streams with low sediment concentration. The last, and probably most important conclusion is that the suspended-sediment concentration in the rinse decreased as several samples were processed through the bag. The bags all were rinsed once with de-ionized water prior to sampling, but possibly there is some surface tension associated with the bag that decreases as the bag is used a couple of times. The surface tension could be associated with lubrication from the machine used to fabricate the bag. A recommended quick and easy way to “condition” the bag prior to collecting a suspended-sediment sample would be to dip water-sediment from the stream and pour it in the bag, agitate it, and dump it out.

Table 4-- Suspended-sediment concentration of Mississippi River samples and bag rinses, mg/L

Sample No.	St. Francisville sample concentration	St. Francisville rinse concentration	Tarbert Landing sample concentration	Tarbert Landing rinse concentration
1	222	9	205	7
2	159	6	229	7
3	168	8	236	6
4	172	5	196	7
5	173	3	197	5
6	146	3	199	3
7	163	4	225	3
8	173	3	207	7
9	171	7	255	6
10	186	6	182	8
11	149	9	224	9
12	150	5	192	5
13	155	6	206	8
14	148	5	230	10
15	165	2	218	9
16	162	2	194	6
17	154	2	233	20
18	149	2	205	7
19	150	0	214	3
20	187	2	223	8

Repeating this process twice, then rinsing with de-ionized water should prepare the bag for use. No information could be found to compare the sediment retention in the collapsible bag to that of a glass, plastic, or TFE rigid bottle.

Water-Quality Equipment Blank

In the past 20 years, much attention has been directed to the quality of water in the Nation's streams and rivers including various constituents other than sediment. The USGS has two active programs that address the quality of rivers and streams in the United States. One is NASQAN that provides information for tracking water-quality conditions in major U.S. rivers. Another is the NAWQA program. It is designed to assess the status and trends in the quality of the nation's ground- and surface-water resources and to develop an understanding of the major factors that affect water quality conditions. Protocols have been developed for the techniques and equipment used is these programs, as well as all other USGS water-quality projects. One such protocol is an equipment blank that insures that samples are not contaminated by the sampling equipment. The US D-96 was subjected to an equipment blank as prescribed in the National Field Manual for the Collection of Water-Quality Data.[19] The equipment blank was performed by the USGS Louisiana District Office and the sample analyzed at the USGS National Water Quality Laboratory in Lakewood, CO. After cleaning the equipment according to the protocol described

Table 5-- Water-quality equipment blank test results

Constituent	Reporting unit	Schedule 172 Method Detection Limit	US D-96
Aluminum	µg/L	0.3	<0.3
Antimony	µg/L	0.2	<0.2
Barium	µg/L	0.2	<0.2
Beryllium	µg/L	0.2	<0.2
Boron	µg/L	2.0	<2.0
Cadmium	µg /L	0.3	<0.3
Calcium	mg/L	0.002	<0.002
Cobalt	µg/L	0.2	<0.2
Chromium	µg/L	0.2	<0.2
Copper	µg/L	0.2	<0.2
Iron	µg /L	3.0	<3.0
Lead	µg/L	0.3	<0.3
Magnesium	mg/L	0.001	<0.001
Manganese	µg/L	0.1	<0.1
Molybdenum	µg/L	0.2	<0.2
Nickel	µg/L	0.5	<0.5
Silver	µg/L	0.2	<0.2
Sodium	mg/L	0.025	<0.025
Strontium	µg/L	0.1	<0.1
Thallium	µg/L	0.1	<0.1
Uranium	µg/L	0.2	<0.2
Zinc	µg/L	0.5	<0.5
Silica	mg/L	0.02	<0.02

in the National Field Manual, a TFE nozzle was threaded into a TFE nozzle holder and a bag attached as shown in figure 4, and placed in the sampler tray. One laboratory person handled the tray while another poured the blank water (water free of the analytes of interest) through the nozzle into the bag. The water was poured out of the bag back through the nozzle into a sample bottle and preserved for analysis. Results for all the analytes of interest were less than the Method Detection Limits; therefore, the sampler met the USGS' Office of Water-Quality's criteria for trace-element sampling as required. Results are presented in table 5.

OPERATING LIMITATIONS

Depth

As previously discussed, the maximum theoretical depth at which the US D-96 can be used is

110 ft with a 3/16-in diameter nozzle, 60 ft with a 1/4-in diameter nozzle, and 39 ft with a 5/16-in diameter nozzle. The maximum practical depth in field use depends on stream conditions. The maximum depth can be reached at low to medium velocities, but probably is not practical at high velocities due to the drift angle.

Stream Velocity

The minimum stream velocity at which the US D-96 sampler will collect an acceptable isokinetic water-sediment sample is 2 ft/sec. The sampler maintains an acceptable inflow efficiency at velocities up to 15 ft/sec, the highest tested. However, the actual upper velocity limitation in field practice depends on stream conditions. For example, the sampler could be used in a shallow high-velocity stream but may not be practical at the same velocity in a deep stream. Safety and the operating platform will determine the upper velocity limit for which the sampler should be deployed.

Transit Rate

The US D-96 is not subject to the same transit rate limitations of rigid bottle samplers. The minimum transit rate is one at which the sample volume does not exceed 3 L. The sampling time for the three diameter nozzles at varying stream velocities is given in table 6. The minimum transit rate can be calculated using the sample time from the table and the total distance to be transited. For example, if the total sampling time is 60 sec, the minimum transit rate should be such that it takes 30 sec to descend from the surface to the bottom, and 30 sec to return to the surface. If the stream is 30 ft deep, the total distance transited is 60 ft in 60 sec for a transit rate of 1 ft/sec.

The maximum transit rate is 0.4 times the stream velocity, which is due to the apparent approach angle of the nozzle as the sampler moves vertically in the stream. The transit rate should never exceed 0.4 times the stream velocity.[1]

Unsampled Zone

The unsampled zone for the US D-96 is 4 in. This zone is the distance between the center-line of the nozzle and the bottom of the sampler. Care should be taken if the sampler is allowed to touch the bottom of the stream so that unconsolidated material is not overly disturbed, possibly biasing the sample.

FIELD EVALUATION

FISP fabricated seven samplers for field evaluation by ten USGS field offices and one Corp of Engineers office. The purpose of the evaluation was to determine if there were any major problems in the design or use of the sampler. Operating instructions, a field data form, and an evaluation questionnaire were sent with each sampler. The samplers were used on the Columbia River in Portland, OR, the San Joaquin River at Jersey Point, CA, the Illinois River at Ottawa,

Table 6-- Filling time to collect 3 L for the 3 US D-96 nozzles, seconds

Stream velocity, ft/sec	3/16 in dia	1/4 in dia	5/16 in dia
2.0	277	156	99
2.2	251	141	90
2.4	231	130	83
2.6	213	120	76
2.8	198	111	71
3.0	185	104	66
3.2	173	97	62
3.4	163	91	58
3.6	154	86	55
3.8	146	82	52
4.0	137	77	50
4.2	132	74	47
4.4	126	71	45
4.6	120	68	43
4.8	115	65	41
5.0	111	62	40
5.2	106	60	38
5.4	102	58	37
5.6	99	56	35
5.8	95	54	34
6.0	92	52	33
6.2	89	50	32
6.4	86	49	31
6.6	84	47	30
6.8	81	46	29
7.0	79	44	28
7.2	77	43	28
7.4	75	42	27
7.6	73	41	26
7.8	71	40	25
8.0	69	39	25
8.2	67	38	24
8.4	66	37	24
8.6	64	36	23
8.8	63	35	23
9.0	61	35	22
9.2	60	34	22
9.4	59	33	21
9.6	58	32	21
9.8	56	32	20
10.0	55	31	20
11.0	50	28	18
12.0	46	26	16
13.0	43	24	15

IL, the Mississippi River at Simmesport, LA, the Arkansas River above Little Rock, AR, the Yazoo River at Vicksburg, MS, the Spokane River at Post Falls, ID, the Yukon River at Stevens Village, AK, and the Tanana River at Henana, AK. No design or efficiency problems were discovered during the evaluation. One response was that the sampler was too heavy to hand crank, but the sampler is intended to be used with a powered reel. Several reported some "clumsiness" in attaching the bag to the nozzle holder with the hook-and-loop strap. It was noted by the FISP research staff that after using the system several times, it became quite natural to make the attachment. It also should be noted that other attachment techniques such as use of a cable tie could be used to secure the bag to the nozzle holder. One respondent noted that they would like a bag sampler that collected 6 to 8 L, rather than the 3 L that the US D-96 collected. One office, which used the sampler from a boat, reported that the sampler seemed to "swing" excessively when suspended in air as a result of waves and tow-boat wakes. Comparison test when the US D-96 and the US P-61 A1 were used both from a boat platform did not visually reveal any difference in "swing" between the two samplers. One respondent thought the US D-96 was more difficult to use than the frame-type bag sampler. It should be noted that the frame-type bag sampler does not sample isokinetically below 3 ft/sec stream velocity and is not FISP approved.

The most often reported uncertainty in the use of the sampler was by field personnel who had only used rigid-bottle samplers. They were unsure how they would handle the sample after collection. At least two offices reported that they processed the sample as soon as it was collected. One respondent suggested a "rack" made of short pieces of plastic pipe stood vertically in an ice chest that the bag with sample could be placed in and transported to the lab. More than likely, after the sampler has been in use for a while, field offices will suggest methods and protocols for handling the samples. Currently no single protocol for processing samples after the bag has been removed from the sampler has been adopted. FISP will solicit insights from users and sediment laboratories on methods and protocols being used to process and ship samples. Processing techniques deemed suitable by FISP will be communicated as appropriate.

Some respondents stated that they were pleased with the ease of use, and that the US D-96 was simpler and easier to use than current samplers. Some said that the sampler would have immediate application in their sampling programs. Others were pleased that they could sample deeper than the 15 ft limitation of rigid-bottle samplers. Another respondent stated they were surprised at how easily the sand came out of the bag, and also said that there was very little difference in evacuating the water from a frame bag and the US D-96 bag. Overall, nothing in the evaluations indicated that FISP should not proceed with production and recommended use of the US D-96 bag sampler.

CONCLUSIONS

For many years there has been a need for a proven collapsible-bag sampler to complement the variety of available depth-integrating rigid-bottle samplers. Such a sampler would not only complement available rigid-bottle samplers, but would overcome some limitations associated with the use of rigid containers. A FISP concept has evolved through the design, fabrication, testing, and evaluation of a collapsible-bag sampler. The sampler has endured rigorous testing and met or exceeded goals FISP set for the sampler. The sampler utilizes nozzles of three intake diameters that allow it to sample to depths of 39, 60, and 110 ft. It is capable of collecting water-sediment samples at an acceptable inflow efficiency at stream velocities of 2 to 15 ft/sec. It will collect up to a 3 L sample. The sampler meets the USGS' Office of Water Quality's requirements for collecting non-contaminated water-quality samples for trace-element analysis. A patent has been granted on the US D-96 sampler (U. S. Patent No. 6,216,549 B1).

REFERENCES

1. Edwards, T.K. and Glysson, G.D., 1999, Field Methods for Measurement of Fluvial Sediment: U.S. Geological Survey Techniques of Water Resources Investigations, book 3 chapter C2, 89 p.

2. Federal Interagency Sedimentation Project, 1952, The Design of Improved Types of Suspended-Sediment Samplers, Interagency Report 6: Minneapolis, Minnesota, St. Anthony Falls Hydraulic Laboratory, 103 p.

3. ______1963, Determination of Fluvial Sediment Discharge, Interagency Report 14: Minneapolis, Minnesota, St. Anthony Falls Hydraulic Laboratory, p. 60

4. Beverage, J.P., 1987, Determining True Depths of Samplers Suspended in Deep Swift Rivers, Federal Interagency Sedimentation Project Report GG, 56 p.

5. ______1951, Field Tests on Suspended Samplers, Colorado River at Bright Angel Creek Near Grand Canyon, Arizona, Interagency Report F, 119 p.

6. ______1940, Field Practice and Equipment used in Sampling Suspended-Sediment, Interagency Report 1: Minneapolis, Minnesota, St. Anthony Falls Hydraulic Laboratory, pp. 154-155

7. Stevens, H.H, Jr., Lutz, G.A., and Hubbell, D.W., 1980, Collapsible-bag Suspended-Sediment Sampler: Journal of the Hydraulics Division, ASCE, vol. 106, No. HY4, pp. 611-616

8. Szalona, J.J., 1982, Development of a Bag-Type Suspended-Sediment Sampler, Interagency Report Y: Minneapolis, Minnesota, St. Anthony Falls Hydraulic Laboratory, 32 p.

9. Meade, R.H., 1995, editor, Contaminants in the Mississippi River, U.S. Geological Survey Circular 1133, Reston, Virginia

10. Moody, J.A., and Meade, R.H., 1992, Hydrologic and sedimentologic data collected during three cruises at low water on the Mississippi River and some of its tributaries, July 1987 through June 1988: U.S. Geological Survey Open-File Report 91-485, 143 p.

11. ______1993, Hydrologic and sedimentologic data collected during four cruises at high water on the Mississippi River and some of its tributaries, March 1989 through June 1990: U.S. Geological Survey Open-File Report 92-651, 227 p.

12. ______1995, Hydrologic and sedimentologic data collected during three cruises on the Mississippi River and some of its tributaries, from Minneapolis, Minnesota, to New Orleans, Louisiana, July 1991-May 1992: U.S. Geological Survey Open-File Report 94-474, 159 p.

13. ______1941, Laboratory Investigations of Suspended Sediment Samplers, Interagency Report 5: Minneapolis, Minnesota, St. Anthony Falls Hydraulic Laboratory, 99 p.

14. Saph, A.V., and Schoder, E.H., An Experimental Study of the Resistances to the Flow of Water in Pipes, Trans. American Society of Civil Engineers, 1903, vol. 51, p. 290

15. Laszloffy, W., Behavior of Ice in Rivers, La Houlle Blanche, 1948

16. Buchanan, T.J., and Somers, W.P., 1969, Discharge Measurements at Gaging Stations: U.S. Geological Survey Techniques of Water-Resources Investigations, book 3, chapter A8, 65 p.

17. Rantz, S.E., and others, 1982, Measurement and Computation of Streamflow: Volume I. Measurement of Stage and Discharge, and Volume II, Computation of Discharge: U.S. Geological Survey Water-Supply Paper 2175, 631 p.

18. Coon, W.F., and Futrell, J.C., 1986, Evaluation of Wet-Line Depth-Correction Methods for Cable-Suspended Current Meters: U.S. Geological Survey Water-Resources Investigations Report 85-4329, 31 p.

19. Wilde, F.D., Radtke, D.B., Gibs, J., and Iwatsubo, R.T., 1998, National field manual for the collection of water-quality data—Cleaning of equipment for water sampling: U.S. Geological Survey Techniques of Water-Resources Investigations, book 9, chap. A3, variously paged.