Federal Interagency Sedimentation Project (FISP)
Technical Committee Memorandum 2011.01

January 2011

Subject: US P-6 Point Integrating Suspended-Sediment Sampler

Introduction

The US series of point-integrating suspended-sediment samplers was first developed in the 1940's. Three experimental samplers lead to the design of the US P-46 in 1946. The US P-46 was the first point-integrating sampler produced for field use. Point-integrating samplers are used to collect a discrete sample at a selected depth. Point-integrating samplers have an electrically operated valve that simultaneously opens and closes passages that allow the collection of a water-sediment sample through a nozzle into a sample container and release of air from the sample container. The samplers operate on the "diving bell" principle. The sampler body has an open cavity with holes in the bottom that allow water to enter as the sampler is submerged. A metal tube connects the cavity of the sampler to the sample container. With the valve in the closed (non-sampling) position, the water entering the sampler body cavity pressurizes the air in the container to the ambient hydraulic static head. The pressurized sample container prevents an in-rush of water accelerated by a hydrostatic pressure difference when the valve is opened to allow isokinetic collection of a sample. When the valve is actuated to the open (sampling) position, the passage connecting the cavity to the sample container is closed and the nozzle and air-exhaust passages are opened.

Previous point-integrating samplers (US P-61-A1, US P-63, US P-72) employ a tapered stainless steel valve body that rotates inside a tapered hole in the brass sampler head (aluminum for the US P-72). A complicated direct current rotating solenoid and hand fabricated brass spring system rotate the valve approximately 30 degrees for opening and closing. Holes are drilled in the valve body and head for conveyance of air and water as previously described. The metal-on-metal fit has to be honed and polished by hand (hand-lapped) to insure the steel valve fit in the brass body is as leak proof as possible. Even the best fits are not completely leak proof, as it is nearly impossible to make a metal-on-metal seal completely leak proof. Since the fit is hand-lapped, valves are not interchangeable and cannot be replaced in the field.

All of the previous point-integrating samplers are calibrated to collect an isokinetic sample by tapering the exit of the water/sediment passage in the sampler head. Consequently each sampler is uniquely calibrated and must be re-calibrated when a valve is replaced. Because of this design, valve repairs to point-integrating samplers have necessitated their return to the U.S. Geological Survey (USGS) Hydraulic Instrumentation Facility (HIF) to machine a new valve body, re-machine the brass sampler head, hand-lap the fit, and re-calibrate the sampler. The cost of re-calibration can be substantial and the expertise to perform the machine work is limited.

In 2006 the FISP entered a cooperative agreement with Carnet Technology, to develop a new point-integrating suspended-sediment sampler. The agreement specified that the sampler would

1. be equivalent in size to the US P-61-A1,
2. operate on the "diving bell" principle just as previous point-integrating samplers
3. employ a more reliable valve system
4. be capable of field repair
5. not require sampler-specific calibration.

This report describes the resulting US P-6 point-integrating suspended-sediment sampler.

Sampler Description

Figures 1 is a photograph and figure 2 a rendering of the US P-6. The sampler consists of three major assemblies: the head, body, and tail. The sampler head and body is cast bronze and the tail section is constructed of high density polyethylene. The sampler weighs 100 pounds (45.4 kg) and is 29.5 inches (0.75 m) long. A 200 pound version of the sampler also is available (US P-6 200). The sampler is streamlined and has tail fins to orient it so the intake nozzle located in the head is directed into the approaching flow. The intake nozzle has an internal diameter of 3/16 inch (4.76 mm); and this is the only nozzle available for the US P-6. The sampler is designed to use various size bottles as a sample container. The bottle cavity has a diameter of 3.95 inches (10 cm), length of 8 inches (20 cm), and an adjustable, removable bottle spring. When the sampler head is closed the mouth of the sample container is sealed against a gasket mounted in the rear of the head. Typical 1-liter sample bottles will fit the sample container, and 1-pint bottles can be accommodated using a sample bottle sleeve.

The sampler head contains an electrically actuated, two-position valve and several passageways that convey the sample and air. The body has a hollow interior, which serves as a compression chamber that forces air through the head to the sample container to equalize pressure in the sampler as it transits through the water. Pressure equalization prevents a hydrostatically induced in-rush of sample as the valve is opened. The sampler head is attached to the body by a hinge and held closed by a latch. The head pivots on the hinge to open and provide access to the sample container (figure 2). When the head is closed the sample container is sealed against a gasket mounted in the rear of the head. A bottle spring exerts force against the base of the sample container to maintain a seal between the bottle gasket and the sample container.

Figure 1 — Photograph of US P-6 point integrating suspended-sediment sampler

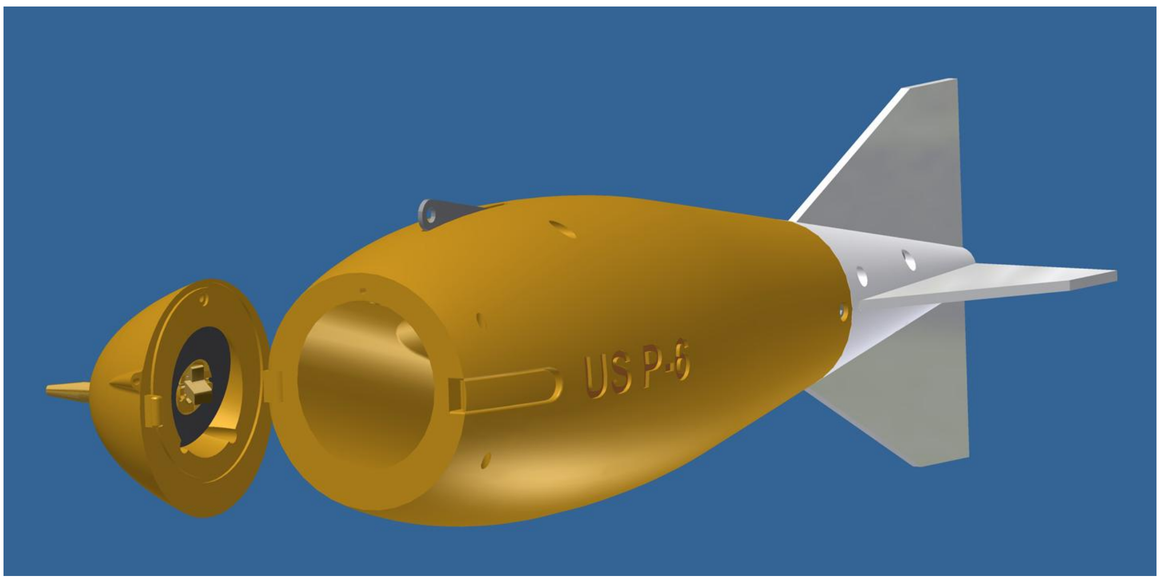

Figure 2 — Rendering of US P-6 sampler with head open

Figure 3 is a rendering of the US P-6 sampler head assembly; and figure 4 is a photograph of the disassembled head. The valve is actuated by a simple direct current tubular linear solenoid and return spring that is commercially available. The operation of the valve causes the sampler to operate in the same way as the other FISP point-integrating samplers; however its design is quite different from the hand-lapped tapered valve used in previous samplers. The valve has two flat faces approximately 120 degrees apart and rotates approximately 30 degrees about the intersection of the two faces. It has foam material cemented to the flat metal faces that create a leak-proof seal of the passage ways. With no electrical power applied, the valve is in the pressure-equalizing position. As the sampler is lowered through the water, hydrostatic pressure forces water through

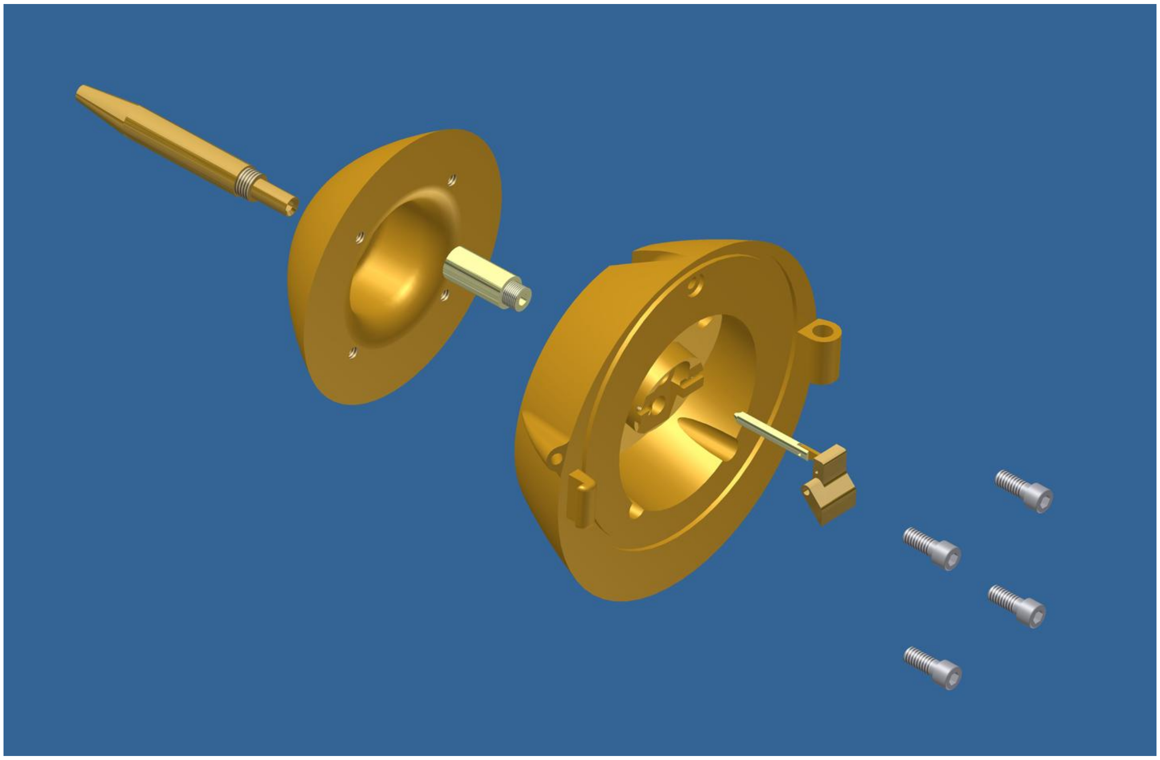

Figure 3 — US P-6 sampler head assembly (rear quarter view)
[[NOTE each component will be labeled in final figure –mnl]]

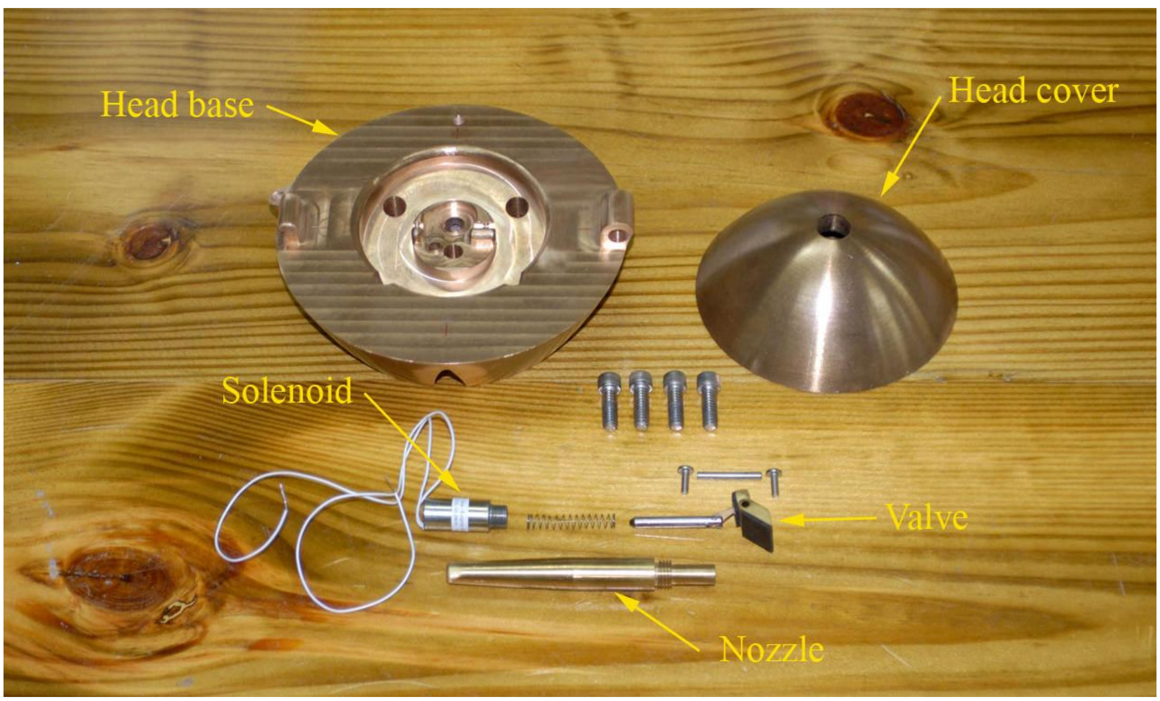

Figure 4 — Photograph of disassembled US P-6 sampler head, intake, and control valve

the holes in the bottom of the sampler into the compression chamber compressing the air in the chamber. The increased pressure is transmitted through passageway that connects the pressure chamber in the body through the head to the sample container. The pressure in the sample container is balanced with the ambient pressure near the nozzle. When power is applied, the solenoid rotates the valve to the sampling position. The connection through the head to the compression chamber closes and the passage through the nozzle to the sample container opens. The sample enters the sample container without surging. Air displaced by the sample is expelled through a passage from the sample container to the exhaust vent on the side of the head. Sampling terminates when power is removed and the valve returns to the equalizing position.

The sampler must be suspended on a sheathed single-conductor cable. The cable should have a diameter of 1/8 inch (3.2 mm) to minimize drag. The resistance in the cable should not exceed 100 ohms per 1000 feet (305 m). The cable sheath (exterior load-bearing strands) is connected to a special clamp which is pinned to the top end of the hangar bar. The insulated conductor, located in the center of the cable, is connected to one of the solenoid (electrical) lead routed through the upper vent of the sampler head. The remaining solenoid lead is connected to the sheath of the coaxial suspension cable or directly to the clamp. This provides proper grounding of the electrical circuit and completes connections at the sampler end of the cable. When power is applied at the reel, current will flow from the supply, through the center conductor of the cable and through the solenoid. Current will return through the grounding jumper wire, cable clamp, the cable sheath, and the reel frame. USGS B and E reels are best suited for deploying the sampler.

The power supply must be direct current (DC) of at least 24 volts which, at remote sites, is most conveniently obtained from dry or wet cell batteries. The supply voltage is set by the required current and the total resistance in the cable and solenoid. For a 100-foot cable with a resistance of 100 ohms/1000 feet, the cable resistance should be 10 ohms. The US P-6 uses a Ledex® Tubular Linear Solenoid (Part No. 195202-231) which has a resistance of 9.56 ohms and requires 24 volts to actuate the valve. With this cable, the voltage must be no less than 24 volts. To provide a margin of reliability and compensate for battery discharge, 36-volt DC may be used.

Hydraulic Efficiency Tests

FISP suspended-sediment sampling equipment is designed and calibrated to sample isokinetically. An isokinetic sampler collects a water-sediment sample from the stream such that the water velocity through the intake nozzle is equal to the ambient incident stream velocity at the nozzle entrance. The water-sediment sample collected is proportional to the instantaneous stream velocity at the locus of the intake nozzle and, therefore, is representative of the suspended-sediment load at that point and time. The hydraulic efficiency of a sampler is the ratio of the velocity of the water through the nozzle to the ambient stream velocity. A ratio of 1.0 is perfectly isokinetic. FISP suspended samplers are calibrated to a hydraulic efficiency of 0.9-1.1. Research presented in FISP Reports 5 and 6 show that minimal error in suspended-sediment concentration is incurred when samples are collected at a hydraulic efficiency of 0.9-1.1. Hydraulic efficiency testing of the US P-6 was conducted at the USGS HIF hydraulic laboratory. The hydraulic laboratory has a tilting flume capable of water flow velocities up to approximately 3.5 ft/sec (1.07 m/sec). The laboratory also has a tow tank with a carriage capable of velocities up to 20 ft/sec (6.1 m/sec). Water temperature in the flume and tow tank ranged from 68 to 81 degrees Fahrenheit during testing. Hydraulic efficiency testing of the US P-6 was conducted in the flume and tow tank. Figure 5 shows the sampler being evaluated in the flume.

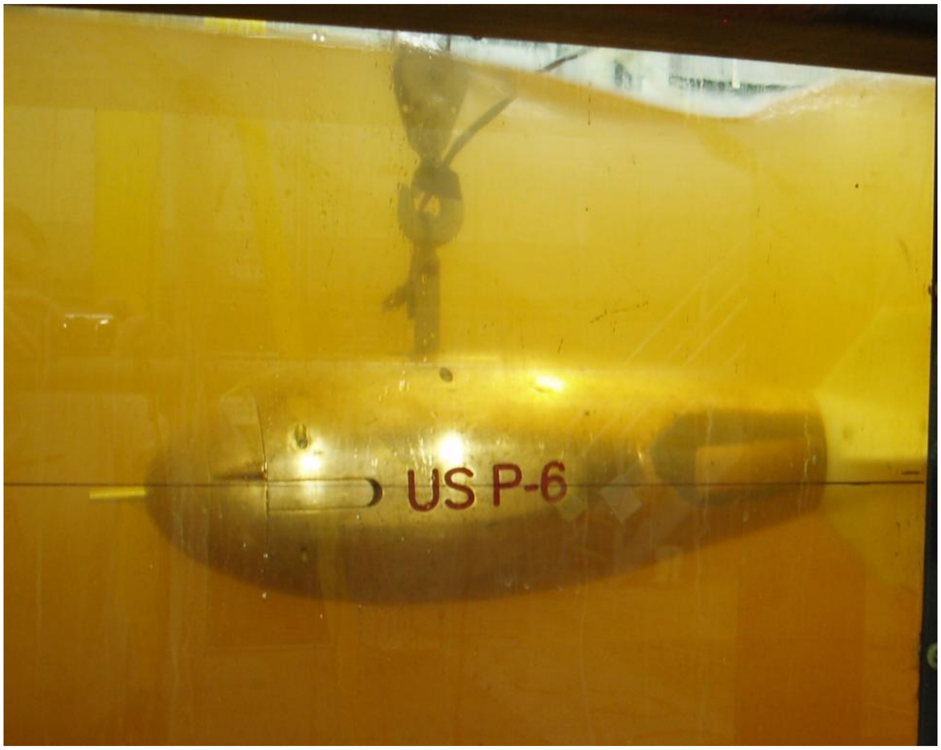

Figure 5—Photograph of tow-tank testing of P-6 sampler

Calibration previous of US series point-integrating samplers requires taper reaming the back of the passage way that conveys the water-sediment mixture from the nozzle to the sample container, which creates a sampler-specific calibration as discussed previously. Calibration of some of the US series depth-integrating samplers requires nozzles designed with a tapering exit so that specific nozzle types are required for specific classes of samplers. An initial attempt was made to calibrate the US P-6 sampler by counter boring the rear of the nozzle instead of tapering it. The rear of the nozzle has to be slightly counter bored to insure a water tight seal between the valve and rear of the nozzle. The idea was to counter bore the rear of the nozzle deeper than necessary for a good seal and determine if the additional counter bore depth would result in a nozzle that produced an acceptable hydraulic efficiency. However, the counter bored nozzle failed to produce an acceptable hydraulic efficiency in velocities greater than approximately 5.5 ft/sec (1.68 m/sec).

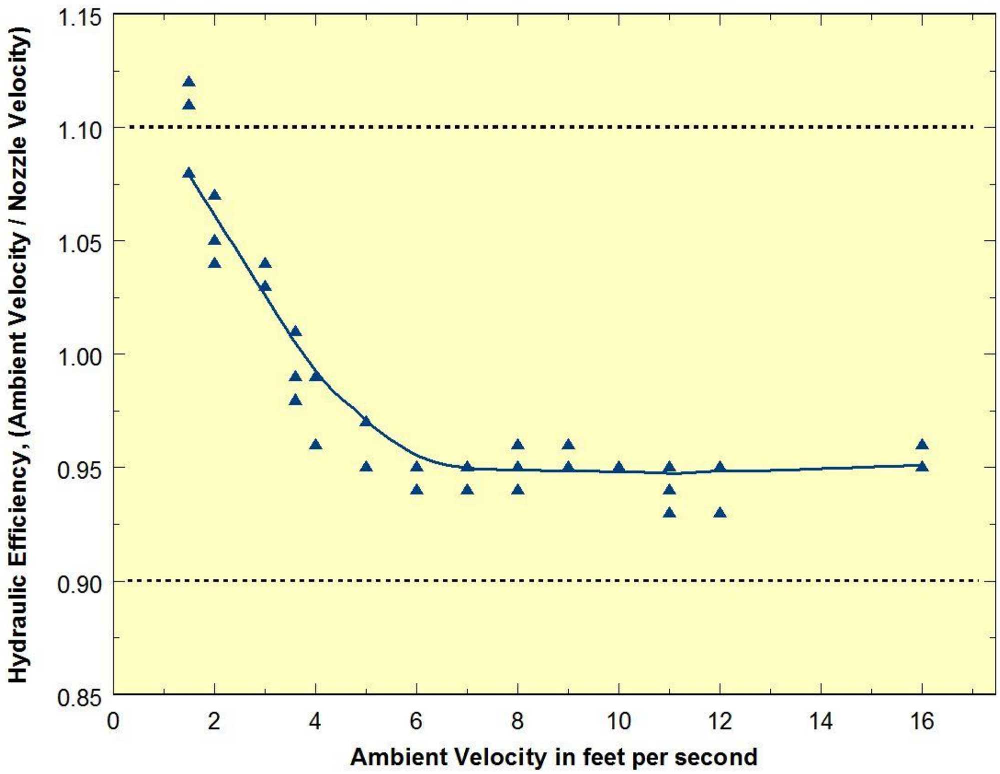

Figure 6—Hydraulic efficiency test results for the US P-6 sampler

The selected nozzle design for the US P-6 has a tapering exit, similar to many depth integrating samplers. The nozzle produced a hydraulic efficiency of near 1.0 at 3.5 ft/sec (1.07 m/sec) flume flow velocity. In tow tank tests the hydraulic efficiency varied from approximate 1.07 at 1.5 ft/sec (0.46 m/sec) to 0.95 at 16 ft/sec (4.88 m/sec), well within the acceptable range of 0.9 to 1.1 (figure 6). It would probably not be practical for safety reasons to use the sampler at a velocity of 16 ft/sec (4.88 m/sec). However it was tested at that velocity to demonstrate that the hydraulic efficiency was stable at velocities higher than those recommended for use. This design allows US P-6 samplers and nozzles to be interchangeably so that the calibration of the US P-6 is not sampler specific. This design also enables straightforward replacement of sampler parts, if required, without recalibration.

Field Tests

The Field Data Collection and Analysis Branch of the US Army Corps of Engineers' Coastal and Hydraulics Laboratory has been using the US P-6 prototype isokinetic sampler since May, 2009. The sampler has been used to collect point-integrated suspended-sediment samples along multiple sections of the lower Mississippi River and the lower Red River in the regions surrounding the West Bay and Old River diversions. Over 1,500 samples have been collected in flow velocities ranging from 2 to 7 ft/sec (0.61 to 2.13 m/sec) and at depths from 1 to 80 ft (0.30 to 24.4 m). The sampler has performed well and allowed for the rapid collection (sampling frequency on average of 2-3 minutes) of suspended-sediment samples.

Operating Limitations

The US P-6 sampler will collect acceptable flow weighted samples in streams with flow velocities above 1.5 ft/sec (0.46 m/sec). The maximum stream velocity at which the sampler is used should be determined by the operator based on field conditions. Depth of sampler deployment and flow velocity affect drag on the sampler and suspension cable and results in downstream drift of the sampler. The upper useful stream velocity limit will likely not exceed 10 ft/sec (3 m/sec), which is comparable to the US P-61-A1. The US P-6 sampler can collect flow-weighted samples to a maximum depth of approximately 160 ft (49 m) at sea level with a 1-liter sample container.

Hydraulic efficiency testing of the US P-6 was conducted in near room temperature water. FISP Report 6 (http://fisp.wes.army.mil/Report%206.pdf) pages 78-80 notes that hydraulic efficiency can decrease in near freezing water temperatures. If the sampler is deployed in cold water, the user should consult Report 6 to determine a possible decrease in hydraulic efficiency that could bias a suspended-sediment sample, especially if sands are in suspension.

Although a 1-liter sample container is used, the maximum sample volume is approximately 475 mL, the same as the US P-61-A1. At volumes above 475 mL the water level in the container approaches the level of the back of the nozzle. If water impinges on the back of the nozzle, isokinetic sampling is affected. This limitation is characteristic of all FISP suspended-sediment samplers.

The US P-6 can sample to within approximately 3.5 inches (9 cm) of the streambed. This unsampled zone is the distance between the nozzle and the bottom of the sampler. Care should be used if the sampler is allowed to touch the bottom, risking digging the lee side of a dune which contains relatively unconsolidated material. Excessive sands and silts could possibly bias the sample.

These operating limitations are not intended to provide the information and training needed to correctly use the US P-6 for obtaining suspended sediment and water quality samples. Specific training courses and their supporting training manuals are required for successful data collection using any sampling equipment. The USGS training course, Sediment-data collection techniques (typically offered annually) and supporting reports (Davis, 2005; Nolan, and others, 2005) are recommended for users of the US P-6.

Conclusions

The US P-6 point-integrating sampler has an electrically operated valve that is simple, easy to fabricate, is field replaceable, and does not requiring re-calibration after replacement. The sampler has a practical operating range from 1.5 to 10 ft/sec (0.46 to 3 m/sec) stream velocity. The sampler has undergone rigorous laboratory and field testing and performed exceptionally well.

References

Davis, B.E., 2005, A Guide to the Proper Selection and Use of Federally Approved Sediment and Water-Quality Samplers: Vicksburg, MS, U.S. Geological Survey, Open File Report 2005-1087, 20 p.

Nolan, K. M., Gray, J. R. and Glysson, G. D. (2005), Introduction to suspended-sediment sampling, U.S.G.S. Scientific Investigations Report 2005-5077