Development and Testing of a Pressure-Difference Bedload Sampler Attachment to Mitigate Scooping

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PRESENTED TO

Federal Interagency Sedimentation Project, Technical Committee
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EXECUTIVE SUMMARY

The potential for scooping of bed material and the resulting bias in bedload transport measurements using pressure-different bedload samplers has been a concern since these samplers were initially developed and used in the early 20th century. There is no known solution to prevent scooping; currently, equipment operators rely on both experience applying standard sampling methods and judgment of whether a measurement appears biased by scooping. In response to the FISP's fiscal year 2019 call for proposals to, in part, provide improvements to physical samplers, Tetra Tech submitted a proposal to develop and test an attachment to the FISP-approved BL-84 pressure-difference bedload sampler. Tetra Tech partnered with Colorado State University's Hydraulics Laboratory to design, fabricate, and test this attachment under the FISP's funding and direction.

From various alternatives identified and screened, a top-mounted flap was selected as the attachment best suited to prevent scooping. The flap, hinged on the top and mounted to the top of the BL-84 nozzle, should be operated to only allow particles to enter the sampler during the timed sampling. A prototype was fabricated for hydraulic testing in a flume. The approximate cost for the materials and fabrication of the prototype was about $180. The flume testing of the prototype attached to a BLH-84 sampler focused on measuring point velocities within and outside of the sampler nozzle width and using these velocities to calculate hydraulic efficiencies. The BL-84 sampler was designed to have a hydraulic efficiency near 1. With the attachment's flap closed, the hydraulic efficiency decreased to about 0.6 to 0.7; however, no sampling of bedload is intended with the flap closed. With the flap open, the hydraulic efficiency is about 0.9 to 0.95 for target velocities (measured 6-inches above the bottom of the flume) of 1.5-, 2.5-, and 3.5-feet per second. Hydraulic efficiency is not a static value, and generally increases with increasing flow velocity.

Informal field testing confirmed the prototype can successfully prevent scooping sediment into the sampler. However, when the flap is closed and flow is diverted around the nozzle, scour can occur on an easily-deformable bed. This scour could trap bedload when the flap is opened, so operation of the sampler with the flap in rivers and streams with sand-dominated bed material may need to be adjusted.

Based on the results of this study, further testing is recommended. Hydraulic testing should extend over a wider range of flow velocities up to the upper limit of 10-fps for a BL-84 sampler. Testing with active bedload transport should follow to quantify reductions in scooping bias.

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ACRONYMS/ABBREVIATIONS

Acronyms/Abbreviations	Definition
ADV	Acoustic Doppler Velocimeter
A_O	Open area of a mesh (percent)
ARS	Agricultural Research Services (of the USDA)
BL-84	U.S. cable-suspended Bedload Sampler, development started in 1984
BLH-84	U.S. hand-held Bedload Sampler, development started in 1984
BLM	U.S. Bureau of Land Management
CSU	Colorado State University
EPA	United States Environmental Protection Agency
FISP	Federal Interagency Sedimentation Project
FPS	Feet per second
FY	Fiscal Year
HE	Hydraulic Efficiency
$HE_{in,2}$	Hydraulic Efficiency calculated from point velocities within the width of the sampler nozzle entrance 2-in. above the bottom of the flume
HIF	Hydrological Instrumentation Facility (of the USGS)
PVC	Polyvinyl Chloride
TC	Technical Committee (of the FISP)
USACE	United States Army Corps of Engineers
USDA	United States Department of Agriculture
USFS	United States Forest Service
USGS	United States Geological Survey

1.0 INTRODUCTION

This report documents the development and testing of a pressure-difference bedload sampler attachment to mitigate scooping impacts during measurements of bedload transport.

This section presents: the problem scooping causes on measurements of bedload transport (Section 1.1); an overview of the Federal Interagency Sedimentation Project (FISP) as an entity that is interested in solving this problem (Section 1.2); the FISP's call for proposal to solve such problems (Section 1.3); the FISP's selection of Tetra Tech's submitted proposal (Section 1.4); and, the Tetra Tech team that completed the study of this problem (Section 1.5).

1.1 PROBLEM STATEMENT

The Fort Collins office of Tetra Tech's River and Coastal Engineering Group (Tetra Tech) is staffed with hydraulic engineers and fluvial geomorphologists with expertise measuring sediment transport in rivers and streams. These staff understand the challenges of collecting accurate bedload transport measurements using pressure-difference samplers. The primary challenge when measuring bedload transport using a cable-suspended sampler is uncertainty in knowing whether scooping of the bed surface has biased a bedload measurement. This uncertainty is compounded when working from a raft (as opposed to a stationary platform like a bridge), or in flows too deep or too turbid to visually confirm (either directly or from underwater photos or videos) if the sampler scooped the bed.

Because of hydraulic forces exerted by flow on pressure-difference bedload samplers while lowered to, and raised from, the bed, the sampler is susceptible to scooping bed material (***Figure 1-1***). Scooping can include particles destabilized and transported into the sampler as it contacts the bed or particles collected when the sampler moves upstream along the bed during the initial phase of raising the sampler. Scooping can introduce substantial error to the collected measurement, leading to inaccurate quantification of bedload transport and confounding interpretation of the largest-size sediment in transport. Current practice relies on the equipment operators to evaluate scooping-induced bias, which is challenging under ideal conditions with experienced operators, and nearly-hopeless otherwise. Measured bedload transport is frequently compared to modeled transport, so substantial error in measurements can (1) bias the calibration and application of a model, (2) compromise the reliability of interpretations of modeled results, and (3) prevent appropriate consideration of risk in decisions based on modeled results.

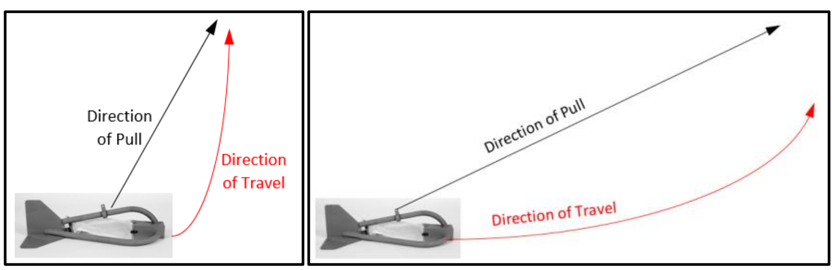

Figure 1-1. Schematic of the effects of hydraulic drag on a bedload sampler as it traverses the water column (upper water column, left; mid water column, right), and the potential for scooping

Tetra Tech was not the first to recognize the problems caused by scooping during measurements of bedload transport with pressure-difference samplers. One of the first pressure-difference bedload samplers was used in 1925 on the Kuban River in Russia (Federal Inter-Agency River Basin Committee 1940). In the 1930s, researchers from the Netherlands designed a pressure-difference bedload sampler with a rudder that was first brought into contact with the bed, then the nozzle was lowered to reduce the possibility of digging or disturbing the material on the bed (Federal Inter-Agency River Basin Committee 1940). Thus, scooping has been a concern since the initial development and use of pressure-difference bedload samplers.

The potential for scooping to cause bias in measurements of bedload transport using bedload samplers was noted in a 1948 study report from the Federal Inter-Agency River Basin Committee. This potential was more-explicitly described in a 1963 update of the study report (Inter-Agency Committee on Water Resources 1963).

Hubbell (1964) noted when deploying a pressure-difference sampler from a cable system that decreasing hydraulic resistance with flow depth can cause the sampler to swing forward and scoop up bed material. Noticing the resulting oversampling, Hubbell (1964) defined sampling efficiency of a bedload sampler as the weight of bedload collected during any single sampling time to the weight of bedload that would have passed through the sampler width in the same time had the sampler not been there.

Helley and Smith (1971), when developing and calibrating their eponymous pressure-difference bedload sampler, defined two metrics used to evaluate bedload sampler performance:

1. *Hydraulic efficiency*: the ratio of the velocity in the orifice of the sampler to the ambient velocity.
2. *Sediment-trap efficiency*: the ratio of the quantity of sediment trapped in a bedload sampler to the quantify of the sediment the stream is actually transporting as bedload.

Regarding hydraulic efficiency of the Helley-Smith sampler, Helley and Smith (1971) concluded:

1. The velocities in the sampler nozzle will be consistently higher than the ambient velocity, and that the percentage departure will increase as the ambient velocity increases.
2. That, because velocities do increase in the approach area of the nozzle, the device should be expected to have a sediment-trap efficiency greater than one.

Regarding the sediment-trap efficiency of the Helley-Smith sampler, Helley and Smith (1971) observed:

1. High variability in flume data. Harvey Jobson, Research Hydraulic Engineer at Colorado State University where the flume testing was carried out, speculated that:
   The sampler was quite heavy, and the bed for this sand was a little soft. Thus, the sampler tended to sink into the sand. The current pulled the sampler downstream as it was lowered to the bed. When the sampler was raised off the bed, it tended to slide upstream a small distance before it was raised from the bed. This sliding upstream would tend to scoop up additional sand. If the bed material was composed of coarse gravel, the sinking of the sampler into the bed would not be much of a problem and the tendency to scoop up additional material when the sampler was lifted would be lessened.
2. If the flume data are accepted as providing some significance as to the sampler performance, the flume data suggests consistently high sediment-trap efficiency. The sediment-trap efficiency averaged 1.5. The error is likely to increase with ambient velocity.
3. Hydraulic disturbances around the sampler nozzle may produce scour that picks up material not in ambient transport.

The USGS (Childers 1992) compared the field performance of pressure-difference bedload samplers and noted that “oversampling” caused by “mining” (scooping or scour) cannot be accurately accounted for in the calibration of sediment-trap efficiency; however, the USGS presented proper sampling techniques and procedures for the operator to avoid errors caused by scooping.

In the instructions for sampling with the BL-84 bedload sampler, the FISP (1999) notes that if the sampler is balanced with the nozzle lower than the tail, it may scoop the bed material as it contacts the streambed.

The oversampling effect of scooping can be mitigated statistically by applying adjustment functions, but not to complete satisfaction (Bunte and Abt 2009; Bunte et al. 2010).

In fiscal year (FY) 2016, the FISP funded testing of the influence of sampler bag mesh size and type on the hydraulic efficiency of pressure-difference bedload samplers (Bunte et al. 2017), results of which identified, in part, that scooping a few gravel particles into a sampler may well introduce more error than bag mesh size and type.

In early 2017, Tetra Tech contacted the United States Geological Survey's (USGS's) Hydrological Instrumentation Facility (HIF) to ask whether equipment was available to prevent a pressure-difference sampler from scooping sediment that biases bedload measurements; HIF staff reported that no such equipment was available. By the end of 2017, Tetra Tech completed a patentability search for a bedload sampler attachment; results from the search indicated that such an attachment may be novel and eligible for a patent. However, financial considerations prevented Tetra Tech from internally pursuing research, development, and testing of such an attachment. Thus, there is no known solution, either available or in development, to mitigate the long-recognized effects of scooping on measurements of bedload transport collected using pressure-difference samplers in cable-suspended deployment.

The lack of a solution is problematic because pressure-difference bedload samplers are so widely-used for measuring bedload transport in streams and rivers. Bedload measurements using pressure-difference samplers have historically been, and continue to be, collected as a component of operational monitoring programs. Consequently, eliminating bias introduced by scooping would provide near-universal benefit to these monitoring programs, as well as to any other bedload measurements collected using pressure-difference samplers. Tetra Tech's recent informal conversations with engineers and hydrologists at the U.S. Bureau of Reclamation's Technical Service Center, the U.S Army Corps of Engineers Hydrologic Engineering Center, and the U.S. Geological Survey's New Mexico Water Science Center confirm support for developing and testing an attachment that would improve the quality of bedload measurements collected with pressure-difference samplers.

1.2 OVERVIEW OF THE FISP

The FISP is an independent, interagency project with the following member agencies:

- USGS
- U.S. Bureau of Reclamation (Reclamation)
- U.S. Department of Agriculture – Agricultural Research Service (ARS)
- U.S. Army Corps of Engineers (USACE)
- U.S Environmental Protection Agency (EPA)
- U.S. Forest Service (USFS)
- U.S. Bureau of Land Management (BLM)

The FISP is overseen and supported by a Technical Committee (TC), which currently includes representatives from the USGS, Reclamation, the ARS, and the USACE. The FISP works with the Subcommittee on Sedimentation to unify the research and development activities of Federal agencies involved in fluvial-sediment monitoring and investigations.

The continuing mission of the FISP is to provide leadership in the development of standardized, calibrated equipment and methods to allow consistent and accurate quantification of sediment characteristics and transport in surface waters. FISP activities focus on the measurement, computation, and analysis of suspended sediment, bedload, bed material, bed topography, sorbed constituents, and other sedimentary characteristics using physical samplers and surrogate technologies.

1.3 FISP FY2019 CALL FOR PROPOSALS

The FISP interacts with other organizations including federal agencies, academia, and private industry to promote research and development and improved quality and cost effectiveness of sediment-based data. To the extent that funds are available, the FISP solicits proposals and seeks to leverage funds and resources to cooperatively achieve these goals.

In general, FISP-supported research studies are formulated to (1) identify, develop, or test emerging sediment surrogate technologies or methodologies, or (2) provide improvements to physical samplers. The FISP encourages proposals relevant to operational monitoring programs. FISP projects are typically funded for one year for less than $30,000. The FISP TC evaluates proposals.

The FISP issued a FY2019 call for proposals that closed October 15, 2018. In response to this call, Tetra Tech submitted a proposal to develop and test a pressure-difference bedload sampler attachment to mitigate scooping.

1.4 SELECTED PROPOSAL

Based on Tetra Tech's proposal, the FISP TC awarded funding for this project. The statement of work for the project is included in Appendix A. Tetra Tech partnered with Colorado State University's (CSU's) Hydraulics Laboratory to provide unique qualifications for the project. Tetra Tech's qualifications focus on experience measuring bedload using pressure-difference samplers deployed from fixed and raft-based platforms in channels with sand- or gravel-dominated bed surfaces across a range of hydrologic and hydraulic conditions. CSU's qualifications include: academic research of measuring bedload transport, including the FY 2016 pressure-difference bedload sampler research carried out for the FISP (Bunte et al. 2017); the experience of the investigators such as Drs. Christopher Thornton and Kristin Bunte; and, the testing facilities at CSU's Hydraulics Laboratory supervised by Taylor Hogan.

1.5 STUDY TEAM

The principal investigator for the study was David Pizzi (Tetra Tech). CSU's lead investigator was Dr. Kristin Bunte, with support from Hydraulics Laboratory Director Dr. Chris Thornton and research associate and Hydraulics Lab Manager Taylor Hogan.

The members of the FISP TC overseeing the study included: acting FISP chief Dr. Tim Straub (USGS); Dr. Jim Selegean (USACE); Molly Wood (USGS); Dr. Roger Kuhnle (ARS); and, Robert Hilldale (Reclamation).

2.0 DEVELOPMENT OF AN ATTACHMENT

The first step in the project was to develop a prototype of an attachment to a pressure-difference bedload sampler that would prevent scooping of bed material. This step consisted of three components: (1) identification of alternatives (Section 2.1); (2) screening of alternatives (Section 2.2); and, (3) selection of the preferred alternative (Section 2.3).

When Tetra Tech drafted the proposal in the fall of 2018, we envisioned the prototype attachment as being affixed to the nozzle of a pressure-difference bedload sampler such as the FISP-approved BL-84 (***Figure 2-1***). We envisioned the prototype would have an operable door that prevents sediment from entering the sampler except when the door is open.

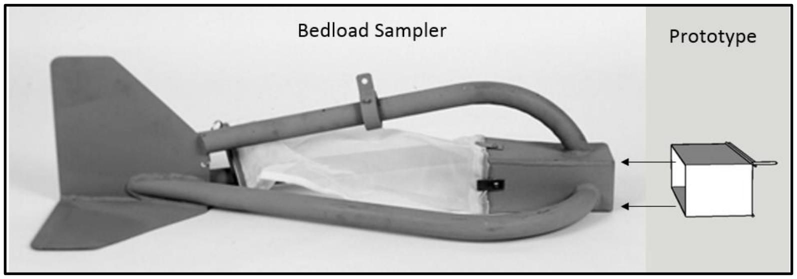

Figure 2-1. Prototype of an attachment for a BL-84 sampler

The envisioned prototype precludes the need for operators to observe the sampler contacting or lifting from the bed. The attachment should allow the operator to open a door on the attachment such that water and bedload can enter the sampler nozzle only when the operator is ready; the operator then closes the door to exclude water and sediment from entering the sampler nozzle before raising it from the bed. The potential drawback to such an attachment is that it could induce differences in the hydraulic efficiency and sediment-trap efficiency of the sampler, differences which could impair reliable comparisons to historical samples measured without the attachment. The ideal situation is to eliminate scooping-induced bias from future measurements while maintaining consistency in sampler performance to facilitate comparisons of future and historical measurements.

2.1 IDENTIFICATION OF ALTERNATIVES

While the proposal was based on a concept for the attachment of an operable door, the concept required refinement. Tetra Tech and CSU brainstormed ideas and identified four alternatives for further consideration: (1) a pull-off cap (Section 2.1.1); (2) bi-fold doors (Section 2.1.2); (3) a top-mounted flap (Section 2.1.3); and, (4) an overhead roller door (Section 2.1.4). We constructed prototypes of the first three alternatives using cardboard (***Figure 2-2*** through ***Figure 2-4***); the fourth was drafted in CAD (***Figure 2-5***).

2.1.1 Pull-off Cap

The pull-off cap would have a rigid, flat-plate frame with each side about 5/8-inch wide and an interior mesh (250-micron) supported by a coarse wire mesh (e.g., 5/16-inch or No. 4). Ideally the interior mesh could be easily changed to match the size of the sampler bag mesh to maximize flow-through area while still ensuring disturbed bed material that could be collected in the sampler bag does not enter the sampler. Relative to a solid cap (i.e., one without mesh in cutouts), the mesh would reduce obstructed flow area while still preventing bedload from entering the sampler. The cap would be secured in place by friction from a rubberized backing and the pressure of approaching flow. The cap would be removed using a cable, and the approaching flow would push the cap downstream of the nozzle where the cap would be secured with a tether. This attachment could not be re-positioned before raising the sampler.

Figure 2-2. Cardboard prototype of pull-off cap attachment (on, left; removed, right)

2.1.2 Bi-fold Doors

The bi-fold doors attachment (***Figure 2-3***) would extend the nozzle length by about 2 inches to house rigid door frames about 1.2-inches wide and about 2.75-inches tall. When closed the doors would make a 20-degree angle from the plane of the nozzle entrance. The rigid door frames would contain 250-micron mesh (or mesh sized to match the sampler bag mesh) supported by coarse wire mesh (e.g., 5/16-inch or No. 4). When open, the doors would recess into the open sides of the attachment to maintain a 3-inch by 3-inch inside opening. The slide-on attachment would be affixed to the nozzle using set screws. Two key challenges of this design concept are: (1) when the doors are closed only sediment up to about 1.4 inches (36 mm), or half the nozzle width, could be ejected through the lateral frame openings; and, (2) the operating mechanism is complex and could require an actuating mechanism to either open or close the doors.

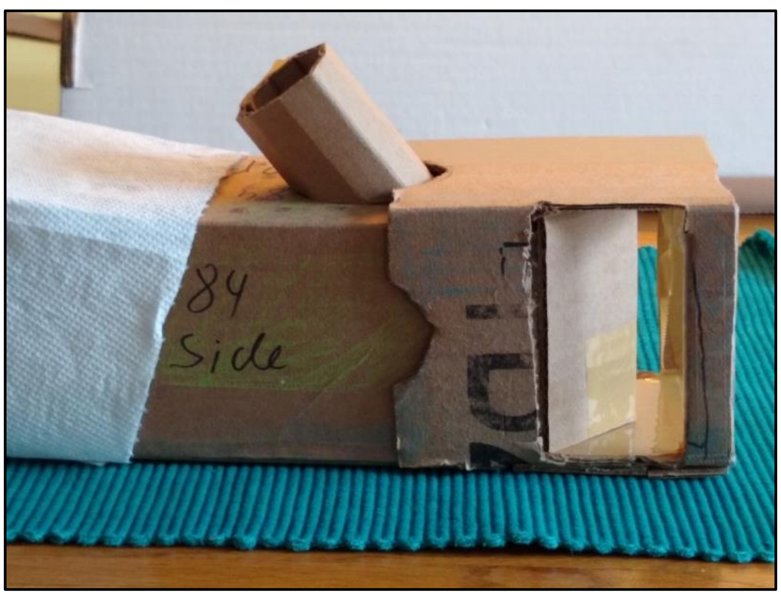

Figure 2-3. Cardboard prototype of bi-fold doors attachment

2.1.3 Top-Mounted Flap

The top-mounted flap would be like the pull-off cap except that the flap would be secured to a piano hinge mounted to the top of the nozzle (***Figure 2-4***). The flap would lay back flat on the top of a handheld BLH-84 sampler, but because of the top-tube that connects the nozzle to the tail vanes on a cable-deployed BL-84 sampler, the flap would be angled up and resting against the top tube when attached to a BL-84. The piano hinge would have a torsion spring that holds the flap closed so that the flap would need to be pulled open with a cable.

Figure 2-4. Cardboard prototype of top-mounted flap

2.1.4 Overhead Roller Door

Unlike the first three alternatives, the overhead roller door (***Figure 2-5***) would not have a rigid door frame. Instead the wire mesh door (250-micron mesh or sized to match the sampler bag mesh) would be affixed to horizontal supports that could be rolled up as the door is raised. This attachment would be affixed using set screws to the nozzle. The flexible door would spool around the top pulley (red) when open, and cables would attach to the belt around the pulleys to raise and then lower the door.

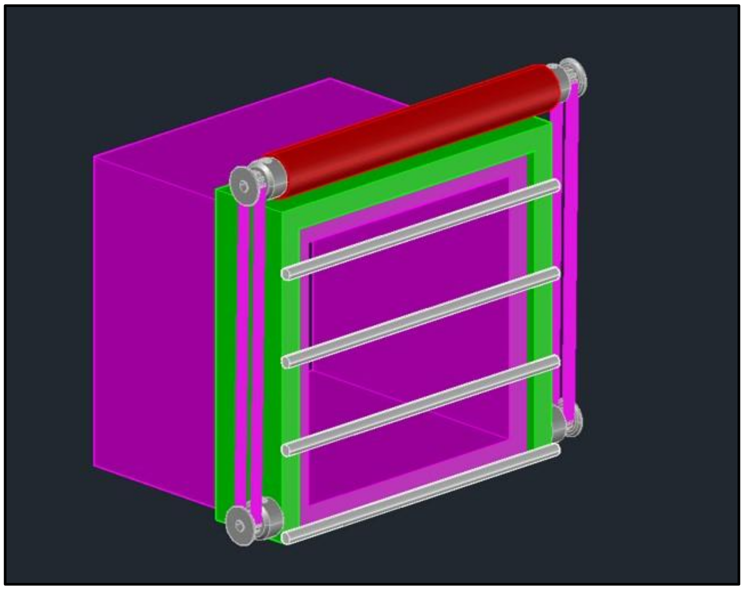

Figure 2-5. CAD prototype of the overhead roller door attachment

2.2 SCREENING OF ALTERNATIVES

After identifying the alternatives, we established objectives for the attachment to formulate a basis for screening the alternatives. The goal of the screening was to have a rational basis for selecting the preferred alternative. Objectives were that the attachment must:

1. Effectively mitigate scooping
2. Be simple to operate
3. Be easy to fabricate
4. Be easy to maintain
5. Be compatible with existing samplers
6. Be compatible with historical bedload measurement
7. Have a reliable opening/closing mechanism
8. Minimize hydraulic impacts
9. Minimize the potential for interference when placing on a gravel-dominated bed
10. Minimize the potential for impaired operability when used on a gravel-dominated bed
11. Minimize the potential for bedload transport to impair operability

2.3 SELECTION OF PREFERRED ALTERNATIVE

We prepared a preliminary ranking of the four alternative sampler attachments using the objectives established in the previous section. We then presented the preliminary ranking to the FISP TC on April 30, 2020 to solicit feedback.

For the preliminary ranking, we identified as a fatal flaw the inability to reposition the pull-off cap before raising the sampler from the bed. Thus, this attachment was eliminated from further consideration. For the remaining three alternatives, we scored on a relative basis the expected performance for each objective with a 1 being best and a

3 worst. The alternative with the lowest sum of the rankings was preliminarily identified as the preferred alternative (***Table 2-1***).

Table 2-1. Preliminary ranking of alternatives

Objective	Alt. 2 – Bi-fold Doors	Alt. 3 – Top-mounted Flap	Alt. 4 – Overhead Roller Door
1 Effectiveness	3	2	1
2 Simplicity	2	1	3
3 Ease of fabrication	2	1	3
4 Ease of maintenance	2	1	3
5 Compatibility w/ existing samplers[1]	1	2	1
6 Compatibility w/ historical measurements	3	2	1
7 Reliable operable mechanism	2	1	3
8 Hydraulic impacts	3	2	1
9 Interference placing on a gravel bed	3	2	1
10 Operability impaired by gravel bed	3	2	1
11 Operability impaired by bedload	3	2	1
Ranking (sum)	**27**	**18**	**19**

Notes: Alt. 1 pull-off cap eliminated by identification as a fatal flaw the inability to reposition the cap before raising the sampler from the bed

[1] Alt. 2 and Alt. 4 are affixed with set screws, so equally compatible; Alt 3. requires tap holes to attach the hinge

The preliminary rankings indicate that the bi-fold doors attachment is notably worse than the top-mounted flap or the overhead roller doors. In thinking critically about the relative rankings, we decided that the third-place rankings for simplicity, ease of fabrication, ease of maintenance, and reliable operable mechanism were substantial concerns for the overhead roller door that justified the preliminary selection of the top-mounted flap.

On April 30, 2020 we presented the concept alternatives, objectives, and preliminary rankings to the FISP TC. The FISP TC agreed with our preliminary selection of the top-mounted flap as the preferred option to take forward to design and fabrication and testing.

3.0 DESIGN AND FABRICATION

Alternative 3, the top-mounted flap was designed (Section 3.1) to allow for fabrication and testing of a prototype (Section 3.2).

3.1 DESIGN OF THE TOP-MOUNTED FLAP AND MATERIALS SELECTION

The design of the top-mounted flap as the preferred attachment started with consideration of materials and properties. We selected aluminum plate for the frame of the flap because aluminum is strong, light, readily available, durable, and low cost. To reduce drag a solid flap would cause, we chose to machine cutouts in the flap; aluminum plate is well-suited for machining. To prevent scooped sediment from entering the sampler through the cutouts, we selected netting material with mesh matching the sampler bag. A two-layer frame is ideal because it allows the mesh to be sandwiched between the two layers, which are screwed together. This design facilitates changing the mesh to match the sampler bag mesh, and it will facilitate maintenance when the mesh needs to be replaced. Using aluminum for the frame and mesh to reduce drag enabled a torsion spring on a piano hinge to close the flap through the approaching flow after the operator released the cable used to open the door. The piano hinge allows the flap to be secured to the top of the nozzle, both on new samplers with pre-drilled holes or on existing samplers after holes are drilled.

The flap in the closed position partially-obstructs flow from entering the nozzle of the sampler, so two meshes with notably different percent open areas (A_O) were selected. The A_O of a mesh is described in Bunte et al. (2017), and it is an industry parameter computed from the ratio of mesh width (w) to thread width (d) using **Equation 3-1**.

$$A_O = \frac{100 * w^2}{(w+d)^2}$$ **Equation 3-1**

Both meshes are precision polyester netting material manufactured by the Sefar Company. One mesh consists of the same netting material used for a mesh bag typically affixed to pressure-difference bedload samplers. This mesh has a 250-micron opening and an A_O of 46 (Sefar Code: 07-250/46). The second mesh has a smaller 240-micron opening and a finer thread width, resulting in an A_O of 59 (Sefar code: 07-240/59).

3.2 FABRICATION OF THE TOP-MOUNTED FLAP

The machine shop at CSU's Hydraulics Laboratory fabricated the flap. The AutoCAD design drawings of the designed flap are provided in Appendix B. The base plate (front layer) was machined from ¼-in. aluminum plate. The BL-84 sampler nozzle has a 3-in. by 3-in. (inside) nozzle, with the nozzle formed from welded 1/4-in. stock. Thus, the 3.5-in. by 3.5-in. size of the flap covers to the outside of the nozzle. Six openings were machined into the flap leaving a web to provide rigidity while reducing area obstructed to flow. The flap has a percent open area (A_O) of 78. The backing plate (back layer) mirrors the openings in the front flap, but it is only 1/16-in. thick.

The Sefar Company provided free samples of both meshes for the flap.

We ordered the 3.25-in.-long stainless-steel, self-closing piano hinge from McMaster-Carr (part no. 15205A71). The hinge has two 0.75-in.-wide wings. One wing was screwed to the flap, the other to the top of the sampler nozzle. In the closed position, the flap is flush with the plane of the nozzle inlet; the hinge allows the flap to rotate 270 degrees to lie flat on the top of a BLH-84 nozzle; on the BL-84, the flap can only rotate through about 225 degrees because of the top tube to the tail vane restrict further rotation. The spring on the hinge was tested to fully-close the flap in velocities up to 3.5 feet per second (fps).

Affixing the attachment to the BL-84 was achieved by drilling blind tap holes into the sampler (meaning the holes did not penetrate through the top plate of the nozzle). Allen-head-screws secured the attachment to the sampler.

While development of the operating mechanism wasn't included in the statement of work, we discussed it with the TC. We agreed that we should at least have a reasonable concept for how the flap could operate. Initially we secured a cable to a bolt in a bottom corner of the flap. When tested in the flume (Section 4.0) and field (Section 5.0), we realized that the direction of force was vertical instead of forward, so the flap could not easily be opened. CSU's Hydraulics Lab staff suggested a cam affixed to the top front of the flap to address this issue, allowing the operator to pull a cable up and open the flap. We envision a few inches of measuring tape marking the distance the cable travels during opening so that when the cable is released and the door is closed, the operator can use the length to confirm the flap is fully-closed before raising the sampler. The TC agreed that this level of design was suitably-functional for the testing of the attachment.

The approximate cost of the materials to develop the prototype was $30, and the approximate cost of the labor to fabricate the prototype was $150, for a total approximate cost of $180. The cost for the initial prototype is expected to be notably greater than cost to produce many attachments because of economies of scale.

The fabricated prototype was delivered with this report. Photographs are the prototype follow (***Figure 3-1*** and ***Figure 3-2***).

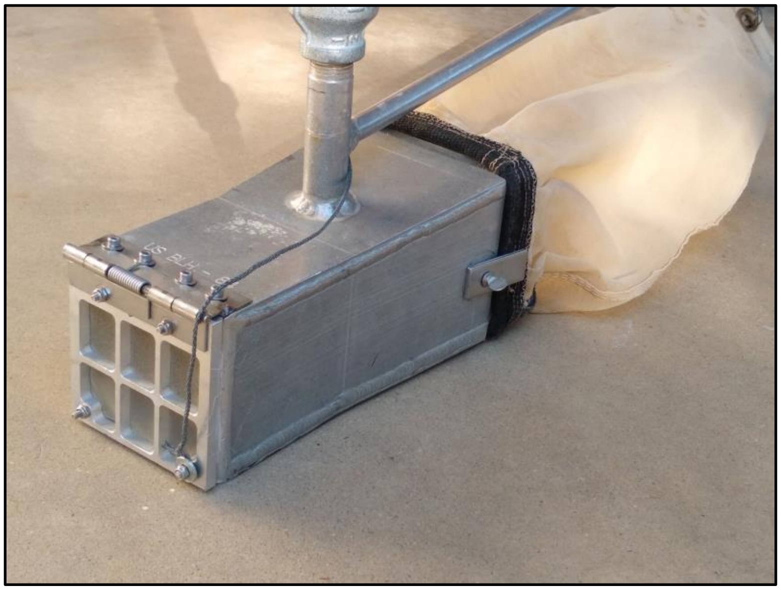

Figure 3-1. Fabricated prototype, flap closed

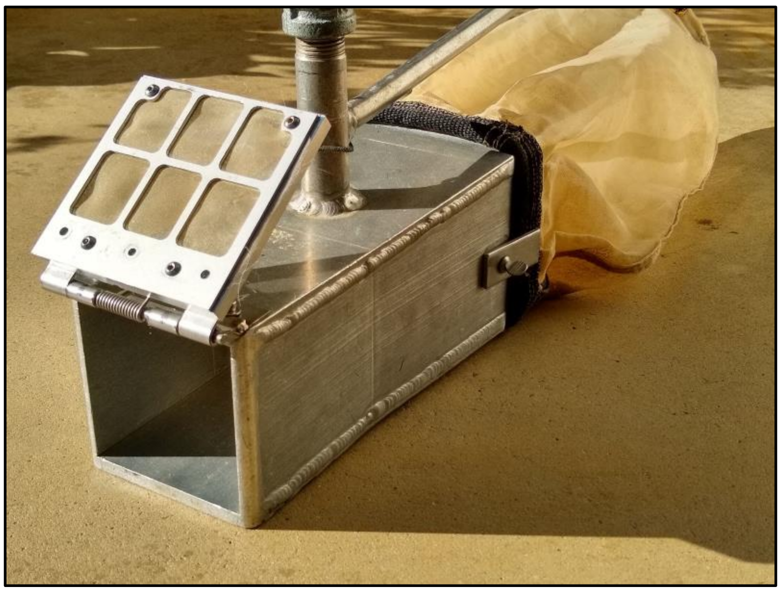

Figure 3-2. Fabricated prototype, flap open

4.0 FLUME TESTING

Key considerations in the testing of the prototype attachment are how it affects the hydraulic efficiency and sediment-trap efficiency. The statement of work (Appendix A) confined the testing to the hydraulic efficiency as measured in a flume, and specifically comparisons of the sampler with the attachment to the sampler without the attachment. We envisioned the testing as building on the FISP's FY 2016 funding of the testing reported in Bunte et al. (2017) (hereafter referred to as "the 2017 Study").

Section 4.1 summarizes key aspects of the 2017 Study. Section 4.2 presents the flume equipment and testing methods. Results are compiled in Section 4.3; analyses of the results follow in Section 4.4.

4.1 KEY ASPECTS OF THE 2017 STUDY

Key aspect of the 2017 Study that are relevant to the flume testing include:

1. Purpose
    a. Flume tests were completed to measure how the hydraulic efficiency (HE) of three pressure-difference bedload samplers, including the BLH-84, was affected by different sampler bag mesh materials and filling of the bag.
2. Methods
    a. The BLH-84 was tested with two sampler bag mesh sizes (250 microns and 500 microns) and each bag was tested empty, filled 30-percent, and filled 50-percent.
    b. The tests were completed in a 40-ft.-long, 6-ft.-wide tilting flume at CSU's Hydraulics Laboratory. Sluice gates at the downstream end of the flume were operated to achieve targeted flow velocities and depths. Measurements were made 22-ft. downstream from the head box.
    c. A false floor was installed in the flume bottom to avoid flow disturbance caused by an abrupt change at the sampler nozzle entrance because of the thickness (0.25-in.) of the bottom of the nozzle.
    d. The flume was lined with epoxy-painted, pressure-treated plywood. Much of the grain was still exposed through the epoxy paint.
    e. Each sampler bag at each of the three fill levels was tested at three target velocities measured 6-in. above the false floor (V_{tar}) of 1.66-, 2.78-, and 3.54-fps. The target velocities produced velocities 2-in. above the false floor of 1.5-, 2.5-, and 3.5-fps, respectively.
    f. A constant flow depth of 2.2 feet was set to ensure that the largest sampler tested was inundated by four times the sampler height.
    g. Flow velocities were measured using an acoustic Doppler velocimeter (ADV) Profiler at various heights on 7 to 9 specified verticals about 1-in. upstream of the nozzle inlet and at the same verticals but at a fixed height 2-in. above the false floor.
    h. At the higher targeted velocities, multiple pumps were required, which caused slight variability in discharge and high turbulence that was not fully-dissipated in the head box by the flow straightener and the diffuser/dampener.
3. Analyses
    a. HEs were calculated by averaging the measured velocities within the width of the nozzle divided by the averaged measured velocities from the same verticals at the same height when no sampler was present.
4. Results
    a. The HE for the BLH-84 was near 1 (100-percent). The choice among coarse sampler bag meshes was less influential on the HE than filling of the bag, especially in slower flow.
    b. HE is not a straightforward measure of sediment-trap efficiency, but a high HE more-likely produces a high sediment-trap efficiency (i.e., oversampling) when: (i) suspended sand is sucked into the sampler; (ii) sand bed material is scoured at the sampler inlet and then sucked into the

sampler; or, (iii) when gravel bed material is dislodged during sampler placement on the bed and then sucked into the sampler (scooping).

4.2 FLUME EQUIPMENT AND TESTING METHODS

The flume testing equipment and methods include the flume equipment (Section 4.2.1), the velocity measurements (Section 4.2.2), and the testing scenario matrix (Section 4.2.3).

4.2.1 Flume Equipment

The 2017 Study tested three pressure difference samplers, the smallest of which was the 3-in. by 3-in. nozzle of the BLH-84. Because only the BLH-84 was tested in the current study, a 25-ft.-long and 3-ft.-wide flume was selected. The flume used a flow straightener in the head box (***Figure 4-1***), but unlike the 2017 Study did not use a diffuser/dampener. The flume was lined with epoxy-coated plywood, producing a smooth surface without the grain of the plywood showing through. The roughness of this surface is comparable to polyvinyl chloride (PVC). The flow in the flume was slightly turbid and did carry a small amount of sand-sized debris.

Figure 4-1. Upstream view of the flow straightener in the 3-ft.-wide flume at CSU's Hydraulics Laboratory

Point gages were used to set the targeted 2.2-ft.-depth of flow (***Figure 4-2***). A Marsh-McBirney flow meter was mounted in the center of the flume a few feet upstream of the position of the sampler to measure the target flow velocity at 6-in. above the bottom of the flume.

Figure 4-2. Point gages (sides) and Marsh-McBirney flow meter (center)

Another key difference in the flume testing methods from the 2017 Study was the current study did not use a false floor. The reason is because the flap was tested in both the open and closed positions and in the closed position it covers the thickness of the bottom of the nozzle and would have interfered with the false floor.

4.2.2 Velocity Measurements

Prior to initiating the testing, the sampler with the prototype attachment was placed in the flume for observations of hydraulics using dye injections. The flap was closed, flow depth was set to about 1-ft., and velocities ranged from 1-fps to 3.6-fps.

Dye generally indicated that the closed flap was an obstruction to flow. Dye dispersed near the bottom of the flume was deflected outside of the sampler; it was not sucked into the sampler as would be expected if the HE exceeded 100-percent. The observations indicated that horizontal variability in velocity across the nozzle should be measured during testing. The 2017 Study showed little difference in velocity measured 1-in. and 2-in. above the false floor. In contrast, the dye showed notable increases in velocity from 1-in. above the bottom of the inside of the nozzle to 2-in. above the bottom of the inside of the nozzle. Not as much difference in velocity was apparent between the bottom of the inside of the nozzle and 1-in. above the bottom of the inside of the nozzle. These observations suggested that vertical variation in velocity should be measured.

To make best use of limited flume testing time we elected to measure point velocities on a 10-point grid (***Figure 4-3***). The lateral grid points were set at the same seven verticals as in the 2017 Study, three within the nozzle (yellow shading within the green line in ***Figure 4-3***), and four outside the nozzle (pink line). Seven points were set 2-in. above the bottom of the inside of the nozzle (green points labeled 1 to 7 in ***Figure 4-3***), with the three interior points repeated 1-in. above the bottom of the inside of the nozzle (green points labeled 8 to 10 in ***Figure 4-3***). The interior points are located at 17.5-, 50-, and 82.5-percent of the inside sampler width, using the left (facing into the sampler) inside wall of the sampler as the zero reference, and the exterior points are located at -45-, -17.5-, 117.5- and 145-percent of the inside sampler width. The distance between points 1 and 7 is 5.7-in.

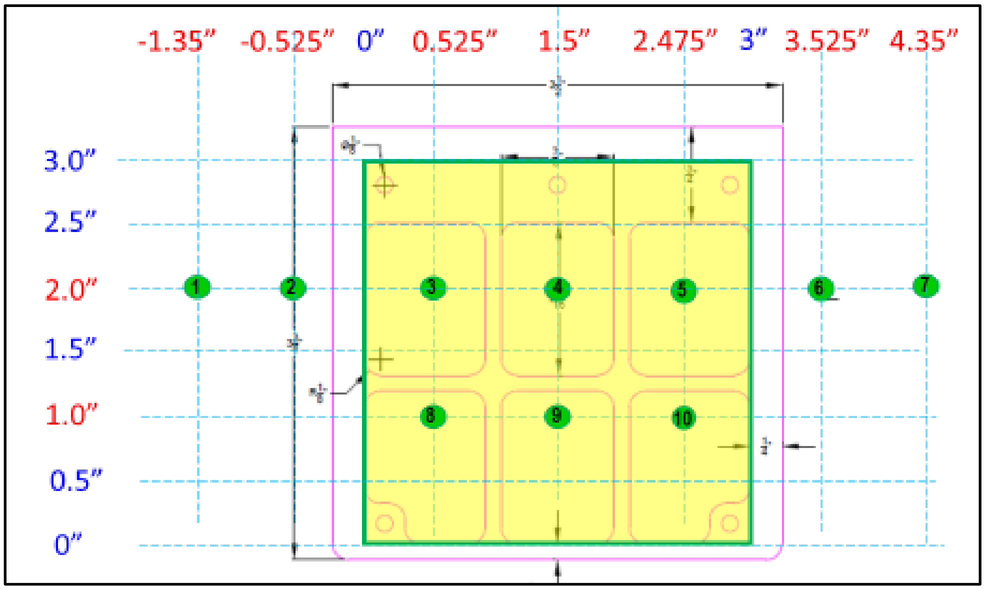

Figure 4-3. Velocity measurements grid (facing into the sampler, imposed on the closed flap)

A Nortec ADV Vectrino II Profiler setup the same as the 2017 Study was used to measure point velocities (***Figure 4-4***). The Profiler measured velocity about 1-in. upstream of the nozzle inlet to allow the Profiler to move without contacting the nozzle (***Figure 4-5***). The velocity measurements were displayed and recorded on a laptop computer (***Figure 4-6***).

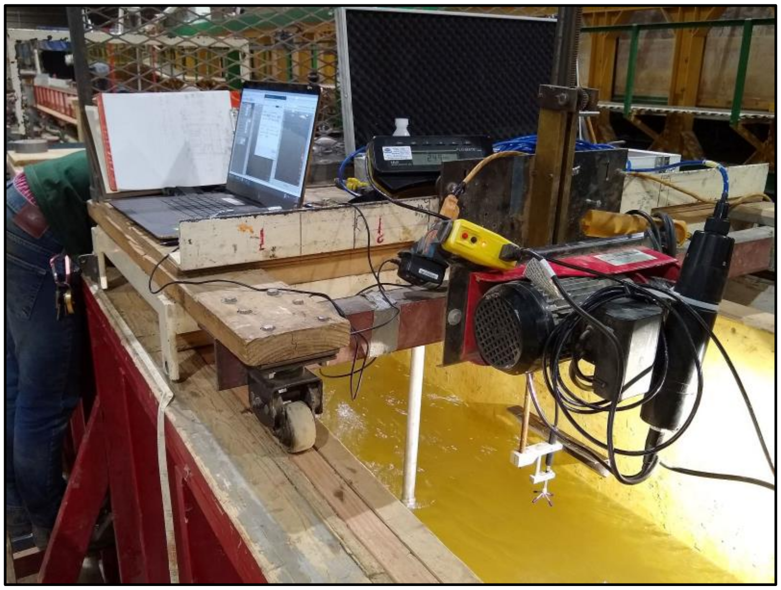

Figure 4-4. Nortec Vectrino II ADV Profiler and recording laptop on bridge over flume

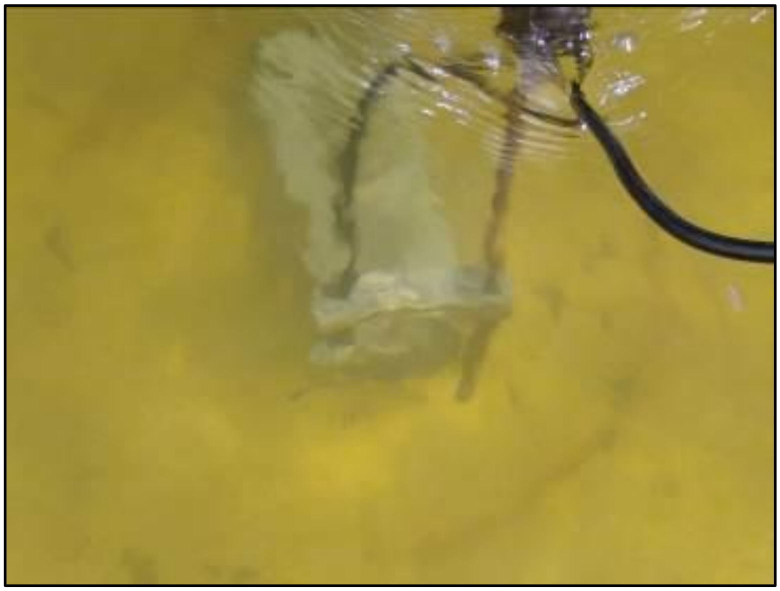

Figure 4-5. Velocity measurement using the Profiler positioned ~1-in. upstream of sampler

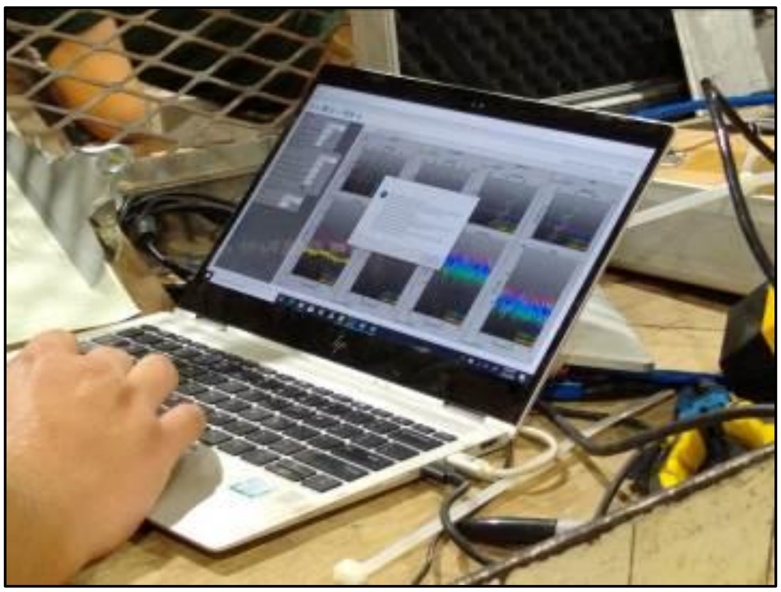

Figure 4-6. Graphic velocity measurements displayed on laptop computer

The target velocity could generally be held within variability of a few percent both during tests and between tests. To account for the minor variability, each measured point velocity was scaled to the ratio of the measured mean velocity to the target velocity.

4.2.3 Testing Scenario Matrix

The target flow depth (2.2-ft.) and target velocities (1.5-, 2.5- and 3.5-fps as measured 6-in. above the bottom of the inside of the nozzle) were set based on the 2017 Study. The following questions shaped the number of testing scenarios:

1. What is the HE of the BLH-84 with the prototype attachment?
2. How does this compare to the HE of the BLH-84 without the prototype attachment?

3. What is the effect on HE of the different meshes on the flap when the flap is closed?
4. What is the effect on HE when the flap is open (assuming the mesh in the flap makes no measurable difference)?

To answer these questions, the following testing scenarios were identified for each target velocity:

- Test 1 – no sampler in flume. This run was needed to compute the HE
- Test 2 – BLH-84 sampler without attachment. The standard 250-micron mesh bag was attached to the sampler in Tests 2 through 5.
- Test 3 – BLH-84 sampler with attachment (250-micron mesh in flap, 46-percent A_O) and flap closed.
- Test 4 – BLH-84 sampler with attachment (240-micron mesh in flap, 59-percent A_O) and flap closed.
- Test 5 – BLH-84 sampler with attachment and flap open (folded back onto the top of the nozzle; nozzle unobstructed)

For Test 5, the differences in the meshes in the flap were expected to be of no measurable effect, so only one mesh was tested.

4.3 RESULTS

Velocities measured over the 10-point grid (***Figure 4-3***) for each of three target flow velocities for five testing scenarios produced 150 point velocity measurements. The resulting flow measurements were tabulated and plotted as groups of laterally-distributed velocity profiles. The results for each of the five testing scenarios are provided in Sections 4.3.1 to 4.3.5.

4.3.1 Test 1 – No Sampler

Test 1 was run to provide a basis for computations of HE (Section 4.4.2).

Figure 4-7 shows the velocity measurements for the three target velocities. The target velocities were measured 6-in. above the bottom of the flume, whereas the point velocities were measured only 2-in. and 1-in. above the bottom of the flume (***Table 4-1***). Without the sampler in the flume, the only drag is the skin friction along the boundary of the flume. Applying the universal-velocity-distribution law, which relates velocity in turbulent flows at some distance above the bottom to a logarithmic function of the distance above the bottom (Chow 1959), velocity 6-in. above the bottom will exceed velocity at 2-in. above the bottom, which will exceed velocity at 1-in. above the bottom. Using a roughness height of 2.30×10^{-5} ft. for PVC (Engineering ToolBox 2003), which is representative of the epoxy-painted flume (Section 4.2.1), the grain Reynolds numbers confirm hydraulically-smooth flow, so the averaged measured point velocities were confirmed within +/- 5-percent using the universal-velocity-distribution law.

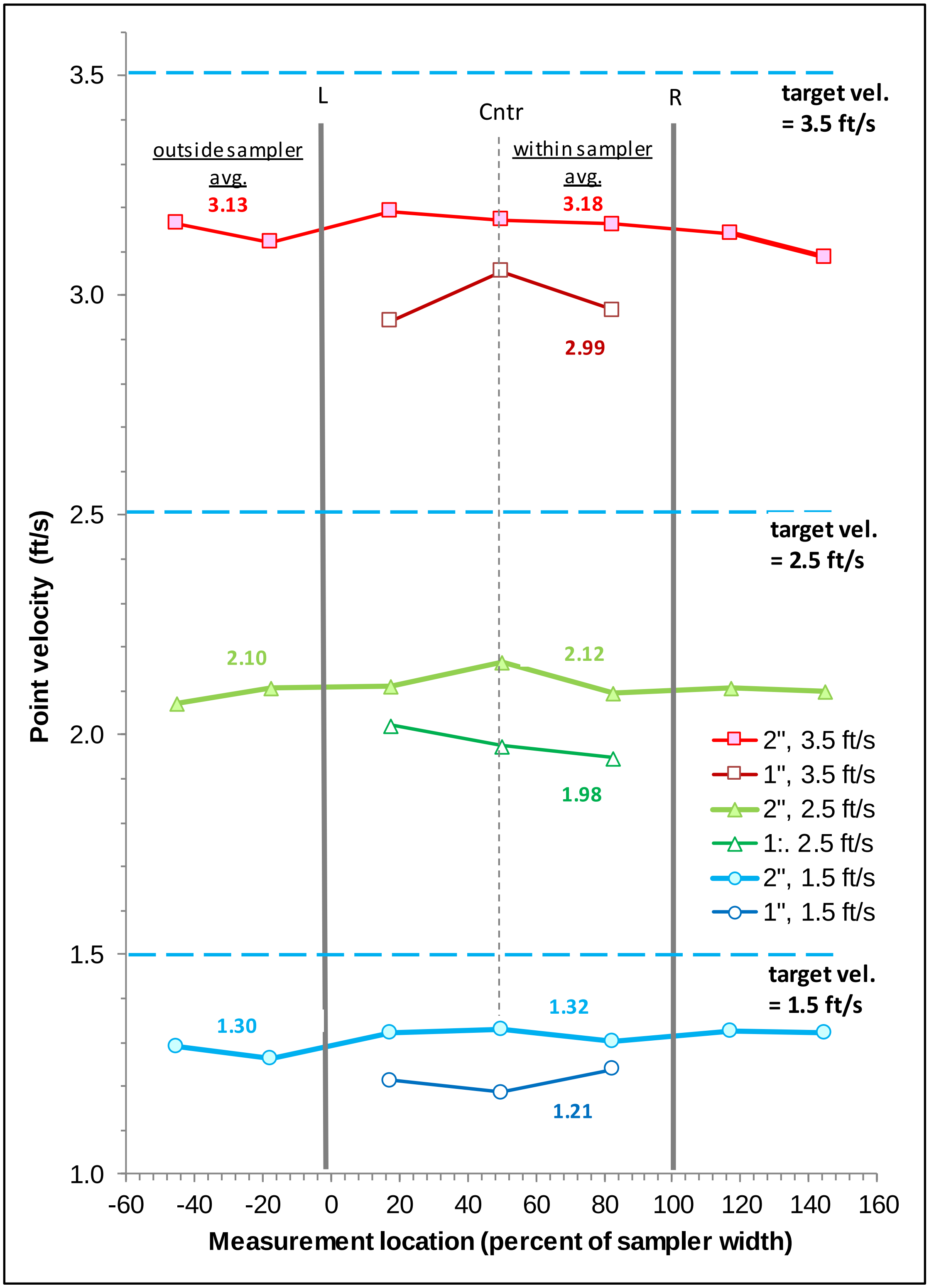

Figure 4-7. Point velocity measurement results for Test 1

Table 4-1. Point velocity measurement results for Test 1

Depth (in.)	Measured Point Velocity[1] (fps)								
	Pt. 1	Pt. 2	Pts. 3 & 8	Pts. 4 & 9	Pts. 5 & 10	Pt. 6	Pt. 7	Avg. Within	Avg. Outside
Target Velocity = 3.5-fps									
2	3.16	3.12	3.19	3.17	3.16	3.14	3.09	3.18	3.13
1	--	--	2.94	3.05	2.97	--	--	2.99	--
Target Velocity = 2.5-fps									
2	2.07	2.11	2.11	2.16	2.10	2.11	2.10	2.12	2.10
1	--	--	2.02	1.97	1.95	--	--	1.98	--
Target Velocity = 1.5-fps									
2	1.29	1.26	1.32	1.33	1.30	1.33	1.32	1.32	1.30
1	--	--	1.21	1.19	1.24	--	--	1.21	--

Note:
[1] Measured point velocities were scaled to the ratio of the measured target velocity averaged over the sampling duration to the prescribed target velocity.

4.3.2 Test 2 – BLH-84 Sampler without Attachment

In Test 2 the BLH-84 sampler with a 250-micron mesh sampler bag (A_O of 46) and without the prototype attachment was placed in the flume. Unlike the 2017 Study, the current study did not have a false floor, so the 0.25-in.-thick bottom of the sampler nozzle abruptly obstructed flow near the bottom of the flume. Test 2 point velocity measurements (***Table 4-2***) show reductions relative to Test 1, with greater reductions at the slower target velocities (***Figure 4-8***).

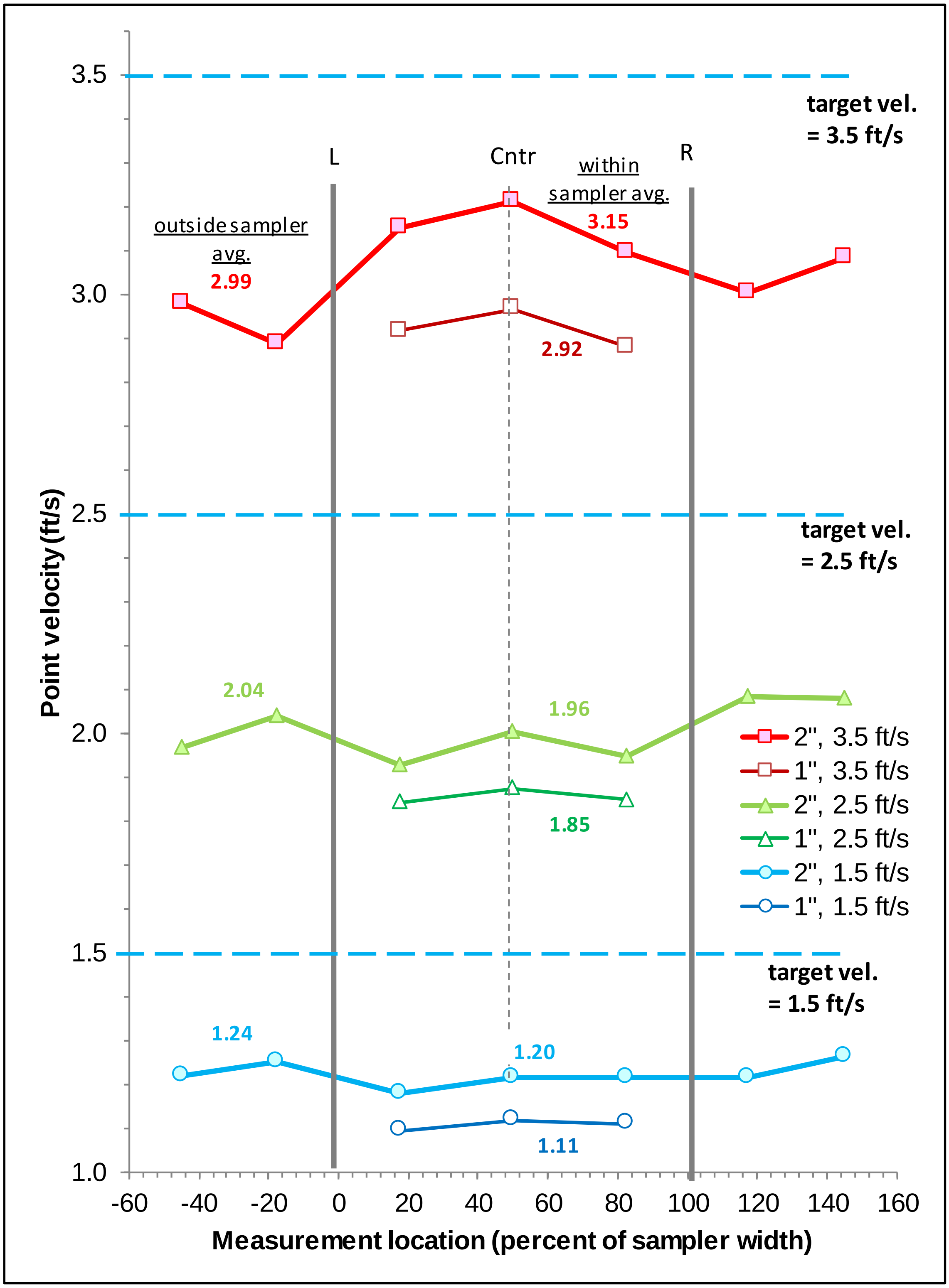

Figure 4-8. Point velocity measurement results for Test 2

Table 4-2. Point velocity measurement results for Test 2

Depth (in.)	Measured Point Velocity[1] (fps)								
	Pt. 1	**Pt. 2**	**Pts. 3 & 8**	**Pts. 4 & 9**	**Pts. 5 & 10**	**Pt. 6**	**Pt. 7**	**Avg. Within**	**Avg. Outside**
Target Velocity = 3.5-fps									
2	2.98	2.89	3.15	3.21	3.09	3.01	3.08	3.15	2.99
1	--	--	2.92	2.97	2.88	--	--	2.92	--
Target Velocity = 2.5-fps									
2	1.97	2.04	1.93	2.00	1.95	2.08	2.08	1.96	2.04
1	--	--	1.84	1.87	1.85	--	--	1.85	--
Target Velocity = 1.5-fps									
2	1.22	1.25	1.18	1.21	1.21	1.21	1.26	1.20	1.24
1	--	--	1.09	1.12	1.11	--	--	1.11	--

Note:
[1] Measured point velocities were scaled to the ratio of the measured target velocity averaged over the sampling duration to the prescribed target velocity.

4.3.3 Test 3 – BLH-84 Sampler, Door Flap Closed, 250-Micron Mesh, A_O = 46

Test 3 evaluated the BLH-84 sampler with (1) a 250-micron mesh sampler bag (A_O of 46), (2) the prototype attachment (250-micron mesh in the flap, 46-percent A_O), and (3) the flap closed. Test 3 point velocity measurements (***Table 4-3***) show reductions relative to Test 2, with greater reductions within the nozzle width than outside the nozzle width (***Figure 4-9***). This pattern of reductions is expected given the flow area obstructed by the flap.

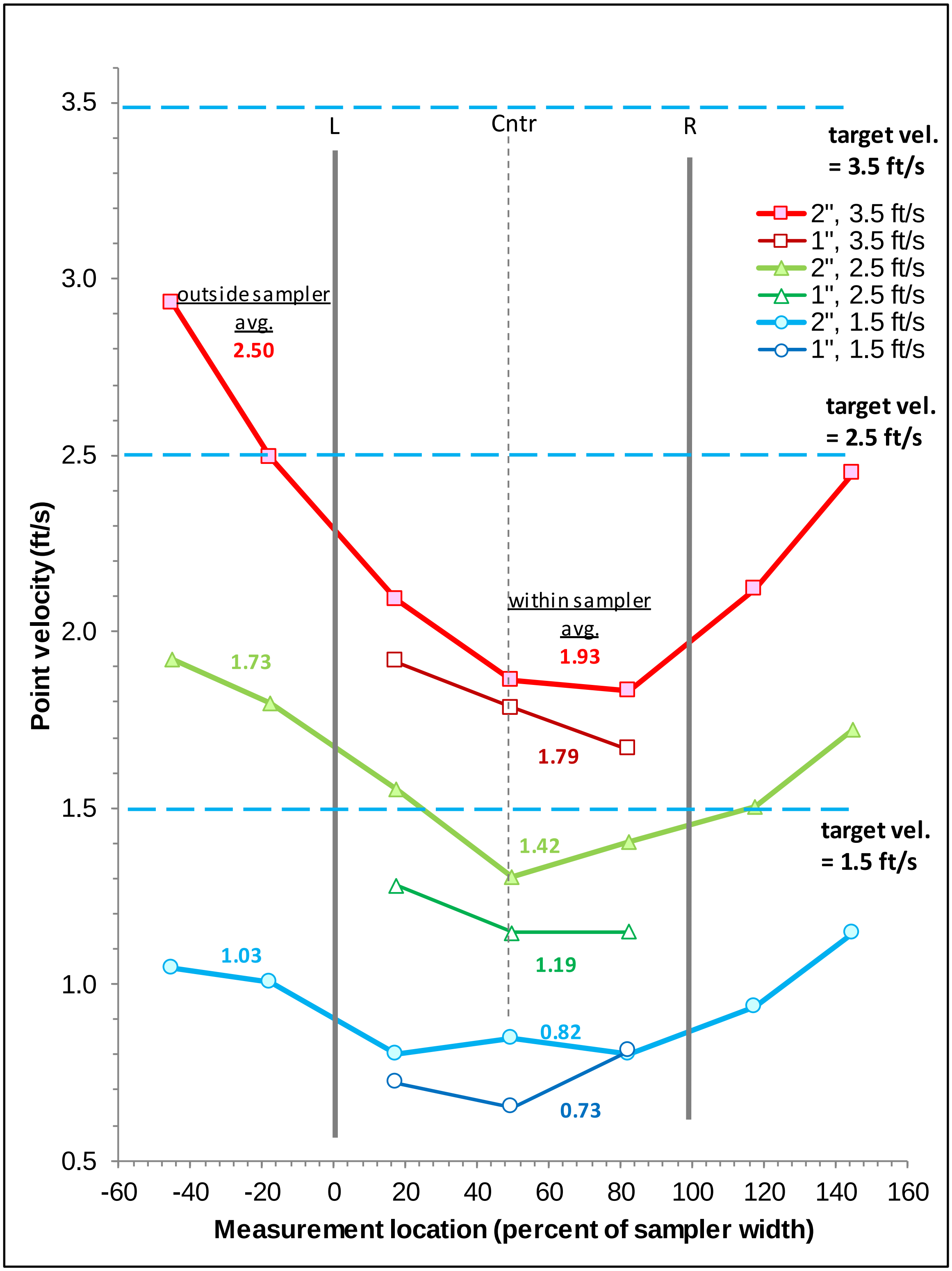

Figure 4-9. Point velocity measurement results for Test 3

Table 4-3. Point velocity measurement results for Test 3

Depth (in.)	Measured Point Velocity[1] (fps)								
	Pt. 1	Pt. 2	Pts. 3 & 8	Pts. 4 & 9	Pts. 5 & 10	Pt. 6	Pt. 7	Avg. Within	Avg. Outside
Target Velocity = 3.5-fps									
2	2.93	2.50	2.09	1.86	1.83	2.12	2.45	1.93	2.50
1	--	--	1.92	1.78	1.67	--	--	1.79	--
Target Velocity = 2.5-fps									
2	1.92	1.79	1.55	1.30	1.41	1.50	1.72	1.42	1.73
1	--	--	1.28	1.15	1.15	--	--	1.19	--
Target Velocity = 1.5-fps									
2	1.05	1.01	0.80	0.84	0.80	0.94	1.15	0.82	1.03
1	--	--	0.72	0.65	0.81	--	--	0.73	--

Note:
[1] Measured point velocities were scaled to the ratio of the measured target velocity averaged over the sampling duration to the prescribed target velocity.

4.3.4 Test 4 - BLH-84 Sampler, Flap Closed, 240-Micron Mesh, A_O = 59

Test 4 evaluated the BLH-84 sampler with (1) a 250-micron mesh sampler bag (A_O of 46), (2) the prototype attachment (240-micron mesh in the flap, 59-percent A_O), and (3) the flap closed. Test 4 point velocity measurements (***Table 4-4***) show reductions relative to Test 2, with greater reductions within the nozzle width than outside the nozzle width (***Figure 4-10***). This pattern of reductions is expected given the flow area obstructed by the flap as initially observed with the dye injections (Section 4.2.2). It is surprising that for the 3.5-fps target velocity point velocities measured 1-in. above the bottom of the flume exceed point velocities measured 2-in. above the bottom of the flume (the measurements and records were scrutinized for accuracy, and a measurement error could not be identified). A plausible explanation is atypical turbulent hydraulics around the closed flap.

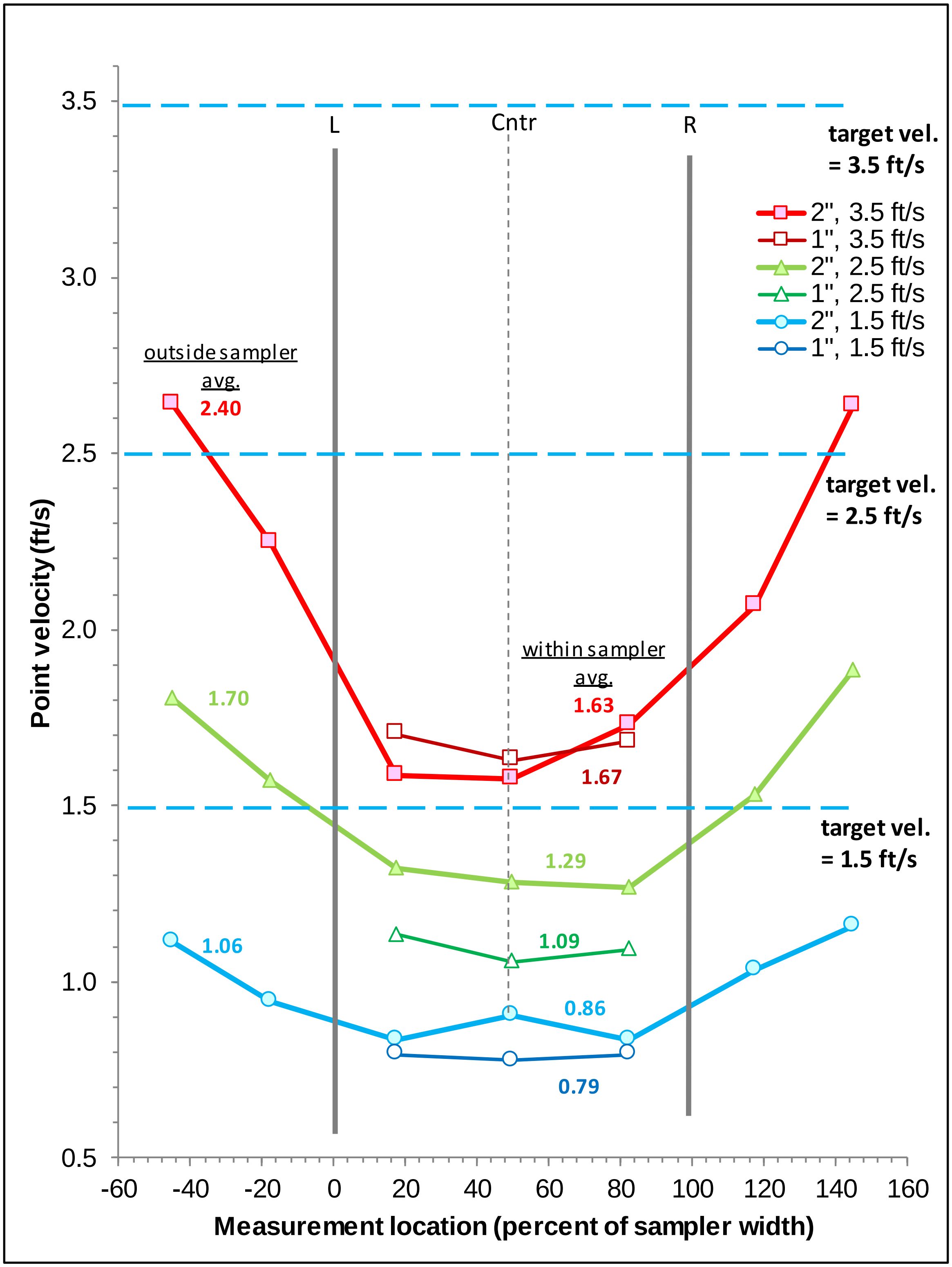

Figure 4-10. Point velocity measurement results for Test 4

Table 4-4. Point velocity measurement results for Test 4

Depth (in.)	Measured Point Velocity[1] (fps)								
	Pt. 1	Pt. 2	Pts. 3 & 8	Pts. 4 & 9	Pts. 5 & 10	Pt. 6	Pt. 7	Avg. Within	Avg. Outside
Target Velocity = 3.5-fps									
2	2.64	2.25	1.59	1.58	1.73	2.07	2.65	1.63	2.40
1	--	--	1.70	1.63	1.68	--	--	1.67	--
Target Velocity = 2.5-fps									
2	1.80	1.57	1.32	1.28	1.26	1.53	1.88	1.29	1.70
1	--	--	1.13	1.06	1.09	--	--	1.09	--
Target Velocity = 1.5-fps									
2	1.11	0.94	0.83	0.90	0.83	1.03	1.16	0.86	1.06
1	--	--	0.79	0.77	0.79	--	--	0.79	--

Note:
[1] Measured point velocities were scaled to the ratio of the measured target velocity averaged over the sampling duration to the prescribed target velocity.

Test 4 flap mesh had a greater A_O than Test 3 (absolute increase of 13-percent; relative increase of 28-percent), so it is surprising that point velocities measured within the sampler nozzle width during Test 4 were about the same (1.5-fps target velocity) or lower (2.5- and 3.5-fps target velocities) than Test 3. Point velocities outside the sampler nozzle width nearly matched between Test 4 and Test 3.

4.3.5 Test 5 – BLH-84 Sampler, Flap Folded Back and Nozzle Unobstructed

Test 5 evaluated the BLH-84 sampler with (1) a 250-micron mesh sampler bag (A_O of 46),and (2) the prototype attachment (250-micron mesh in the flap, 46-percent A_O), and (3) the flap folded back onto the top of the nozzle so the nozzle is unobstructed. Different meshes in the flap were expected to perform similarly, so the other mesh was not tested with the flap open. Test 5 point velocity measurements (***Table 4-5***) show reductions relative to Test 2, but much less than the two tests (Test 3 or Test 4) with the flap closed (***Figure 4-11***). The effect of the flap in the open position relative to Test 2 is noticeable at the 3.5-fps target velocity, and nearly transparent at the other two slower target velocities.

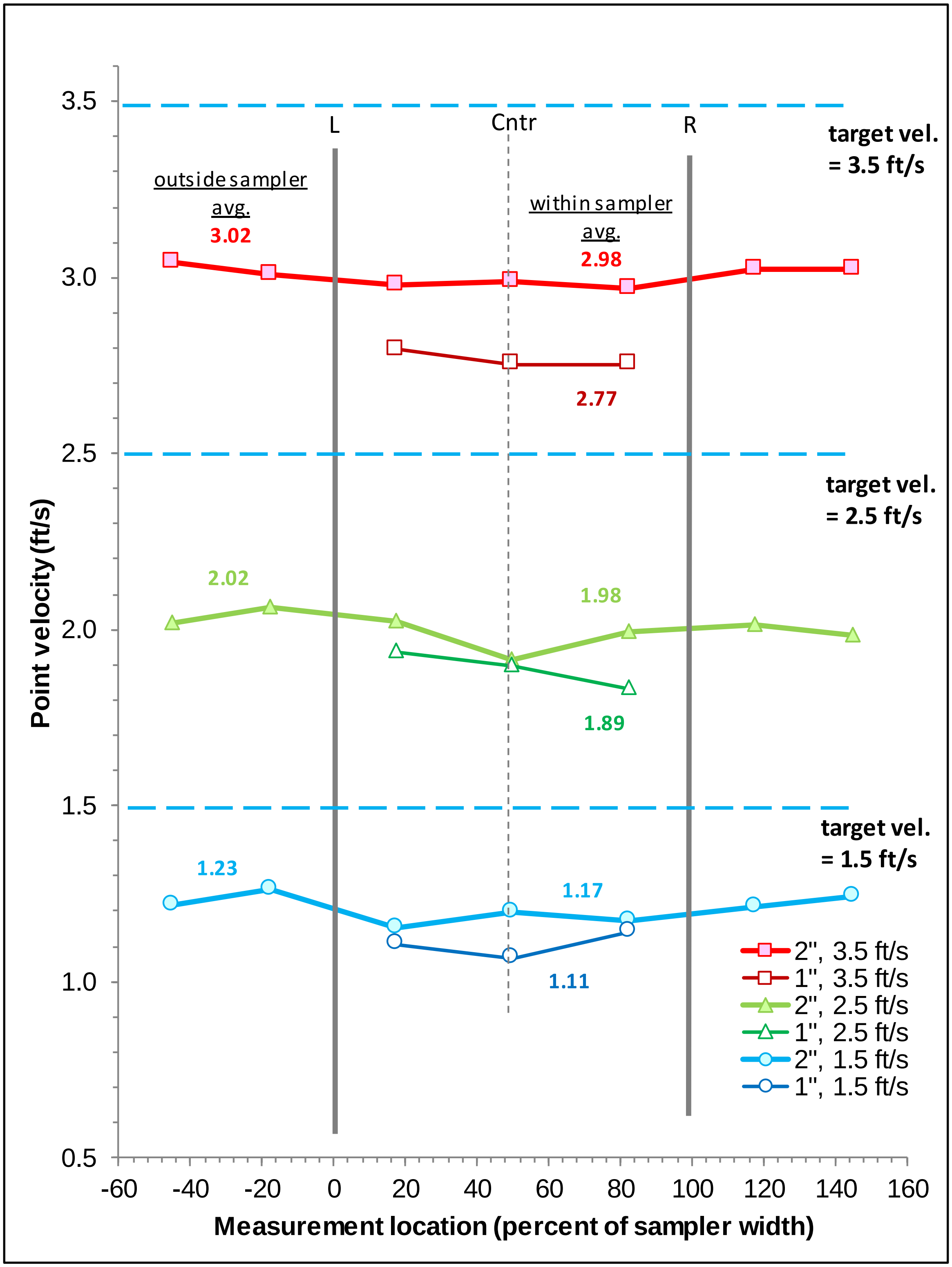

Figure 4-11. Point velocity measurement results for Test 5

Table 4-5. Point velocity measurement results for Test 5

Depth (in.)	Measured Point Velocity[1] (fps)								
	Pt. 1	Pt. 2	Pts. 3 & 8	Pts. 4 & 9	Pts. 5 & 10	Pt. 6	Pt. 7	Avg. Within	Avg. Outside
Target Velocity = 3.5-fps									
2	3.05	3.01	2.98	2.99	2.97	3.02	3.02	2.98	3.02
1	--	--	2.80	2.75	2.75	--	--	2.77	--
Target Velocity = 2.5-fps									
2	2.02	2.06	2.02	1.91	1.99	2.01	1.98	1.98	2.02
1	--	--	1.94	1.90	1.83	--	--	1.89	--
Target Velocity = 1.5-fps									
2	1.22	1.26	1.15	1.20	1.17	1.21	1.24	1.17	1.23
1	--	--	1.11	1.07	1.14	--	--	1.11	--

Note:
[1] Measured point velocities were scaled to the ratio of the measured target velocity averaged over the sampling duration to the prescribed target velocity.

4.4 ANALYSES

Analyses of measured point velocities (Section 4.4.1) and HEs (Section 4.4.2) were completed to evaluate the performance of the prototype attachment. The ideal value for the HE is 1, or 100-percent, indicating that the flow entering the sampler matches the ambient flow just upstream of the sampler nozzle. Comparison of any test to Test 1 (no sampler) provides the input needed to calculate the HE. Comparison of Tests 3 and 4 (flap closed), or Test 5 (flap folded back, nozzle unobstructed) to Test 2 (sampler without attachment) characterize the hydraulic effects of the attachment with the flap in different configurations and positions. Comparison of Tests 3 and 4 illustrate the hydraulic effect of the two different meshes within the flap.

4.4.1 Analyses of Measured Point Velocities

Two analyses that inform interpretation of the HE are: (1) comparing point flow velocities measured 2-in. above the bottom of the flume to point velocities measured 1-in. above the bottom of the flume; and (2) comparing point velocities measured within the sampler nozzle width to point velocities measured outside the sampler nozzle width.

4.4.1.1 Vertical Velocity Profile

One way to check that the velocity entering a sampler nozzle closely aligns with ambient velocity upstream of the sampler nozzle influence is to compare the vertical velocity profiles. With the available measurements, the percent increase in point velocities measured 2-in. above the bottom of the flume relative to those measured 1-in. above the bottom of the flume facilitates comparing the vertical velocity profiles. It is obvious that this comparison doesn't provide value for Tests 3 and 4 because no sampling is occurring when the flap is closed. ***Table 4-6*** shows the similarity in the shape of the velocity profile between Test 1 and Test 2, and the similar profiles between Test 2 and Test 5 with a notable decrease in velocities at the target velocity of 3.5-fps.

Table 4-6. Point velocity increases at 2-in. relative to 1-in. above the bottom of the flume

Test	1.5-fps Target Velocity			2.5-fps Target Velocity			3.5-fps Target Velocity		
	Vel. at 1-in. (fps)	Vel. at 2-in (fps)	In-crease (%)	Vel. at 1-in. (fps)	Vel. at 2-in (fps)	In-crease (%)	Vel. at 1-in. (fps)	Vel. at 2-in (fps)	In-crease (%)
1	1.21	1.32	8.7	1.98	2.12	7.2	2.99	3.18	6.3
2	1.11	1.20	8.6	1.85	1.96	5.6	2.92	3.15	8.0
5	1.11	1.17	6.1	1.89	1.98	4.6	2.77	2.98	7.6

This analysis indicates that the HEs for the BLH-84 with a 250-micron mesh sampler bag (A_O of 46) and without the attachment are close to one (consistent with the findings of the 2017 Study), and the HEs for the BLH-84 with the same sampler bag and with the prototype attachment (flap open) will be slightly less than one for the target velocity of 3.5-fps.

4.4.1.2 Lateral Velocity Profile

The results of the point velocity measurements provide a means to compare the velocities within and outside the sampler nozzle width (***Table 4-7***).

Table 4-7. Lateral point velocity variability

Test	1.5-fps Target Velocity			2.5-fps Target Velocity			3.5-fps Target Velocity		
	Vel. within (fps)	Vel. outside (fps)	In-crease (%)	Vel. within (fps)	Vel. outside (fps)	In-crease (%)	Vel. within (fps)	Vel. outside (fps)	In-crease (%)
1	1.32	1.30	1.3	2.12	2.10	1.3	3.18	3.13	1.5
2	1.20	1.24	-2.8	1.96	2.04	-4.1	3.15	2.99	5.5
3	0.82	1.03	-21.0	1.42	1.73	-18.1	1.93	2.50	-22.8
4	0.86	1.06	-19.2	1.29	1.70	-24.0	1.63	2.40	-32.0
5	1.17	1.23	-5.0	1.98	2.02	-2.1	2.98	3.02	-1.6

Without a sampler in the flume, the velocities measured 2-in. above the bottom of the flume within the sampler nozzle width were about 1.5-percent greater than the outside velocities. Expecting these velocities would be the same, the results indicate that variation of about 1.5-percent may not be meaningful (or if meaningful, the difference may be caused by distance from the flume walls and their associated drag). For Test 2, the sampler slightly decreases velocities within the nozzle width for the target velocities of 1.5-fps and 2.5-fps ; the sampler bag and the slow target velocities keep HE below 100-percent. By contrast, velocities increase within the nozzle width for the 3.5-fps target velocity, indicating that flow is sucked into the sampler and that HE exceeds 100-percent. In Test 5, the sampler with the flap folded back and the nozzle unobstructed decreases velocities within the nozzle width for all target velocities but more so for the 1.5-fps target velocity and least for the 3.5-fps target velocity. The results show that the reduction in velocity within the nozzle width diminishes with increasing target velocity and switches the increase to a decrease for the 3.5-fps target velocity.

In Test 3 and Test 4, the obstructed area of the closed flap with either mesh decreases velocities both within and outside the nozzle width. The decrease is greater within the nozzle width than just outside of it. The flow that is prevented from entering the nozzle appears to be deflected laterally reducing downstream velocities outside the nozzle width. This deflected flow accelerates down and around the nozzle, creating turbulent velocities at the bed. Even though flow velocities are lower than when the flap is folded up, the localized flow acceleration and the horseshoe vortex induce scour when the flap is closed.

As evidenced by Test 3 and Test 4 (flap closed), and Test 5 (flap folded back, nozzle unobstructed), the presence of the attachment increases velocities outside the nozzle width more than velocities with the nozzle width.

Figure 4-12 presents the lateral velocity variation as a ratio of the average point velocity within the nozzle width to the average point velocity outside the nozzle width. The inside/outside ratios for the BLH-84 sampler without a flap and the flap folded back with an unobstructed nozzle hover around one like occurs with no sampler. However, inside velocities drop substantially when a flap with either mesh insert is closed and flow into the sampler nozzle is obstructed.

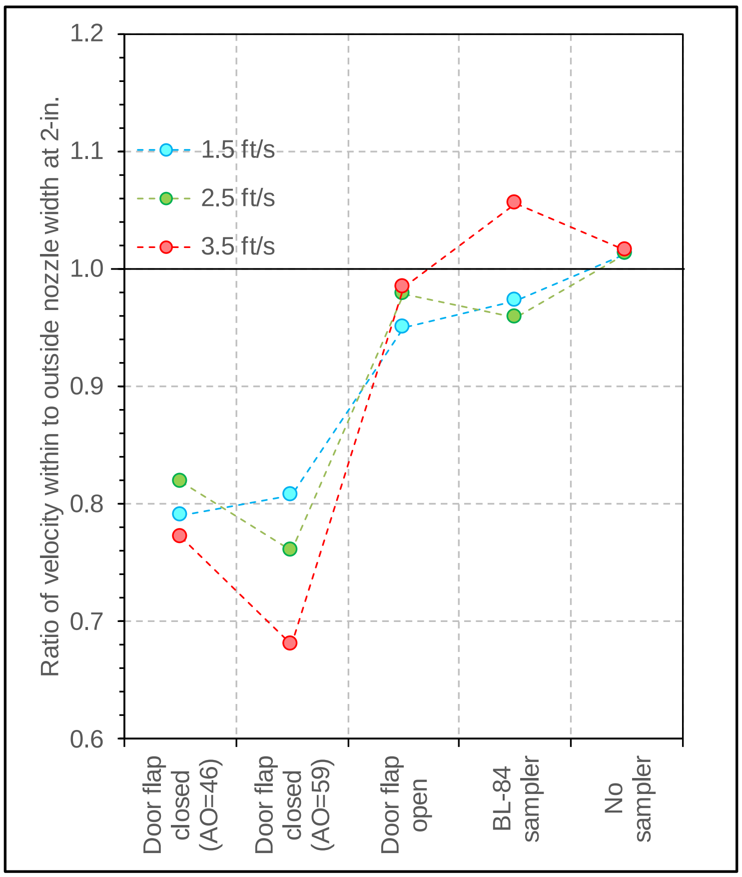

Figure 4-12. Velocity ratios within to outside sampler nozzle width

4.4.2 Analyses of Hydraulic Efficiency

Analyses of the results of the measured point velocities over the five tests focused on calculations and comparison of HEs. This focus was driven by the need to answer the key questions presented in Section 4.2.3. Consistent with the 2017 Study, the HEs were calculated by averaging the point velocities measured within the nozzle width 2-in. above the flume bottom (points 3, 4, and 5 in ***Figure 4-3***). For clarity, this HE is termed $HE_{in,2}$.

4.4.2.1 BL-84 Sampler

In the 2017 Study, the presence of the BLH-84 with the mesh sampler bag made almost no difference in the point velocity measurements relative to point velocities measured without the sampler in the flume, producing $HE_{in,2}$ values near 100-percent and serving as the basis for the noted trend of increasing $HE_{in,2}$ with increasing target velocity (***Table 4-8***). For the current study, as expected without the false floor in the flume and the slower target velocities, the presence of the BLH-84 with the mesh sampler bag produced a slightly greater impact on the $HE_{in,2}$ values (***Table 4-8***).

Table 4-8. Hydraulic efficiency for BLH-84 with 250-micron mesh sampler bag (A_O = 46)

2017 Study		Current Study	
Target Velocity (fps)	$HE_{in,2}$ (%)	Target Velocity (fps)	$HE_{in,2}$ (%)
1.66	97	1.5	91
2.78	99	2.5	92
3.54	102	3.5	99

The known trend of increasing $HE_{in,2}$ with increasing target velocity is apparent in both studies' results. So, despite the overall lower point velocities in the current study, the $HE_{in,2}$ values are still within 7-percent of $HE_{in,2}$ values for comparable but unequal target velocities in the 2017 Study. The current study, without the false floor, may better represent hydraulic effects at the nozzle when the sampler is deployed in a natural channel with a gravel-dominated bed; the 2017 Study, using the false floor, may better represent hydraulics at the nozzle when deployed in a natural channel with a sand-dominated bed.

4.4.2.2 Comparisons of the BLH-84 Sampler with and without the Attachment

Test 5 was completed to quantify the $HE_{in,2}$ of the BLH-84 sampler with a mesh sampler bag and the flap folded back and the nozzle unobstructed against the sampler without the attachment.

Table 4-9. Hydraulic efficiency for BLH-84 with 250-micron mesh sampler bag (A_O = 46) with and without attachment (flap folded back and nozzle unobstructed)

Without Attachment		With Attachment	
Target Velocity (fps)	$HE_{in,2}$ (%)	Target Velocity (fps)	$HE_{in,2}$ (%)
1.5	91	1.5	89
2.5	92	2.5	93
3.5	99	3.5	94

The hydraulic influence of the flap folded back is small for low target velocities but amounts to a 5-percent absolute reduction in $HE_{in,2}$ at a target velocity of 3.5-fps. In velocities of 3.5-fps and greater, it is possible the flap folded back might cause a measurable decrease in sediment-trap efficiency.

The purpose of the flap is to prevent scooped bed material from oversampling bedload transport rates and particle sizes in transport. Thus, no sampling is intended with the flap in the closed position. However, for reference, the $HE_{in,2}$ values were calculated for Test 3 and Test 4 (***Table 4-10***).

Table 4-10. Hydraulic efficiency Test 3 and Test 4 (with prototype attachment flap closed)

Test 3 (250-micron mesh, A_O=46)		Test 4 (240-micron mesh, A_O=59)	
Target Velocity (fps)	$HE_{in,2}$ (%)	Target Velocity (fps)	$HE_{in,2}$ (%)
1.5	62	1.5	65
2.5	67	2.5	61
3.5	61	3.5	51

The hydraulic influence of the closed flaps is substantial. Test 4 with flap mesh having a greater open area than Test 3 (absolute increase of 13-percent; relative increase of 28-percent), but a mesh opening 10 microns smaller than Test 3, produces lower $HE_{in,2}$ values. Mesh opening size appears to be more influential than the A_O in terms of the hydraulic influence of the closed flap.

Figure 4-13 illustrates the $HE_{in,2}$ values calculated for the three target velocities for each of the 5 tests.

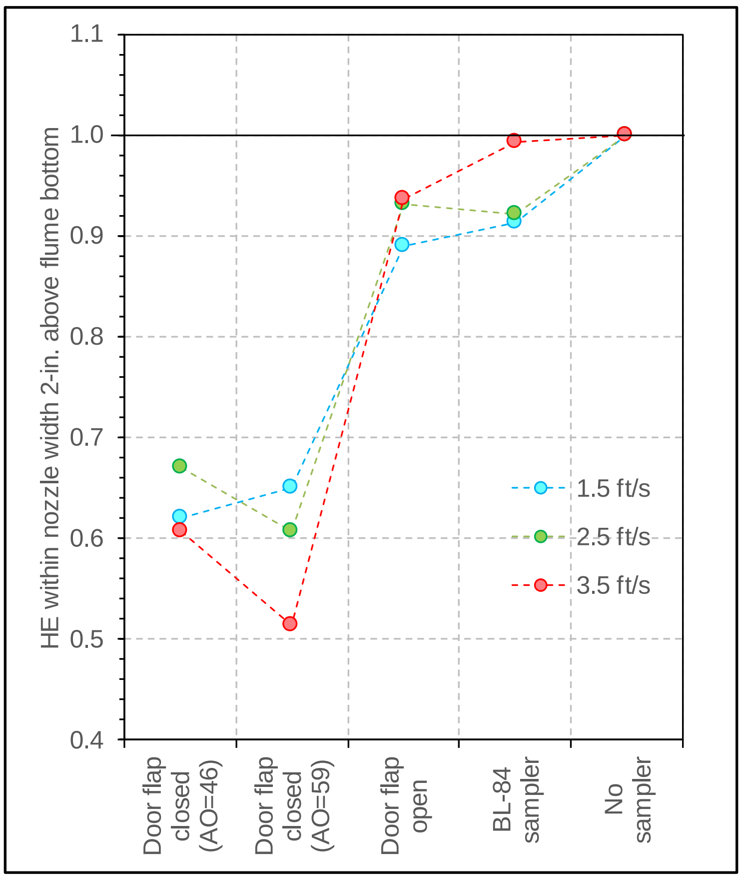

Figure 4-13. HE for three target velocities for each of the 5 tests

5.0 FIELD TESTING

While not required in the statement of work, we carried out informal field testing to observe how the presence of a flap visually affects flow around a BLH-84 in a stream with bed material dominated by sand and small gravel (***Figure 5-1***). We notified the FISP TC before the field testing to ask if anyone was interested in participating; Covid-19 travel restrictions precluded such participation. On August 6, 2020 we visited Fossil Creek in southeast Fort Collins, about 300 feet downstream of Trilby Road between Lemay Avenue and Timberline Road (***Figure 5-2***).

Figure 5-1. Sand and gravel bed surface at the field testing site on Fossil Creek in Fort Collins, CO

Figure 5-2. Facing north at Trilby Road, testing site at riffle in foreground (red circle)

The late-summer low flow conditions of only a few cubic feet per second were too low to mobilize the bed surface. However, the bed surface was loose enough that it could be scooped, and after agitating the surface with a rake, sand and finer gravel could be transported as bedload a short distance downstream. The prototype top-mounted flap was affixed to a BLH-84 handheld sampler and a steel-wire cable was connected to the flap to open it (***Figure 5-3***).

Figure 5-3. Prototype attachment on BLH-84 sampler with steel-wire cable to operate the flap [Note: the flap position shown isn't fully open, like the folded back position during flume testing]

The field testing confirmed the closed flap with the 250-micron mesh prevented sediment (that could be retained in the 250-micron mesh sampler bag) from entering the nozzle. When the sampler was pushed upstream into the bed surface, sediment was not scooped into the sampler. When the flap was opened, sediment could enter the nozzle like it would in a sampler without the attachment. When the cable was released for the spring to close the flap, we did encounter a problematic situation – the door closed on a gravel that prevented full closure of the flap (***Figure 5-4***). However, during actual measurements this situation could likely be avoided by measuring the length of cable pulled to open the flap and ensuring that full length of cable was retracted before raising the sampler. Under such conditions, the sample would need to be discarded. The minor inconvenience of having to resample the bedload transport is well worth knowing the initial sample may have been biased by scooping of bed material. The field testing also confirmed that a cam is needed on the flap because when pulling on the cable to open the flap, the direction of force is not about the hinge and the flap doesn't easily open. Attaching a cam would provide a pivot point to redirect the force of the cable to more-easily open the flap.

Figure 5-4. Gravel stuck between the flap and the nozzle as the flap was closed

When the flap was closed and the sampler was placed on the bed, flow deflected around the nozzle (***Figure 5-5***) and the resulting scour removed bed material in front of the nozzle and along the sides of the nozzle. The scoured area around the nozzle could not be seen through the turbid flow, but it was evident when feeling the bed. The scour is probably caused by a horseshoe vortex like scours around a bridge pier. This scour is likely to bias measurements of bedload transport in rivers with finer-grained beds because when the flap is opened, the scour area will refill with some of the bedload, and this will reduce the sediment-trap efficiency. The magnitude of the scour is expected to increase with flow velocity and fining of the bed material. Scour is not expected to be an issue in gravel-dominated bed material, but sand-dominated beds will be susceptible. For sand-dominated bed material, the flap could be left open when the sampler is lowered to the bed and then closed before raising the sampler so there would be no scour from the closed flap. While this operation would prevent scooping during raising, the measurement is still susceptible to scooping when the sampler is lower to the bed. However, in our experience, the operator can better control the sampler when lowering it to the bed compared to raising it from the bed, so this operation may still be advantageous.

Figure 5-5. Flow deflection around the nozzle when the flap is closed (left) relative to open (right)

6.0 KEY FINDINGS AND CONSIDERATIONS

We identified the following key findings from our observations and analyses of the prototype attachment as tested in the flume and in the field:

1. We expect the prototype attachment can be manufactured relatively cheaply and quickly using readily-available materials and shop techniques.
2. Existing BL-84 pressure-difference bedload samplers can be easily modified with blind tap holes in the top of the nozzle to accept bolts used to secure the attachment.
3. The simplicity of the fabrication, operation, and maintenance of the top-mounted flap makes this solution attractive for mitigating the effects of scooping on measurements of bedload transport using pressure-difference bedload samplers.
4. As identified in the 2017 Study and confirmed in the current study, HE is not a fixed value for a sampler; rather, the HE increases with flow velocity. This is generally known but often neglected.
5. When the flap is closed it diverts approaching flow around the sampler. The resulting hydraulic conditions can create a horseshoe vortex that erodes the bed around the inlet and sides of the nozzle. Refilling of the scoured area during a measurement will likely cause undersampling. This condition should be avoided.
6. The flap folded back on the nozzle of a BLH-84 sampler only decreases the HE by a few percent; this reduction may not preclude comparison of measurements made with and without the attachment.
7. Further testing of the attachment is highly encouraged to better understand the benefits and performance.

We offer the following considerations from our observations and analyses of the prototype attachment as tested in the flume and in the field:

1. Even when the HE is slightly less than 100, gravel bedload transport has inertia that is likely to overcome the slower flow velocity entering the sampler nozzle. Therefore, reductions in HE associated with the prototype attachment are expected to have the greatest influence on sand bedload.
2. The flap and its hydraulic effects may be scalable to pressure-difference bedload samplers with larger nozzles. We expect that the deflected flow across a wider nozzle will increase potential for scour, but the

larger nozzle tend to be used in systems with gravel beds less prone to scour, so this concern may not impair measurements.

3. While the attachment causes a slight reduction in HE, the potential benefit is substantial. The effect of scooped bed material could reach a few orders of magnitude, much less than envisioned to be caused by a slight reduction in HE from the attachment with the flap folded back. So the attachment is considered a reasonable trade-off for mitigating the effects of scooping.

7.0 RECOMMENDATIONS

We offer the following recommendations for the FISP TC's consideration in support of the continuing mission of the FISP and FISP-supported research studies:

1. The upper mean velocity limit for using the BL-84 is 10-fps, so additional flume testing at higher velocities, while challenging for pump capacities, would be informative for evaluating HEs for velocities that may be more representative of bedload transport measurements at higher flows. If only the BL-84 is tested, flow depths could be decreased to reduce demand on the pumping capacity.
2. Confirm the spring on the piano hinge can close the flap in velocities up to the 10-fps limit for the BL-84.
3. Identify options for a cam to be affixed to the flap to improve the ease of opening the door.
4. Test the flap folded back on a BL-84, which poses greater potential for hydraulic effects at the nozzle because the top tube prevents the flap from lying flat on the top of the nozzle. On the tested BLH-84, there is no top tube to prevent the flap from lying flat on top of the nozzle.
5. The changes in $HE_{in,2}$ of a few percent, if confirmed over a range of target velocities up to about 10-fps, should justify testing the sediment-trap efficiency. While the flap folded back is likely to produce minor changes in sediment-trap efficiency, the real value comes from exclusion of scooped bed material in the bedload transport measurement.
6. Testing sediment-trap efficiency likely requires flume testing in a mobile-bed flume, which is a considerably greater undertaking than fixed-bed flume testing. However, preliminary testing could be efficiently carried out. For example, on the South Fork of the Cache la Poudre River near the confluence with Little Beaver Creek there is a sampling bridge that crosses near a wadeable section. This section of the creek is ideal for sampling bedload transport because of the plane bed morphology and substantial bedload transport. During the 2021 snowmelt runoff, testing could be carried out to compare samples collected using a BL-84 deployed from a cable using a reel and a crane (Tetra Tech can donate use of their sampler, reel, and crane). Previous samples show a relatively high transport of sand over a gravel bed surface. The creek experiences diurnal fluctuations in flow during the snowmelt, so testing could occur over a range of flow. A field crew of three could spend three days collecting measurements followed by a targeted analysis and documentation for a low-cost continuation of testing.
7. Refine the cable system for opening and closing the flap. Include a tape measure to identify the length of cable moved to open the flap so closure of the flap can be ensured when the same length is retracted.

8.0 REFERENCES

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APPENDIX A

Appendix A – Attachment 1 to PO# 140G0119P0341

STATEMENT OF WORK FOR

Development and Testing of a Pressure-Difference Bedload Sampler Attachment to Mitigate Scooping

I. GENERAL INFORMATION

A. INTRODUCTION: This statement of work is for the development and testing of an improved pressure-difference bedload sampler to prevent bias introduced by scooping. Specifically, the improvement is an attachment to the nozzle of a bedload sampler. This attachment has an operable door that prevents sediment from entering the sampler except when the door is open. Development and testing of this improvement is expected to lead to a standardized, calibrated piece of Federal Interagency Sedimentation Project (FISP)-maintained equipment that will facilitate more-consistent and more-accurate measurements of bedload transport.

B. BACKGROUND: In FY 2016, the FISP funded testing of the influence of sampler bag mesh size and type on the hydraulic efficiency of pressure-difference bedload samplers (Bunte et al., 2017)., results of which identified, in part, that scooping a few gravel particles into a sampler may well introduce more error than bag mesh size and type. Practitioners regularly encounter challenges in bedload sampling driven by uncertainty in knowing whether scooping of the bed surface has biased a bedload measurement collected using a pressure-difference sampler. This uncertainty has been compounded when working from raft-based platforms, and in flows too deep or too turbid to visually confirm (either directly or from underwater photos or videos) if the sampler scooped the bed.

The lack of a solution is problematic because pressure-difference bedload samplers are so widely-used for measuring bedload transport in streams and rivers. Bedload measurements using pressure-difference samplers have historically been, and continue to be, collected as a component of operational monitoring programs. Consequently, eliminating bias introduced by scooping would provide near-universal benefit to these monitoring programs, as well as to any other bedload measurements collected using pressure-difference samplers.

Reference: Bunte, K., Klema, M., Hogan, T., and C. Thornton. 2017. *Testing the Hydraulic Efficiency of Pressure Difference Samplers while Varying Mesh Size and Type.* Submitted to the Technical Committee of the Federal Interagency Sedimentation Project. Colorado State University, Engineering Research Center, Fort Collins, CO. 75 p., plus appendix.

C. PURPOSE AND SCOPE: The goal of the work is for the vendor to develop and test an attachment to pressure-difference bedload samplers that will lead to a standardized, calibrated piece of equipment that will facilitate more-consistent and more-accurate measurements of bedload transport by preventing bias introduced by scooping. To achieve this goal, the purpose of the work is to carry out the initial development and testing of the proposed attachment. The vendor will fabricate an attachment for testing, and the testing can be carried out in a flume. The results of the development and testing will be documented in a report.

II. WORK REQUIREMENTS

A. TECHNICAL REQUIREMENTS: The key technical requirement is the development (design and fabrication) of a prototype attachment for testing. With the prototype in hand, the hydraulic efficiency of the sampler with the attachment needs to be compared to the hydraulic efficiency of the sampler without the attachment (ideally, using data from the FISP's FY 2016 funding testing (Bunte et al. 2017).

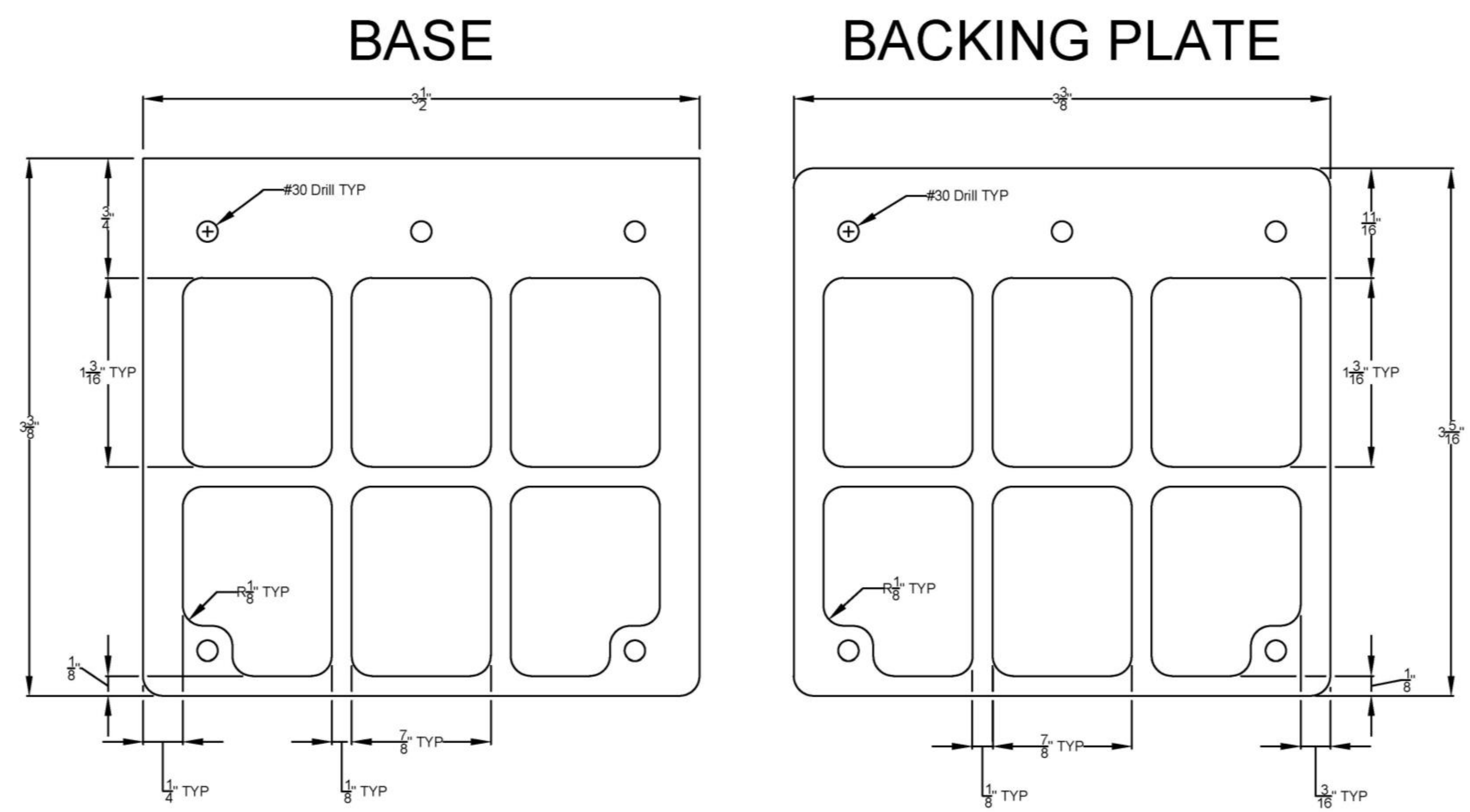
B. DELIVERABLES: The prototype attachment, design plans for the attachment, and testing results in a report.

III. SUPPORTING INFORMATION

Period of performance is from October 1, 2019 through September 30, 2020.

APPENDIX B

Appendix B – AutoCAD Design Plans for the Top-Mounted Flap Attachment



NOTES

- Base plate is $\frac{1}{4}$" Aluminum plate and the backing plate is $\frac{1}{16}$" Aluminum plate
- #5 Screws hold the base and backing plate together and sandwich the selected screen
- Hinge used in prototype was McMaster part number 15205A710
- Provides 71% open area (not considering screen)

DRAWING SCALE 1" = 1"	HYDRAULICS LABORATORY COLORADO STATE UNIVERSITY		NO.	DATE	REVISION	BY
DATE 08/25/2020						
CLIENT Tetra Tech						
SHEET # 1 of 2	Flap Door Specifications	BL-84 Mesh Flap Door	DRAFTED BY Taylor A. Hogan		SUPERVISOR Christopher I. Thornton, P.E	

NOTES

- #5 Screws hold the base and backing plate together and sandwich the selected screen
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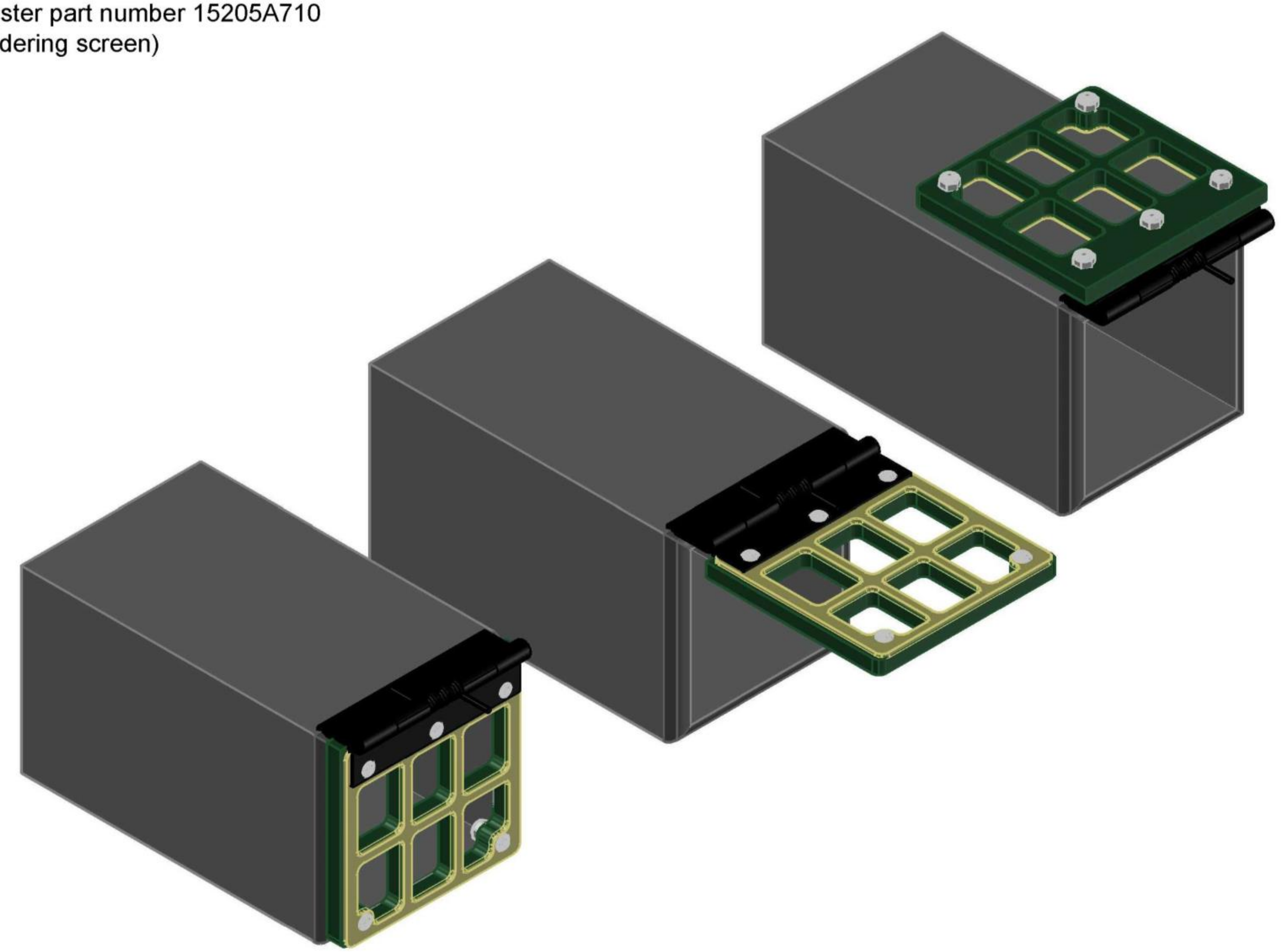
- Provides 71% open area (not considering screen)



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DATE 08/25/2020						
CLIENT Tetra Tech						
SHEET # 2 of 2	Flap Door 3D Views	BL-84 Mesh Flap Door	DRAFTED BY Taylor A. Hogan		SUPERVISOR Christopher I. Thornton, P.E	