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Guidelines for Using Bedload Traps in Coarse-Bedded Mountain Streams:

Construction, Installation, Operation, and Sample Processing

Kristin Bunte, Kurt W. Swingle, and Steven R. Abt

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Abstract

A bedload trap is a portable sampler designed specifically for collecting gravel and cobble bedload (4 to 180 mm in diameter) in wadeable streams. Bedload traps consist of an aluminum frame with a 12 by 8 inch (0.3 by 0.2 m) opening to which a 3- to 5.5-ft (0.9 to 1.65 m) long trailing net is attached. Bedload traps are installed on ground plates that are anchored to the stream bottom with metal stakes. Traps do not have to be hand-held while sampling and have a large volumetric capacity. This permits collection of bedload over relatively long intervals, typically one hour per sample. In this document, we provide detailed guidelines for bedload trap construction and operation. We describe component parts and offer instructions for making the nets and assembling the sampler. Appropriate site selection and preparation are discussed as well as bedload trap installation, use, and maintenance. These guidelines also show how to process the collected bedload samples in the field and how to perform some of the typical calculations used in bedload evaluation.

Key words: Bedload traps, bedload transport, sampling, field work, mountain gravel-bed rivers

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cover photos: **Top:** Six bedload traps and a footbridge installed at Hayden Creek at the beginning of the highflow season. ***Bottom left:*** Two ground plates—one with a bedload trap ready for sampling. ***Bottom center:*** Operators untying the trap net to retrieve the bedload sample. ***Bottom right:*** Two operators emptying bedload traps at a site without a footbridge.

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Preface

This document is the product of 7 years of field experience with bedload traps during highflow events. Over this period the design of bedload traps has evolved, and the techniques of operation and sample processing were continuously modified and refined. We recognize that the techniques described in these guidelines are adapted to the conditions in Rocky Mountain streams during snowmelt highflows. Streams in other climatic and hydrologic regimes undoubtedly will pose different problems requiring creative solutions from the bedload investigator. Nevertheless, in the hope that others will not have to repeat our mistakes, we strongly suggest first trying the procedures as described in these guidelines and only then, as necessary, alter them as seems fit.

At times, the guidelines use non-standard units of sample volume such as “a cupful of sediment,” a “household pail,” or “5-gal bucket” filled with debris. This was done to provide the reader with a quick, visual image of a sample volume, not an exact measurement.

If there are further questions regarding the construction, installation, and use of bedload traps, please do not hesitate to contact the authors (kbunte@engr.colostate.edu).

Acknowledgments

The shop of the Engineering Research Center (CSU) built the bedload trap frames and had the idea of using shaft collars. The Engineering Research Center Hydraulics Lab (CSU) provided field gear, advice, and support (Chris Thornton, Chad Lipscomb, Mike Robeson, Andy Darrow).

CSU students (Sean McCoy, Jill Holladay, Dan Armstrong, Rhett Travis, Brian Smith, Dan Mastburgen, Simon Stachnik, Brenton Swift) and Janice Barman (staff) as well as Forest Service personnel (Paul Bakke, Mike McNamara, Walt Lucas, Tim Sullivan, Scott Richards, Missy Shuey, Richard Ford, Terry Smith, Wes Smith, Randy Davis, Manuel Martinez, Mark Dixon, Kate Dwire, Megan Kabele and her co-workers, Dan Cenderelli, Mark Weinhold and others) helped us with field and lab measurements or provided other support.

The Fraser Experimental Forest (CO), Bridger-Teton National Forest (Jackson Hole, WY), Winema National Forest (Klamath Falls, OR), and Pike and San Isabel National Forest (Leadville, CO) provided general support for our field studies. John Potyondy (USDA Forest Service, Stream System Technology Center) helped us with guidance, insight, and support all along the way. The U.S. Forest Service Stream Systems Technology Center (Stream Team) funded the development of the bedload traps and the subsequent field studies. Sue Hilton (Forest Service, PSW Research Station), Mark Dixon (Forest Service, Rocky Mountain Research Station), and Brod Davies (Federal Interagency Sedimentation Program) provided insightful reviews. We are grateful to all people who helped with the bedload trap project.

Contents

Chapter 1.

Introduction

Properties of Gravel Bedload Transport in Gravel-Bed Streams

Gravel and cobble transport is a stochastic process in which discrete particles ranging in size from 2 to 256 mm hop, roll, slide, and bounce over an uneven streambed surface. At any given flow, particles will move fitfully and infrequently, particularly the largest ones. Although sampling these particles to determine transport capacity and flow competence is often a primary study goal, doing it without bias is a challenge.

Due to the irregular particle movement, transport rates fluctuate over time. Consecutive short-term (for example, one-minute) samples collected at near constant flow typically comprise transport rates that range from almost zero (for example, less than 10 percent of the long-term average rate) to four or more times the mean transport rate.

Gravel and cobble transport measured over a highflow event extends over a wide range of particle sizes and transport rates. At the very beginning of a highflow event, only a single pea-sized particle might be collected over a sampling period lasting several hours. At flows exceeding bankfull, several 10-liter buckets of gravel and cobbles can be collected within only a few minutes. Described in terms of mass transport rates, this difference ranges from 0.00001 g/s to 100 g/s and covers seven orders of magnitude.

Most samplers are designed to collect only a relatively narrow range of particle sizes or transport rates. Accurate measurements of gravel and cobble transport rates are difficult to obtain given the wide spectrum of particle sizes and transport rates, the infrequent movement of larger particles, and the fluctuating nature of transport. This problem has limited our understanding of bedload transport processes in gravel-bed streams. In order to address these specific challenges, bedload traps were designed to facilitate sampling irregularly and infrequently moving gravel and small cobble particles over a wide range of transport rates in wadeable mountain streams. The development was a joint effort between the Colorado State University (CSU) Engineering Research Center, and the U.S. Forest Service (FS) Stream Systems Technology Center.

Desirable Sampler Attributes

Sampler properties desirable for collecting representative samples of gravel and cobble bedload in coarse-bedded wadeable streams are:

- A large opening that permits large particles to enter the sampler,
- A deployment technique that permits long sampling times and thus integration over fluctuating transport rates,
- A large capacity that permits collection of large volumes of gravel and cobble bedload,
- Satisfactory hydraulic efficiency (good through-flow rate with little retardation or acceleration of flow),
- Satisfactory sampler efficiency (neither involuntary particle pick-up nor hindrance of particle entry),
- Coverage of a large percentage of the stream width,
- Portability for use at remote sites,
- Relative low cost,
- Ease of installation, and
- Usable by a two-person team in wadeable flow.

The CSU/FS bedload traps shown in figure 1 were designed to have these attributes. The basics of the system are briefly described, with detailed construction and operation guidelines in the following sections.

Bedload Trap Overview

Bedload traps are portable samplers that provide sievable samples of gravel and cobble-sized bedload material. They are easy to install in the stream, operable at wadeable flow, and not prohibitively expensive. Several traps are typically installed across the stream, covering much of the stream width. The combination of these properties (esp. the large opening, the large sampler capacity, installation on ground plates, and long sampling times) are essential for obtaining representative samples of gravel and cobble bedload transport. These attributes are more typical of a “trap,” which collects all sediment supplied to it until filled to capacity, than a “sampler,” which provides a small sample of what is currently being transported. The term “bedload trap” is therefore more characteristic of our device in most sampling situations, even though bedload traps are not installed below the bed surface.

Bedload traps have an aluminum frame 1ft (0.3 m) wide at the sampler opening. This width allows coarse gravel and small cobble particles to enter the trap. The frame has a trailing net with a 3.6 mm mesh opening that stores the collected gravel bedload. The net, 3 ft (0.9 m) in length

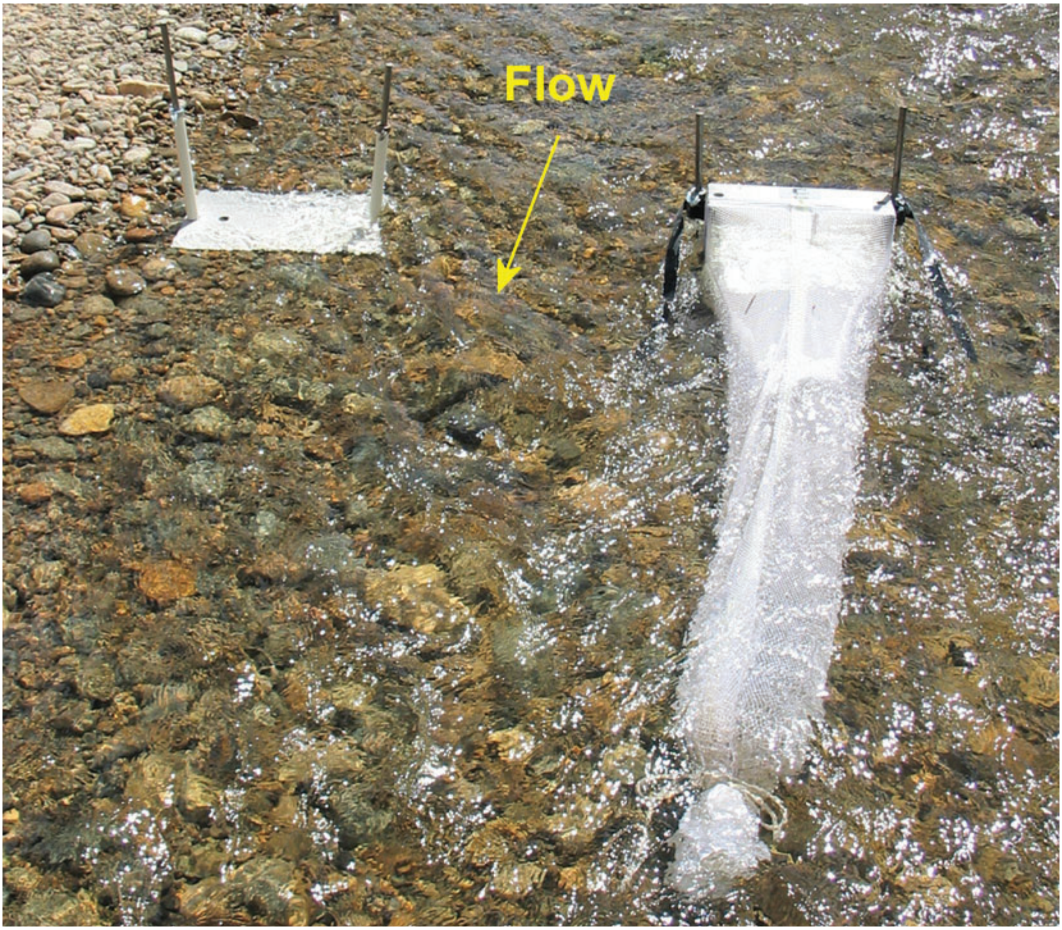

Figure 1—A bedload trap installed on a ground plate (right). A ground plate with no trap installed (left).

or longer, can be opened, emptied, and closed from the back without removing the frame from the streambed. Bedload traps are placed on 12 by 16-inch (0.3 by 0.41 m) ground plates that are anchored to the stream bottom with metal stakes. Adjustable nylon webbing straps are used to fasten the frame to the stakes. Ground plates not only prevent involuntary particle entrainment at the sampler entrance, but their smoothness increases the near-bottom flow velocity, which ensures that all particles that have moved onto the ground plate will enter the trap without much delay. The large-capacity nets and fixed position of the traps on ground plates permit a long sampling time, usually an hour. During this time, an operator does not need to attend to the sampler. Long sampling times allow infrequently moving large particles (in other words, particles of the size near the threshold of motion) to be collected, which averages out short-term temporal variations in transport rates. This reduces variability in sampled transport rates and avoids sampling bias when the distribution of transport rates is skewed[1]. Hour-long sample times also allow for sampling a much larger proportion of the total bedload than a 1 to 2 minute deployment typical of a Helley-Smith type sampler. See Appendix A for details.

The guidelines presented here refer to bedload traps that are 1 ft (0.3 m) wide, have 3- to 5.5-ft (0.9 to 1.65 m) long nets, and a 3.6 mm mesh opening width. Although bedload traps can be constructed with different dimensions, these devices should not be radically scaled up or down without considering the effects these changes would produce.

Purpose of the Guidelines

These guidelines were assembled in response to the many inquiries received about how to make and use bedload traps. Instructions on how to construct traps are provided in Chapter 2 of this report, and installation in the stream is described in Chapter 3. Chapter 4 explains how to operate bedload traps to obtain accurate samples of gravel and cobble bedload, while Chapter 5 shows sample processing and computation of transport rates from trap samples. The guidelines are geared toward project managers and graduate students, as well as research hydrologists and fluvial geomorphologists who plan to use bedload traps in their field studies.

Guidelines for using bedload traps cannot be strictly limited to the mechanics of installing and operating them. External factors such as stream wadeability, site selection, operator clothing, and sample processing are so closely related to the success of bedload trap operation that they need to be discussed as well. The use of trade or firm names in this publication is for reader information and does not imply endorsement of any product or service by the U.S. Forest Service or Colorado State University.

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[1] Transport rates in mountain gravel-bed streams are often not symmetrically distributed around a mean rate but skewed toward large rates (see Chapter 4).

Construction of Bedload Traps

Bedload Traps and Their Parts

Each bedload trap consists of:

- 1 aluminum frame,
- 1 nylon net,
- 1 piece of cotton-covered clothesline, 2 to 3 ft long,
- 1 metal ground plate,
- 2 cold-rolled steel stakes,
- 4 nylon straps with metal friction buckles,
- 4 plastic tension buckles, and
- 2 shaft collars with thumb screws.

A schematic overview of a bedload trap and its parts is presented in figure 2, while components are discussed in more detail in the following chapters. A list of components to purchase for making bedload traps is provided in Appendix B.

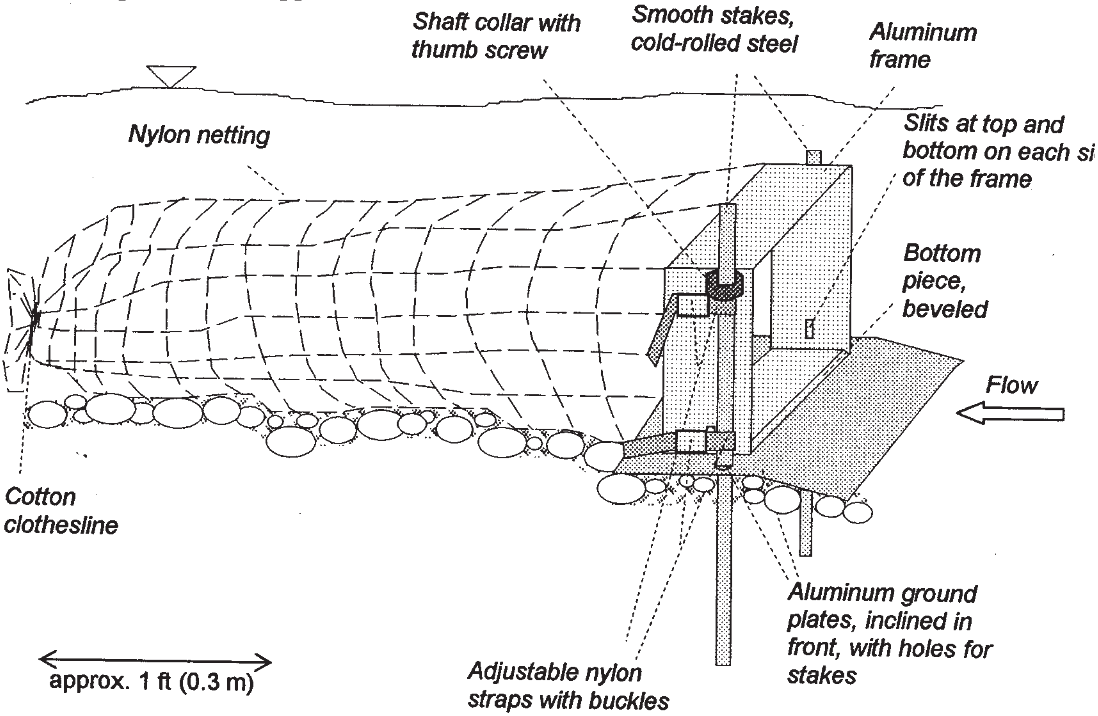

Figure 2—Schematic diagram of a bedload trap and its parts.

The Frame

The aluminum frame has the shape of a large shoe box without a bottom. It is made from aluminum stock 0.25 inches thick and 4 inches wide (6.3 by 101 mm) that is welded together at the corners or along the edges (fig. 3). The inside dimensions of the frame are 12 inches (0.3 m) wide and 8 inches (0.2 m) high. A slightly different frame size should not affect the sampling properties of the bedload traps. The bottom front edge of the bedload trap frame is beveled at an angle of 30° so particles can easily enter the trap. The frame has four vertical slits cut into the sides near the top and the bottom. The slits are 1.25 inches (32 mm) long and 0.375 inches (10 mm) wide with rounded tops and bottoms. Nylon webbing straps that hold the traps to the stakes and onto the ground plates go through these openings. All edges of the frame, but particularly the slits, need to be smooth so that they don't cut the

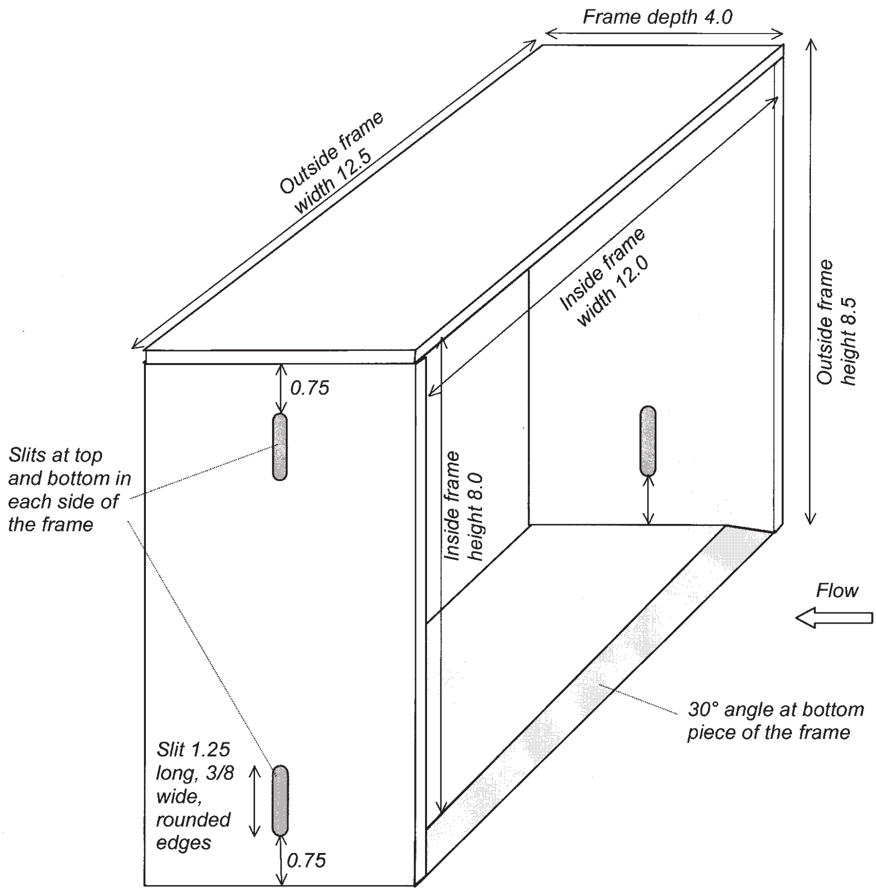

Figure 3—Detail of the frame with slits and beveled front edge (all measures in inches; oblique view).

webbing, the nets, or the operator's hands and gloves. A deburring tool works well for smoothing, but sandpaper can be used as well.

The Ground Plate

The bedload trap frame is mounted onto a metal ground plate (fig. 4) when in the stream. The ground plate extends a few inches upstream of the trap and prevents inadvertent particle pick-up at the sampler entrance (Bunte and others 2005). The smoothness of the ground plate accelerates the near-bottom flow velocity by 25 to 50 percent, which ensures that particles that have moved onto the ground plate will

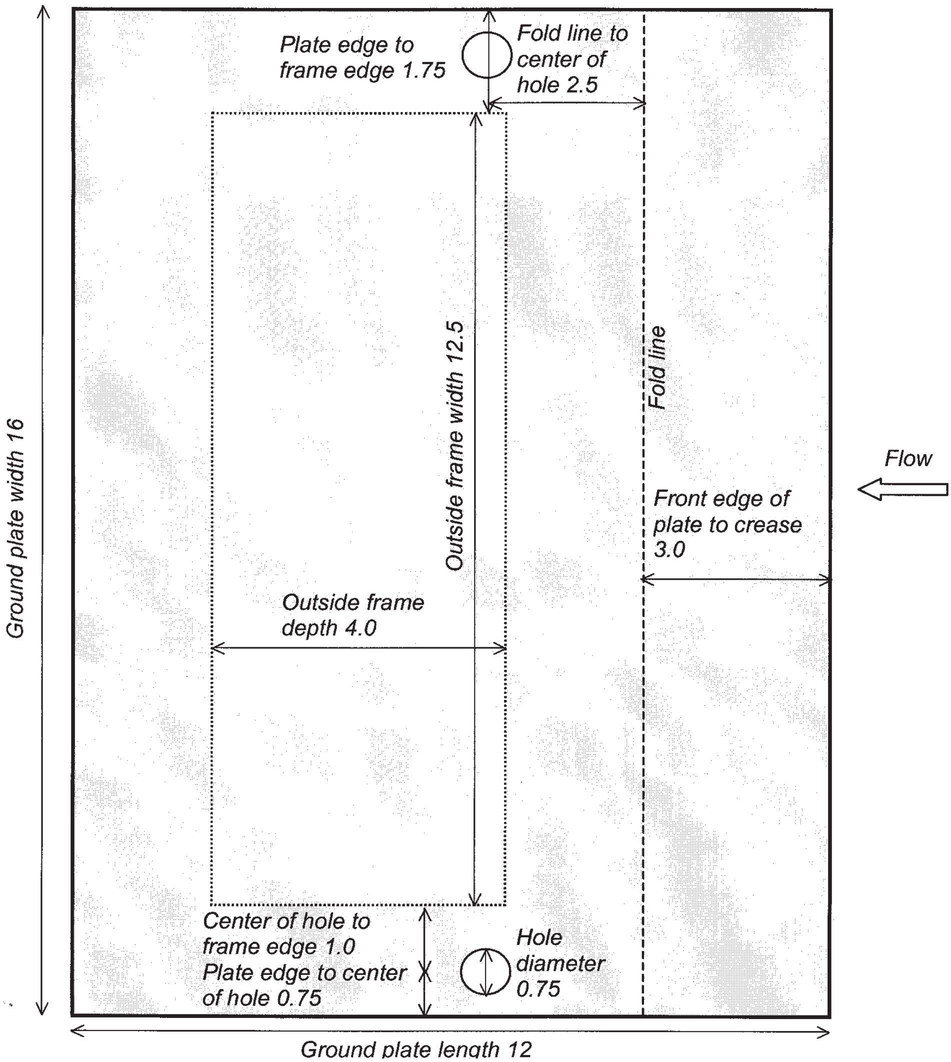

Figure 4—Top view of a ground plate and frame outline with dimensions (all measurements in inches).

proceed into the trap. Measurements to determine whether this accelerated flow extends onto the streambed in front of the traps have been inconclusive (Bunte and Swingle 2004).

The ground plate is 12 by 16 inches (0.3 by 0.41 m) in size and made of $^{1}/_{8}$ inch (3.2 mm) aluminum stock. Steel could be used, but is heavy, rusts under water, and should be painted (preferably in some bright color). The leading edge of the ground plate is bent downward slightly (by about 10°) along a fold line 3 inches (76 mm) from the front of the plate (fig. 5). This allows the upstream end of the ground plate to be pushed slightly into the streambed sediment. Sharp edges on the ground plates should be smoothed.

Stakes, Stake Driver, PVC Pipes, and Capping

Stakes are used to anchor the ground plates on the streambed (the process is described in Chapter 3). Stakes are made of 0.5 inch (12.7 mm) diameter cold-rolled steel and are available in hardware stores. Rebar is not a suitable alternative because the stakes need to be smooth. The bottom end of the stake should be ground to a pointed tip to facilitate penetration through the streambed material. The top end should be slightly beveled. Stakes of different lengths, between 2.5 and 4 ft (0.75 to 1.2 m), are useful to have on hand. Short stakes suffice at locations where flow depths and velocities are expected to be low, and stakes need only to be driven into the bed about 1 ft deep. Short stakes can also be used when the bed is difficult to penetrate. Longer stakes are necessary when the bed is loose and deeper anchoring is needed. Stakes should not extend above the plate more than about 2 ft (0.6 m) as placing and

Figure 5—Ground plate with inclined front edge, pieces of PVC pipe, and pieces of garden hose.

removing the traps becomes awkward. Stakes do bend occasionally and should be replaced if this happens. Stake tops may need to be re-shaped after a few seasons of use, and the tips may need to be re-sharpened.

Stake driver

We recommend using a stake driver to pound stakes into the streambed. A stake driver is a metal pipe approximately 1 ft (0.3 m) long with a 1-inch inside diameter onto which a 0.5-ft (0.15 m) long piece of solid steel rod, with the same outside diameter as the pipe, is welded as a cap. A metal shop can easily make this device. The open pipe end is set over the stake and the steel cap is pounded with a hammer. The stake driver prevents (much of the) mushrooming of the stake head during repeated hammer blows. A mushroomed stake head should be avoided because it makes removal of the traps difficult.

PVC pipes

At times when a bedload trap is not placed on the ground plate, pieces of PVC pipe (fig. 5) hold the ground plate on the stream bottom. These pieces are about 8 inches (0.2 m) long with a ¾-inch (19 mm) inside diameter that slides easily over the stakes. The bottom end of the pipe rests on the ground plate. A shaft collar is slid over the stake and screwed tight to hold the pipe pieces in place.

Stake capping

Pieces of garden hose about a foot long (figs. 5 and 6a) or mushroom-shaped plastic rebar caps (fig. 6b) are placed onto the ends of the stakes as a safety device to protect the operators in case they fall. Attaching garden hose to the stake tops has the added benefit of identifying the trap location when traps and stakes are submerged in deep flows (fig. 6c).

Webbing Straps

The frame is attached to the ground plate by four adjustable webbing straps that connect the frame to the stakes (fig. 7). An adjustable connection between the traps and the stakes is needed because, in practice, stakes are not exactly parallel to the frame, and each bedload trap plate configuration requires individual adjustment. Plastic friction-lock buckles (like those found on a backpack) tend to allow the webbing to slip and are not adequate to maintain the frame in position. Webbing straps with attached metal spring-loaded friction buckles are preferable because they resist slippage. Such straps are available in hardware or sporting goods stores. Select a sturdy strap, 1 inch (25 mm) wide, about 2 ft (0.6 m) long with a mid-sized buckle. The buckle should operate smoothly as it needs to be tightened under water when one is wearing neoprene gloves. Note that each trap requires four straps. See the section “Attaching the straps” in this chapter for details on how to attach webbing straps to the frame.

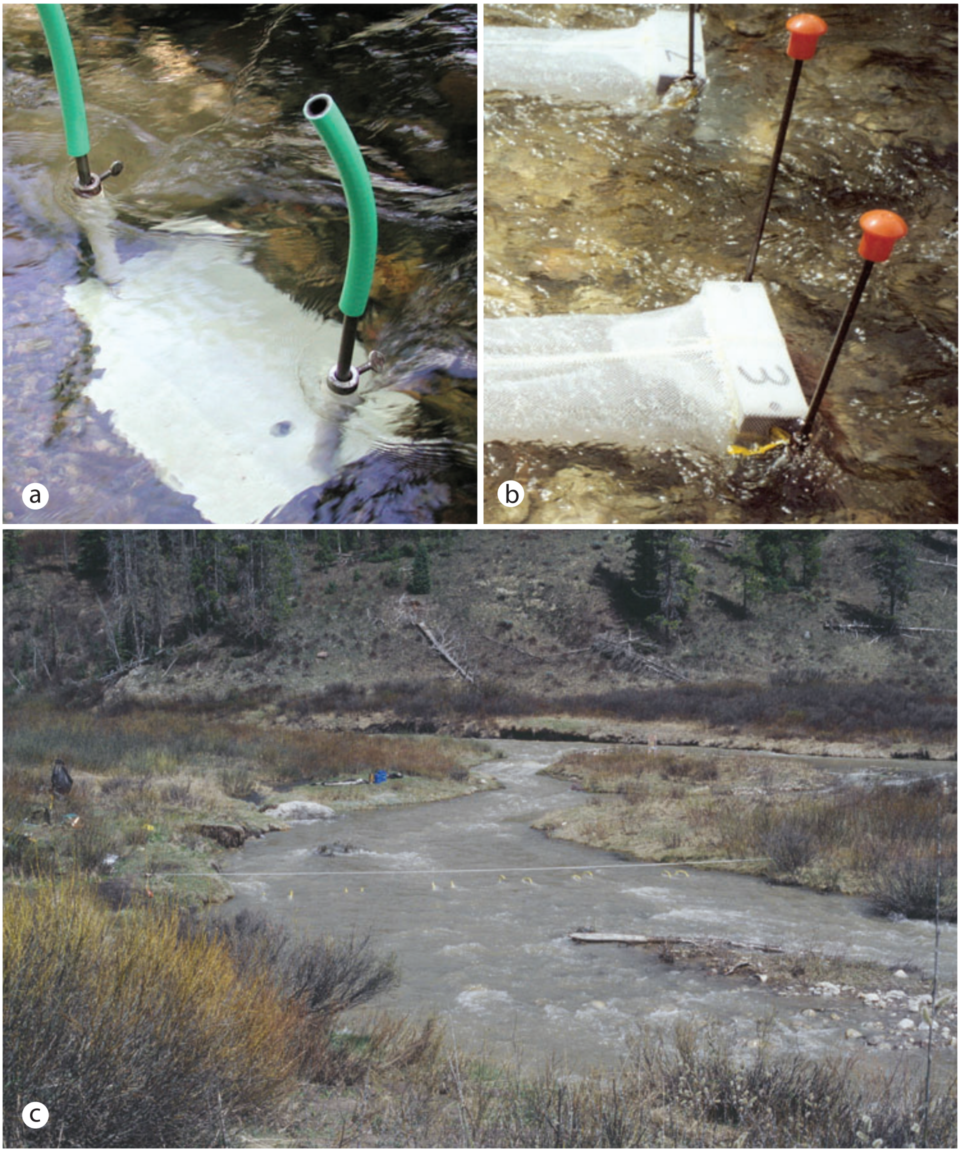

Figure 6—Stakes capped with pieces of garden hose (a) and rebar caps (b). Trap locations are only visible from the hose pieces sticking out of the flow (Little Granite Creek, 1999) (c). Note the tongue of fine gravel moving onto the ground plates (a).

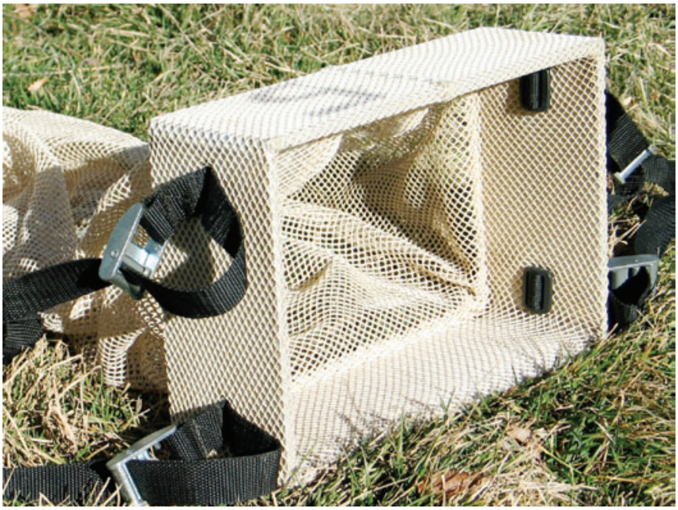

Figure 7—Four webbing straps with sturdy, metal spring-loaded friction buckles are attached to the frame.

Shaft Collars to Hold the Frame Down

The force of flow on the frame and the net can make the frame tilt backward, which disrupts the contact between the frame and the ground plate. If not corrected, this will cause an inaccurate sampling result. To prevent the frame from tilting or moving up the stakes, the webbing straps need to be held in place. We accomplished this by sliding shaft collars over the stakes and fastening them right above the webbing straps. Shaft collars are thick metal rings with an inside diameter slightly larger than the outside diameter of the stakes (fig. 8).

When buying shaft collars, select an inside diameter of $^5/_8$ inches (16 mm) for 0.5-inch (13 mm) diameter stakes. Shaft collars come with Allen set-screws. Replace the small Allen set-screw with a thumbscrew so that an operator wearing neoprene gloves can fasten and unfasten

Figure 8—Shaft collars with thumb screws to hold the webbing straps in place.

shaft collars under water. Use a center punch to deform the last thread at the tip of the thumb screw after it has been inserted into the shaft collar so it can't come lose and get lost in the stream. Both shaft collars and thumb screws are available in the specialty section of hardware stores. Lightly oiling the shaft collars and thumb screws after the field season reduces rust.

Net Materials and Fabrication

Gravel collected by a bedload trap is stored in an attached trailing net 3 ft (0.9 m) long or longer (figs. 1 and 7). Bedload trap nets are hand-sewn from netting material[2].

Netting Material

Bulk nylon Raschel knotless netting is used to make the bedload trap nets. This material is sturdy, abrasion resistant, and knitted of thin nylon yarn. It has proved remarkably strong and durable—able to hold samples of 20 kg—and requires little maintenance other than cleaning. It is commercially available from aquaculture suppliers in several mesh sizes and yarn thicknesses (Appendix C).

Recommended mesh size

The authors used a 3.6-mm mesh width netting. This mesh width seems to be a good compromise between permissible retardation of flow through the net and collection of small gravel particles (fig. 9). Using this net reduced the flow in the center of the trap entrance (4 inches above the plate) by about 10 percent, an effect considered too small to compromise accurate sampling (Bunte and Swingle 2004). A mesh width of 3.6 mm generally collects particles 4 mm and larger. However, flat particles with a b-axis slightly larger than 4 mm can escape because the mesh openings form parallelograms instead of perfect squares when the net is under load. To get a mesh *opening* of 3.6 mm, order a nominal mesh size of 3/16 inches (4.7 mm) (see Appendix C for further information).

Finer mesh sizes

We have experimented with attaching a 0.5 mm mesh-width net to the bedload traps (fig. 10a) and **do not** recommend using this configuration. The 0.5 mm mesh seriously retarded the rate of flow through the bedload traps. This caused the net to bulge and water to pond excessively upstream

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[2] We have experimented with machine sewing. Using a zigzag stretch stitch and stretchable nylon thread provides a stretchable seam. However, we have not tested the durability of such seams during a field season.

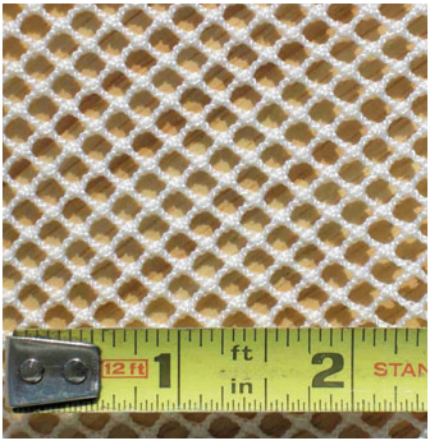

Figure 9—Detail of Raschel nylon knotless netting with 3/16 inch mesh size (3.6 mm mesh opening) used for bedload traps. The netting is shown stretched such that the mesh openings are approximately square.

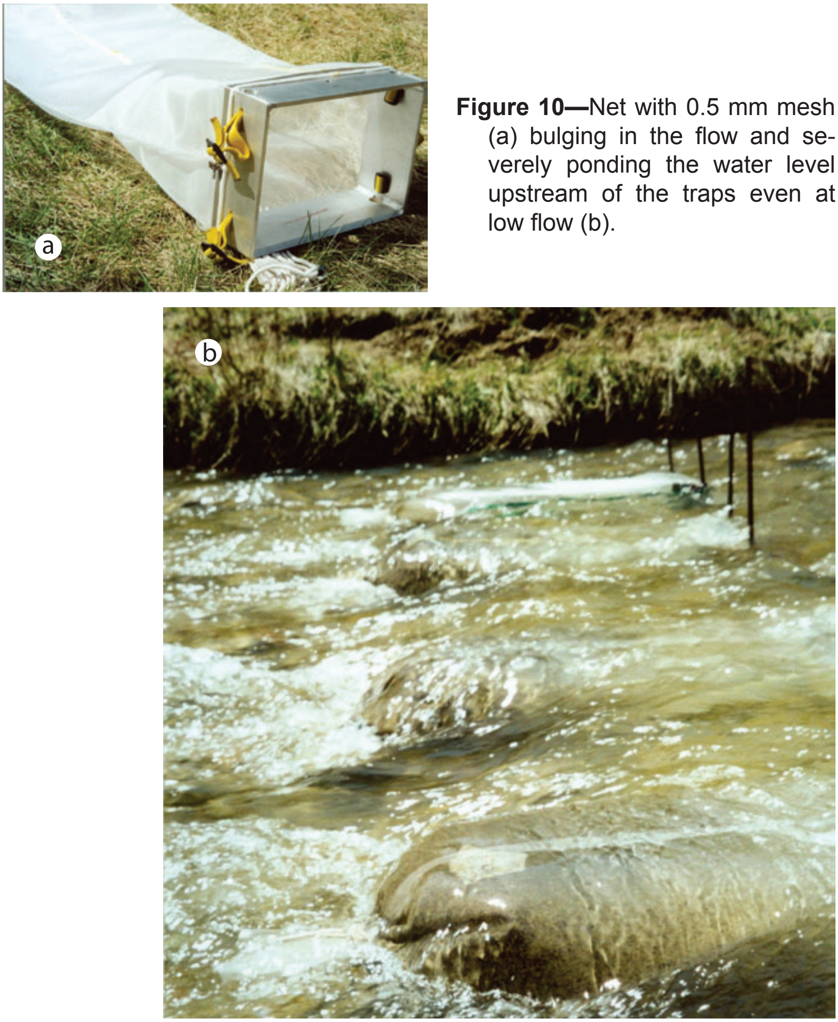

Figure 10—Net with 0.5 mm mesh (a) bulging in the flow and severely ponding the water level upstream of the traps even at low flow (b).

of the bedload traps (fig. 10b). Algae and fine debris caught in the net clogged the mesh and further exacerbated the hydraulic impedance. Unlike the flared entry of a pressure-difference Helley-Smith sampler that sucks water into the sampler entrance in order to compensate for the reduction of flow velocity caused by the fine 0.25 mm mesh, the bedload trap frame is unflared and therefore not designed for nets much finer than 3.6 mm[3].

Mesh sizes larger than 3.6 mm

Some studies are particularly interested in the transport of large gravel and cobbles that typically move together with a lot of finer-sized bedload during only the highest flows. In order to focus on the collection of very large particles at high flows, one could use a larger mesh size that lets the abundantly moving finer gravel, sand, and some of the coarse organic material pass through while leaving space in the sampling nets for the collection of the less abundant and less frequently moving coarse gravel and cobbles. Although we have not used a net with a mesh larger than 3.6 mm for bedload traps, larger mesh widths have been used successfully with a similarly designed net frame sampler to which Bunte (1996) applied a 0.39-inch (10 mm) mesh. Whitaker (1997) and Whitaker and Potts (1996) used a 1.25-inch (32 mm) mesh in a gravel bed stream with relatively few fines.

Net lengths

Nets should be at least 3 ft (0.9 m) long behind the trap to provide a sufficiently large sampling capacity and to permit the nets to be emptied while the traps remain in place on the ground plates. Shorter nets are not recommended because they fill quickly, and the sampling efficiency of the trap decreases if the nets fill beyond a capacity that is generally assumed to be 40 percent of the total sampler bag volume (Bunte and Abt 2005; Bunte and others 2006a; Emmett 1981). With a total net volume of about 6.4 gal (25 liters), the capacity of the 3-ft long net is about 2.7 gal (10 liter) of sediment and/or organic material or 44 lb (20 kg) of gravel. Nets need to be 5 to 6 ft long (1.5 to 1.8 m) when they are emptied from a footbridge (Chapter 3) in order to provide sufficient space for the operator to lift them (fig. 11, see also fig. 41 in Chapter 4).

Nets up to 8 or 9 ft long (2.4 m) can be used for bedload traps installed in parts of the stream that are unwadeable at high flow (fig. 12). With the help of a hook, the downstream end of the net is pulled from deep to shallower water where it can be emptied more easily. Long nets,

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[3] The performance of nets with mesh width slightly smaller than 3.6 mm, for example, 2 and 3 mm, has not been evaluated.

Figure 11—3-ft long nets proved too short for emptying the net from a bridge. Note the cramped workspace for the operator in the stream (a) (Photo courtesy of J. Potyondy, USFS Stream System Technology Center); 5-to 6-ft long nets are more suitable (b).

Figure 12—Two 8.4 ft (2.6 m) and one 8 ft (2.4 m) nets are installed in the outside bend in the deepest part of the stream. Two 3.6 ft (1.1 m) nets are installed in shallower water.

however, have a higher drag, and traps become more difficult to install on the ground plates as the flow pulls harder on the net. Long nets also have a tendency to be compressed by the flow. A few stiff hoops could be sewn on the outside of long nets to keep them open along their entire length. The exact length of the net might be best decided at the field site. An extra piece of netting can quickly be sewn on the net in the field. Long nets, however, should not be used for collecting samples (much) larger than is possible with 3-ft nets because the sample mass becomes unmanageably large.

Amount of netting material to order

The netting material is knitted to a width of 8 ft (2.44 m) when stretched (in aquaculture, this width is referred to as a hanging depth of 8 ft; see “depth” in table 1C, Appendix C). The material can be ordered to any length (in full feet).

A 4-ft (1.22 m) long section of this netting provides enough material to make two short nets, each about 3 ft (0.91 m) long behind the bedload trap frame (see “Cutting Patterns” in the next section). Nets longer than about 3 ft require a 4-ft long piece of material to build one net. Ordering an additional 4 to 8 ft of netting provides extra material should the nets have to be extended later. A piece of netting can easily be sewn on the end of a net to extend it.

Cutting the Netting Material and Sewing the Net

Cutting patterns

Measure the outside circumference of the bedload trap frame. For the frame 12.5 inches wide and 8.5 inches high shown in figure 3, the outside circumference is 42 inches (107 cm). Add 1.5 to 2 inches to the circumference plus 2 inches for the seam for a total length of 46 inches (117 cm) of material needed for one net. The distance from A to D in figure 13 indicates this length. Cut along the dashed line from A to B’. For a net 3 ft (0.91 m) long behind the frame, measure 4 ft (from A to B)—while the net is stretched—and cut along the line BC. For a 5-ft (1.52 m) long net, cut along the line B’C’. Use the entire width of the material (from A to B’’) for a net that is approximately 7 ft (2.13 m) long behind the frame. Use scissors to cut along the same mesh row to ensure that all cut pieces will be of the same size. A piece of netting 12 ft long provides material for either six nets, each 3 ft long, or three nets longer than 3 ft.

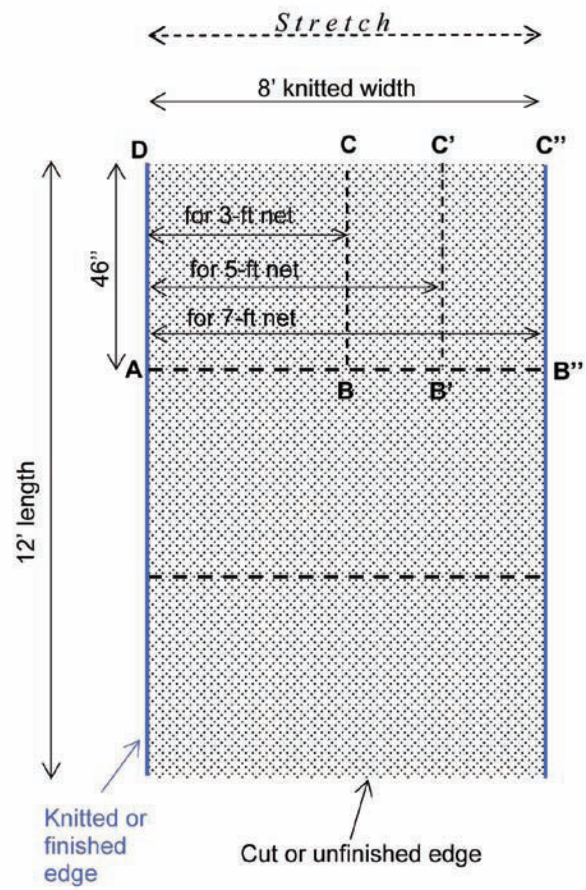

Figure 13—A piece of netting with a knitted width of 8 ft (in other words, with an 8 ft hanging depth) and 12 ft long. The corner points A, B, C, and D refer to the corner points in figure 14.

Sewing the nets

***Needle and thread*—**To hand sew the nets, use tightly twisted nylon yarn[4], about 1 mm in diameter, and a carpet needle with an eye large enough for 1 mm thread. Both can be purchased in a sewing or hardware store. A carpet needle is about 2.5 inches (6.4 cm) long, slightly curved, flattened near the tip and only slightly pointed. For a 4-ft long seam, thread the needle with a piece of yarn about 6 ft (1.8 m) long. Prevent the yarn from unraveling by using a butane lighter to sear both thread ends lightly after the needle is threaded. While it is still hot, squeeze a seared end quickly between your wetted thumb and index finger to flatten it (careful, hot). Avoid forming a big blob that will be in the way when sewing.

[4] Yarn used for tying purposes; un-stretchable and more tightly twisted than used for knitting or crocheting.

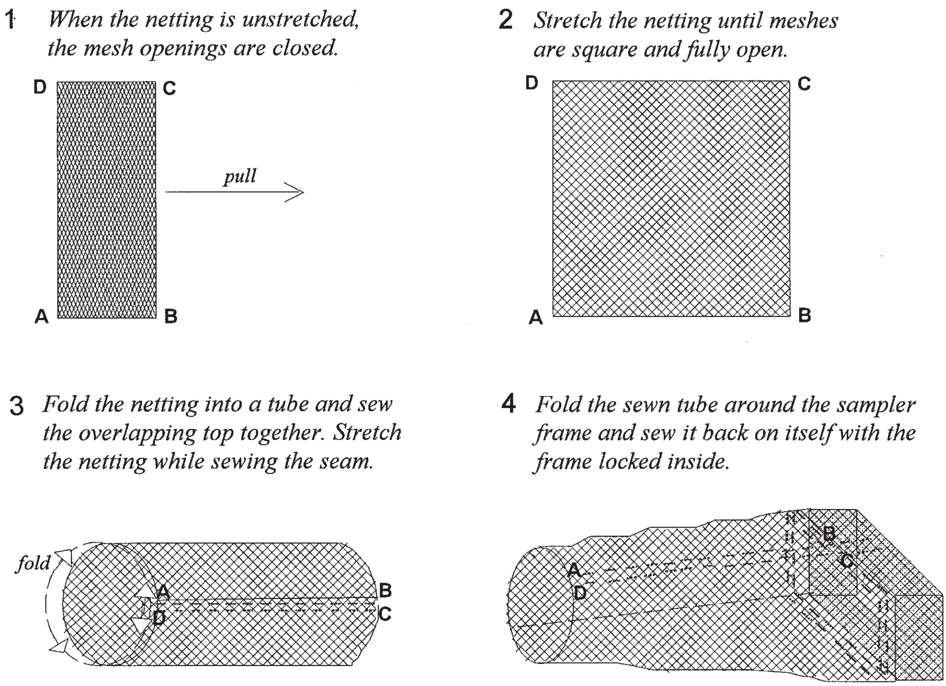

Figure 14—Step 1 to 4: Sewing the nets for the bedload traps. The lettering of the corners corresponds to the lettering in figure 13.

Sewing the tube—A cut piece of netting material has a tendency to pull together into a rectangular shape (fig. 14; step 1). Stretch the material to open the mesh holes to see the size that the netting will assume when deployed in the stream. The direction of the stretch is in the upstream-downstream direction of the net (fig. 14; step 2). Fold the netting into a tube that stretches along its lengthwise direction. To make a flat seam, lay the netting edges on top of each other so they overlap by about 1.5 inches (4 cm) (fig. 14; step 3). Position the netting so that the mesh holes of the upper and lower net line up exactly. Leave about a foot of thread hanging at the beginning of the seam (to be secured later). Using a simple forward up-and-down stitch, sew through the mesh openings, not through the netting material itself. For a straight seam, keep the stitches within a row of mesh holes (fig. 15). Sew two parallel seams in two separate mesh rows.

It is important to *stretch the netting* while sewing it because the netting material will have a tendency to pull together and away from the direction of stretch. Hold part of the material tight between your knees while stretching the part that is being sewn, or press the netting against your knee with your sewing hand and stretch the material with your other hand. Repeatedly stretch the piece of seam that was just sewn.

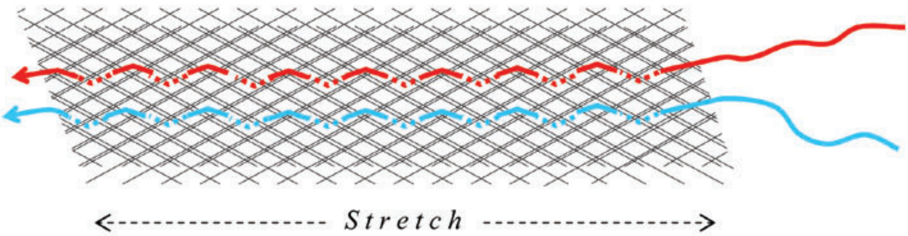

Figure 15—Two parallel seams sewn through the mesh openings using a simple forward up-and-down stitch. The two layers of netting are positioned such that mesh holes exactly overlay each other.

After the entire seam is completed, stretch it to its fullest extent. Ensure that the piece of thread hanging at the end of the net is not pulled entirely into the seam when stretching the net. Then secure the thread ends, either by sewing through a few inches of netting or by tying a few knots. If the seam is not stretched while sewing, it will be shorter than the length of the net as soon as the net is stretched in the water during sampling. Nets that have a seam along the top that is too short or shriveled are awkward to operate.

Sewing the tube around the frame**—**After the tube is sewn, push one end of the tube through the inside of the frame and fold it outward around the frame (fig. 16, fig. 14; step 4). The beveled edge of the frame

Figure 16—The sewn netting tube is folded around the frame.

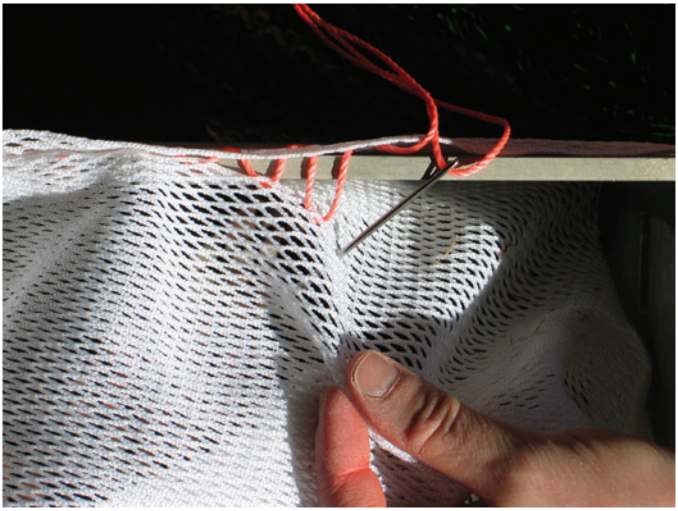

Figure 17—Stitching loosely through the upper and lower layers of netting while the layers are apart and the mesh holes are visible. The thread is pulled tight after a few stitches to close the seam.

must point toward the front of the sampler; the net points to the back of the sampler. The seam along the length of the tube should be placed along the middle of the top of the frame. The nylon yarn used for sewing the tube abrades and becomes nappy if the seam is placed on the underside of the trap where it can rub against the gravel bed.

The fold of the net tube around the frame should have some slack. The netting can be temporarily secured into its folded position with a few twist ties, tooth picks, or paper clips. To sew the netting around the frame, stitch through the mesh holes, staying within the same row of holes. It may be difficult to line up the mesh holes of the upper and lower layers of netting. Loosely stitch through the upper layer of the net, the lower layer, and the upper layer again. Hold the two layers apart so that mesh holes are clearly visible (fig. 17). After a few stitches, pull the thread tight to connect the upper and lower layers. Place the second seam parallel to the first so that none of the seams is more than about 1 inch away from the metal of the frame.

Attaching the Straps

Webbing straps are attached to the frame through the vertical slits. The webbing is fastened behind the slits with a plastic tension buckle that is placed inside the frame and acts as a crossbar. The first step to attaching the webbing straps is to cut open about three of the mesh

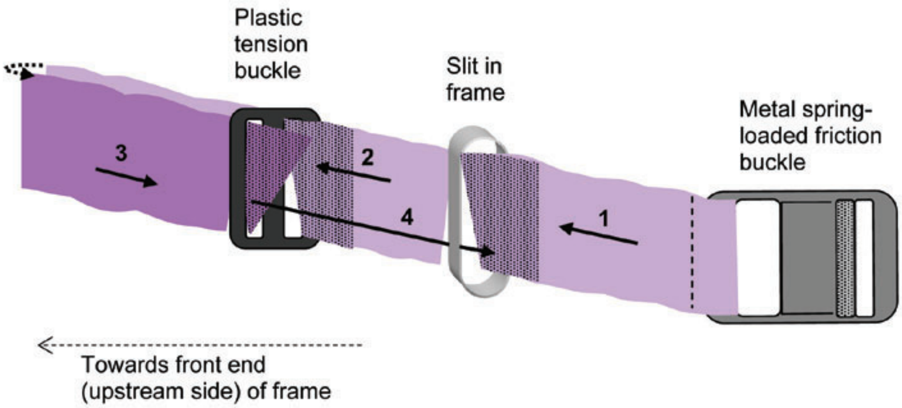

Figure 18—Four steps of fastening the webbing straps to the frame. The numbers refer to the steps described in the text (see fig. 7).

holes covering the slits. Insert the stiff front end of the strap (with the friction buckle on the trailing end) into a slit on the frame from the outside of the trap (fig. 18; step 1) and pull it through so that about 2 inches of strap remain before the buckle. Insert the stiff front end into the right slit of the plastic tension buckle (fig. 18; step 2) and bring it back through the left slit (fig. 18; step 3). Place the tension buckle right behind the slit inside the trap frame. Lead the stiff end of the strap from the inside to the outside of the slit of the frame (fig. 18; step 4), and pull the strap tight. A close-up view of a bedload trap with netting and straps in place is shown in figure 7.

Numbering Bedload Traps

Each trap should be numbered on its top with a permanent marker (for example, 1 through 4 or A through F) depending on the number of traps to be used at a site. Numbering identifies which trap goes with which ground plate. This match is important because the straps on each trap are specifically adjusted to the position of the stakes at each plate. Bedload traps and collection buckets should be labeled with the same number to ensure samples correspond with their location in the stream cross-section.

CHAPTER 3.

Installation of Bedload Traps

Installation of bedload traps on the stream bed involves four steps: 1) Selecting a site, considering both the stream reach and the cross-section; 2) Positioning the traps within the selected cross-section; 3) Setting and anchoring the ground plates; and 4) Preparing the area next to the traps. The four steps are described as follows.

Selecting a Sampling Site

Careful selection of the study location is important in order to adequately sample bedload, meet study objectives, and avoid undesirable site-specific results. Two main criteria need to be considered: Appropriateness of the site to answer the study question and suitability of the site to deploy bedload traps.

Appropriateness of the Site to Answer the Study Question

Several criteria may be involved in the selection process depending on the study aim and local stream conditions:

- Distance from upstream gravel sources and sinks,
- Selection of a representative site versus sampling at a specific stream location, and
- Proximity to infrastructure (gauging station, road, work area).

Distance from upstream gravel sources or sinks

Proximity to upstream gravel sources or sinks affects measured bedload transport rates and influences the shape of the bedload transport–discharge relationship. In general, it is better to avoid sites just downstream from either source or sink locations. If gravel bedload is collected just downstream from a gravel source, measured transport rates may be generally higher than at other stream locations. Transport may also increase markedly on the first rising limb of seasonal flow, and the same rates may not be reached during the falling limb of flow, resulting in a clockwise hysteresis loop in a graph of transport versus flow. This is particularly true if the sediment source becomes depleted over the course of the highflow event. If gravel bedload is collected at a site below a sediment sink, transport rates are generally lower there than at other stream locations and there may be a delayed response of bedload transport to flow, causing a counterclockwise hysteresis loop.

Sources of gravel to the stream may include accumulations of hillslope sediment at the stream banks supplied over periods of low flow, easily erodible material from bank collapse, gravel supplied from recently destroyed log jams or beaver dams, bedload waves traveling downstream, and material from degrading reaches upstream. Complete gravel sinks include beaver dams, new log dams or log jams, some flow diversion structures, or sediment retention ponds. Partial sediment retention may occur below a partially filled log dam or when sediment deposits upstream and downstream from a partial stream blockage, such as a log protruding into flow.

Selection of a representative site versus sampling at a specific location

One criterion for selecting a study site might be that the data collected must be suitable for making generalizations regarding transport over the entire stream reach. This means that bedload transport rates and particle sizes measured at the sampling site should be representative of a study reach and not be excessively influenced by local conditions. By contrast, a study aim might be tied to a specific stream location. For example, one might want to compare bedload transport rates or particle sizes upstream and downstream from a tributary or a site that received gravel augmentation or was subject to gravel mining. Similarly, a study may want to compare transport rates collected between riffles and pools, over a series of downstream cross-sections, or at the same location over time. The site location may also be influenced by proximity to a gauging station, a road, or other infrastructure.

Suitability of the Site to Deploy Bedload Traps

Using bedload traps poses additional criteria for site selection. These site criteria are:

- Wadeability at high flow,
- Sufficient dry workspace on the banks, and
- Absence of boulders from the sampling site.

Further desirable features are:

- Suitability for placement of a footbridge (if one is to be used) and
- Vehicle accessibility.

Wadeability at high flow

Wadeability of the cross-section, preferably up to bankfull flow, is a prerequisite when using bedload traps. There are several considerations involved in identifying wadeable locations and making marginal areas more wadeable. These include:

- Operator stature,
- Magnitude of flow and stream geometry,
- Sampling across the head of a point bar,
- Applying long nets to the bedload traps, and
- Installation of a footbridge.

***Operator physique*—**Whether a specific flow condition is wadeable for a person depends on the wading person's physique. Based on flume experiments with tethered people holding their footing against increasing flow, Abt and others (1989) assessed wadeability by establishing a relationship between the wading person's physique and flow conditions. The person's physique was determined as the product of body weight (lb) and height (inches). Flow conditions were quantified by the product of mean flow velocity (in units of feet/second) and flow depth (in units of feet), also called the product number. The critical product number, PN_{crit}, for a tethered operator when footing was lost increased with the product of the person's weight and height. The critical product number for wadeability can be predicted from a linear regression

$$PN_{crit} = 0.8\ (wt * ht/1000) + 6. \tag{1}$$

Based on Eq. 1, the average point at which footing was lost occurred at a product number of about 10 for a petite (5 ft; 90 lb [1.52 m; 41 kg]) person and at 18 for a tall (6 ft 3 inches [1.9 m]) and heavy (200 lb [91 kg]) person (fig. 19).

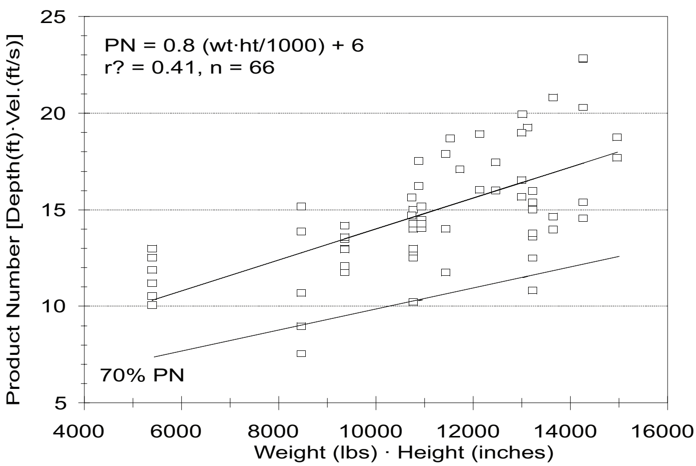

Figure 19—Limit of wadeability quantified by the product number for persons of different weight and height. Data plotted from Abt and others (1989) and fitted with a linear equation (thin line). The thick line indicates 70 percent of the critical product number, a more practical limit of wadeability in coarse-bedded mountain streams.

Based on our experience, the practical limit of wadeability in the field is substantially lower than predicted from Eq. 1, perhaps at 60 to 80 percent of the flume value, because a wading person usually does not push wadeability to the limit of falling. Factors such as bottom slipperiness, bulkiness of waders, objects carried, and work near the stream bottom further decrease the wadeability of a particular flow, while a person's athletic capability, safe wading practices, and use of safety devices increase it. However, a person needs to consider not only the risk of slipping, but also the risk associated with the consequences of lost footing. See Appendix D for more information on safety issues while wading.

***Wadeable flows in Rocky Mountain streams*—**Whether flow conditions are wadeable at high flow depends on the discharge and on the channel geometry. Even small streams with moderate highflow discharges may not be wadeable at all locations in the stream. Cross-sections wider than average have the best chance of being wadeable at bankfull (or higher) flow and are preferred study sites when using bedload traps (fig. 6c). However, the selected site should not scour or aggrade during a highflow.

To determine whether a specific discharge is wadeable at bankfull flow would require fixed relationships between discharge, stream morphology, and wadeability for streams in different climatic regions. Without fixed relationships, one can resort to a rule of thumb: coarse-bedded Rocky Mountain streams with mainly plane-bed morphology tend to remain wadeable at the widest cross-sections in flows up to about 200 cfs (6.2 m^3/s). A bankfull flow of 200 cfs may be expected in watershed sizes of approximately 20 to 40 square miles (50 to 100 km^2), depending on mean annual precipitation and watershed conditions.

***Bedload sampling across the head of a point bar*—**If a cross-section expected to remain wadeable at high flow cannot be located, sampling only across the head of a point bar may be another option. Our experience at several streams has shown that gravel transport follows a particular downstream path in a coarse-bedded stream with a meandering thalweg (Bunte and others 2004a, 2006b; fig. 20)[5]. For a specified cross-section within the reach, the lateral position of most gravel bedload transport is generally predictable. In a transect across the *head* of a point bar, most of the gravel is transported over the submerged (and likely wadeable) point bar, while almost none of the gravel moves through the thalweg (at least not in flows below bankfull). The lateral location of maximum gravel transport even appears to shift further

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[5] The path is similar to the path of the coarsest particles in sand-bedded streams (Anthony and Harvey 1991; Bridge and Jarvis 1982; Dietrich and Whiting 1989; Julien and Anthony 2002).

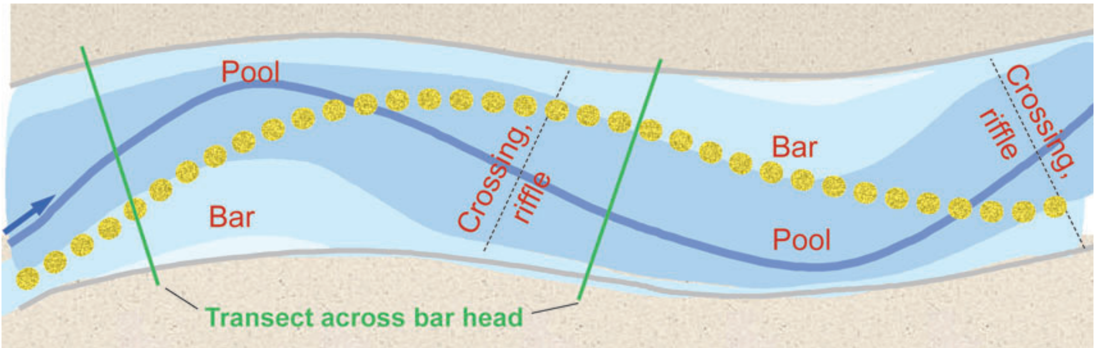

Figure 20—Approximate path of major gravel transport in a meandering-thalweg, coarse gravel-bed stream (yellow dottes band). Darkest blues indicate deepest flows (from Bunte and others 2006 b, slightly modified).

toward the bar side (and away from the thalweg) with increasing flow (Bunte and Swingle 2005, Bunte and others 2006b). Thus, little of the gravel transport is missed if the thalweg of that cross-section is not sampled in flow below bankfull.

Long nets—In order to extend sampling as far as possible into the deeper flows of the thalweg area, the authors have attached nets 6 to 8 ft (1.8 to 2.4 m) long to the bedload traps (fig. 12). The end of a long net can be pulled aside into shallow flow to empty it. Note, however, that a daily period of lower flows is needed to set and retrieve the bedload traps from their ground plates when operating under these conditions.

Adding a footbridge—The best option for using bedload traps in marginally wadeable flows (and flows of all depths) is to install a footbridge positioned a few inches above the water surface. The operator can then hold on to the bridge when wading through the water to service the bedload traps. In addition, the amount of bank-to-bank wading is greatly reduced because the second operator does not enter the water, but assists from the bridge surface, carrying buckets, gravel samples, and support equipment across the bridge. Footbridge use is described ahead in this chapter. If a footbridge is used, the selected site should have a stable bed near the banks to support the cinderblocks on which the bridge rests (or an opportunely placed boulder), and the stream should be somewhat incised.

Adequate dry workspace on the banks

Another practical aspect to consider when selecting a site is ensuring adequate workspace on the banks for handling the bedload traps and the samples collected in them. Open space on the banks is needed for washing and bagging samples, as well as for storing field gear. A work area of about 400 ft^2 (37 m^2) is minimal for two people. Water seepage and rain can quickly turn a vegetated work area into a morass. Areas

Figure 21—Foot mats placed at the end of a footbridge to protect the grass from trampling and to avoid creating a mud puddle.

receiving high foot traffic can be protected by placing permeable foot mats on the ground [6] (fig. 21).

Absence of boulders in the stream bed

Avoid sites dominated by large cobbles and boulders in the streambed when using bedload traps. Buried large clasts make it difficult to drive the stakes into the bed, while protruding boulders direct the flow, cause scour jets, and lead to irregular spatial patterns of transport and deposition of bedload within the cross-section. Note that the influence of boulders on the lateral distribution of transport can extend downstream for a distance several times larger than the boulder diameter.

Accessibility by vehicle

Bedload traps are portable, so two or three people with backpacks can carry into remote areas all of the equipment necessary for a bedload trap study. This allows studies to be performed independent of direct road access and at undisturbed sites. Transporting the majority of the gear can be limited to the beginning and end of the field season. Most of the gear can be left out overnight, covered with a tarp, and tied to a tree with a long plastic-mantled cable and a padlock. Other advantages of a remote site study are lower probability of site disturbance by curious explorers and reduced potential for vandalism. What speaks for a

[6] Foot mats that are made from cut tire pieces have worked well and are available in hardware stores.

vehicle-accessible site is its convenience and support for the often wet and cold operators. If a footbridge will be hauled to the site, vehicle accessibility to within a few hundred feet is required.

Final Site Selection

Before selecting potential study sites, the authors suggest ranking the selection criteria according to their importance and walking along the stream for a mile or two at low flow. Walking provides an overview of gravel source and sink locations, channel width and wadeability, stream morphology, stream accessibility, etc. Selecting a sampling site is often a competition between factors that speak for or against a specific location. Listing pros and cons of potential sites and discussing them can help the selection process. One also needs to consider that appropriate locations need to be found for ancillary measurements such as stage and discharge, and that a space conflict might arise at the sampling site (Chapter 4).

Once the site is selected for the bedload traps, the cross-section should be flagged and marked with rebar stakes for the duration of the study. If the site is not remote, signs informing passers-by and anglers about the study site and asking people to stay off may be helpful (fig. 22).

Figure 22—Sign set up at a bedload trap study site near well-frequented camp sites at Halfmoon Cr., CO.

Positioning Bedload Traps Within the Cross-Section

Several bedload traps should be deployed per cross-section to cover the majority of the stream width. In narrow and high gradient streams, we have spaced bedload traps as close as 2 ft (0.6 m) apart. In wider streams, the maximum trap spacing was 6 ft (1.8 m). Traps may be spaced evenly or unevenly across the stream. Use an even spacing along a transect if the study objective is to document the lateral variability of transport or if the lateral distribution of gravel transport is unknown. Perfectly even spacing (such as the *equal-width* spacing typical of Helley-Smith sampling) is usually not possible because some of the ground plates may need to be shifted laterally in order to find a location where the stakes holding the ground plates can be driven in.

If the study objective is to provide the most accurate prediction of the cross-sectional transport rate, trap spacing should coincide with width increments of approximately *equal transport*. This requires predicting the locations of the highest transport rates, either from patterns of stream morphology or from pilot measurements. However, the user must weigh the advantage of increased accuracy in measured cross-sectional transport rates against the risk that the selected spacing may become unrepresentative, because transport locations vary to some degree over time and with flow. A major change in transport paths is likely to occur after changes in the local stream morphology, in response to high flows, with a change in sediment supply, or with high bed mobility. In practice, the bedload trap spacing is a compromise between equal-width spacing, equal-transport spacing, and finding the location where the stakes can be driven into the bed. Ground plates can be laid out and arranged on the streambed in low flow to help visualize the best position of the bedload traps in the cross-section (fig. 23).

Figure 23—Ground plates are laid out in a cross-section at low flow.

Setting and Anchoring Ground Plates

Placing Ground Plates at the Right Height on the Bed

Position ground plates flush with the mean surface level of the bed without protruding above, or lying below, this level (fig. 24 a through c). Two methods can be used to obtain this position: 1) When flows are low, remove large surface particles from the area where the ground plate is to be placed and replace them with smaller ones. Place the ground plate onto the streambed (fig. 25) and check it for the appropriate height. Remove large stones, replacing some with smaller ones, and continue to check the ground plate height until it is flush with the mean level of the bed. Fill gaps along the sides of the ground plate with a few stones large enough to fill the gap. 2) If flow is already high, ground plates are best

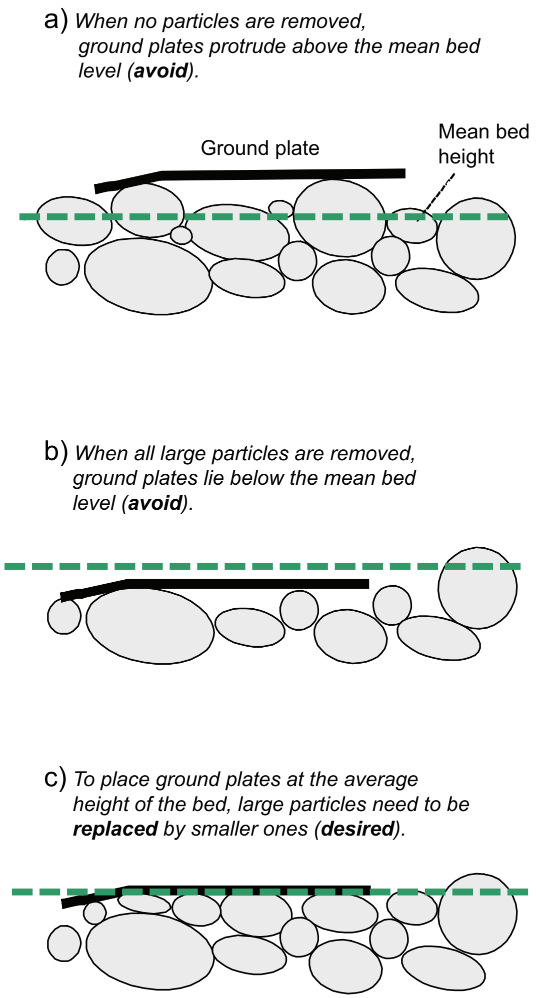

Figure 24—Ground plate positions in relation to the mean bed level (side view). Avoid positions a) and b).

Figure 25—Setting a ground plate onto the stream bottom.

installed by shoving the bent front edge of the plate about an inch deep into the bed surface. Hold the back end of the ground plate above the bed and remove all large surface particles below the plate. Lower the plate onto the bed and check for the appropriate elevation relative to the mean height of the bed. Remove or replace larger stones with smaller ones until a satisfactory position for the ground plate is reached.

Water flow should be as low as possible as the operator must crouch on the stream bottom to install the ground plates. The best time for setup is shortly before the onset of the snowmelt highflow season. However, installation may be hampered in early spring by snow drifts that cover roads and stream banks, making them inaccessible and complicating logistics. On the other hand, if you wait until the snow has melted, you may find yourself in a sudden warming spell that quickly increases flows. Installation of bedload traps at near bankfull flow is possible in some streams, but may result in poor placement of the ground plates and is a rather wet and cold enterprise. Ground plate heights may need to be adjusted occasionally during highflows to match the bed plane in actively degrading or aggrading beds (Chapter 4).

Driving in the Stakes

Once a ground plate is properly positioned, anchor it to the streambed by pounding the stakes through each hole at the sides of the ground plate 1 to 1.6 ft (0.3 to 0.5 m) deep into the bed (if necessary). Step on the plate to hold it in place on the bed. Use a driver (fig. 26) to pound the stake to prevent the head from mushrooming. The first few inches of penetration into the bed can usually be obtained by sliding the stake

Figure 26—Starting to drive the stakes in by sliding the stake driver up and down.

driver down on the rod. Driving the stakes with a hammer is generally a two person operation. One person holds the stake driver with both hands, keeping the orientation of the stake as vertical as possible, while the other person pounds the stake driver using an engineers' hammer or a lightweight sledge hammer. The pounding must be controlled and deliberate so that if the stake hits a rock and vibrates heavily, quick blows with the hammer do not miss the stake and hit the hands of the person holding the driver.

If a stake hits an impenetrable rock, which happens more frequently in cobble than gravel beds, try a new location a few inches away. Go through the procedure described previously for positioning the plates relative to the streambed. Ideally, the stakes holding the plate are parallel and at right angles to the plate. In practice, one or both of the stakes will be off vertical to some degree. Adjust the length of the webbing straps on the traps to compensate for this imperfection in stake orientation (Chapter 2). It is important to make the strap adjustments and actually position the trap over the stakes and onto the plate before deciding that the installation is adequate and that the stakes will not have to be removed and re-driven.

Restoring the Streambed Area Around the Ground Plates

If the installation process disturbed the streambed at the upstream side of the traps, the bed must be restored to avoid artificially increased or decreased particle entrainment conditions near the bedload trap

Figure 27—Ground plates installed on the stream bed during low flow (view upstream).

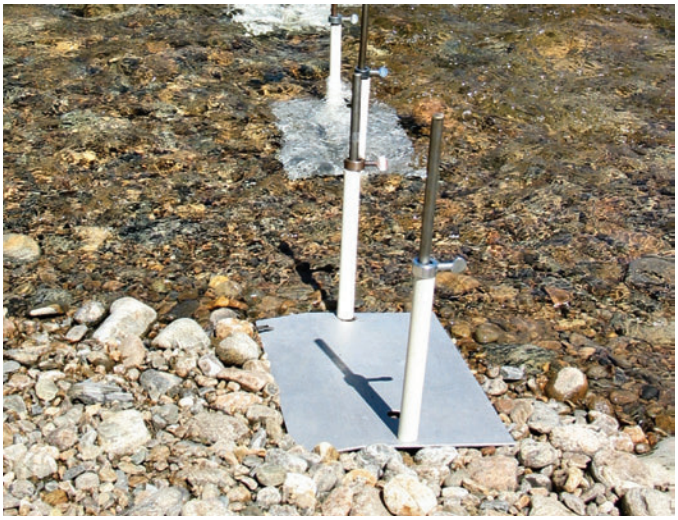

Figure 28—Ground plates with PVC pipe pieces fastened with shaft collars.

entrance. Replace the large particles that were removed at the upstream side of the ground plates with smaller ones along the front edge of the ground plate that sticks slightly into the bed. Gather finer bed material from a nearby location and carefully place it over the replacement stones to refill interstitial spaces (figs. 27 and 28). To ensure that particles at the remodeled streambed have settled into place, do not commence sample collection for at least several hours after the ground plate installation.

Finishing Plate Installation

When bedload traps are not installed for sampling, the ground plates must be held down on the streambed to prevent them from being lifted by flow and presenting an obstacle that might cause bed scour. Ground plates are held in place by pieces of PVC pipe and shaft collars. The pipe acts as an extender, such that the shaft collar does not need to be fastened deep under water directly on the ground plate (fig. 28). Place foot-long pieces of garden hose on the top of the stakes (figs. 6a and b) so they are more visible, particularly if flow starts to overtop the stakes, and to add a safety feature should a person slip and fall onto a stake.

Once the ground plates are installed, confirm they are still positioned within the originally selected cross-sections and adjust the cross-section markers on the bank (rebar stakes) if necessary. Next, measure the ground plate locations along a tape strung between the two rebar stakes. Accurate measures of trap spacing along the cross-section are necessary because transport rates are individually computed for each trap and the stream section that it represents (Chapter 5).

Protecting the Streambed

Foot Traffic, Bed Armor, and Stepping Stones

Walking repeatedly on the bed can shift surface particles—even cobbles—and loosen their interlock with other bed particles. All foot traffic upstream of the trap cross-section should therefore be strictly avoided whether or not bedload transport is taking place. Walking behind the traps (unavoidable) disturbs the armor layer and can form a scour trough. The scour increases with the amount of foot traffic, strength of flow, and erodibility of the bed. If scour advances upstream between the ground plates, the traps will become pedestalled, which greatly reduces their sampling efficiency and requires resetting the ground plates (Chapter 4). In a relatively fine-grained stream bed or high flow velocities, stepping stones are useful to prevent tread impacts on the bed and subsequent scour. Barbell weights with a diameter of about 15 inches and a weight of 35 lb make good stepping stones (Bunte and Swingle 2007). Stepping stones that are of lighter weight (for example, 1-foot diameter concrete garden foot path stones) are useful only at moderate flows (fig. 29). At high flow velocity, they become entrained, leave scour holes, and become obstacles to the operators (Bunte and Swingle 2003a). If scour does occur behind the traps, it can be reduced by strategically placing and embedding a few cobbles (collected downstream) more or less flush with the bed surface.

Figure 29—Stepping stones placed behind ground plates in relatively fine gravel bed material at the East St. Louis Creek sampling site. Note the impractical, unnecessarily long stake lengths at the two ground plates near the left bank. The 16-ft long footbridge in the back is placed too close to the ground plates causing a cramped work space for the trap operator.

Use of a Footbridge

A footbridge greatly reduces the amount of treading and subsequent bed scouring. It also extends wadeability to higher flows and is generally useful when operating bedload traps (figs. 29, 30; see also fig. 41 in Chapter 4). Although stepping on the bed is required when servicing the bedload traps, standing next to the footbridge provides support to the operator and allows him/her to deposit the traps and the collected sample onto the bridge before and after deployment in the stream. A second person on the bridge assists the operation (Chapter 4). Using a footbridge is highly recommended with the bedload traps, particularly if the bed is erodible, flows are expected to be high, or large numbers of samples are to be collected.

The footbridge rests on cinder blocks at each side of the stream (fig. 31). As flow rises, additional cinder blocks may be added to elevate the bridge above the water surface. The goal is to keep the underside of

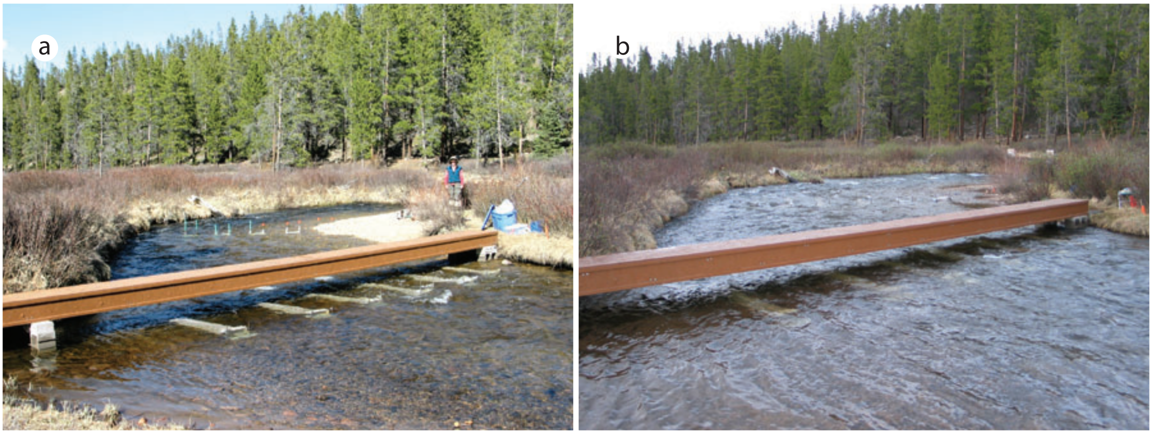

Figure 30—A 32-ft long footbridge installed at Halfmoon Creek at low flow (a) and at 70 percent of bankfull flow (b).

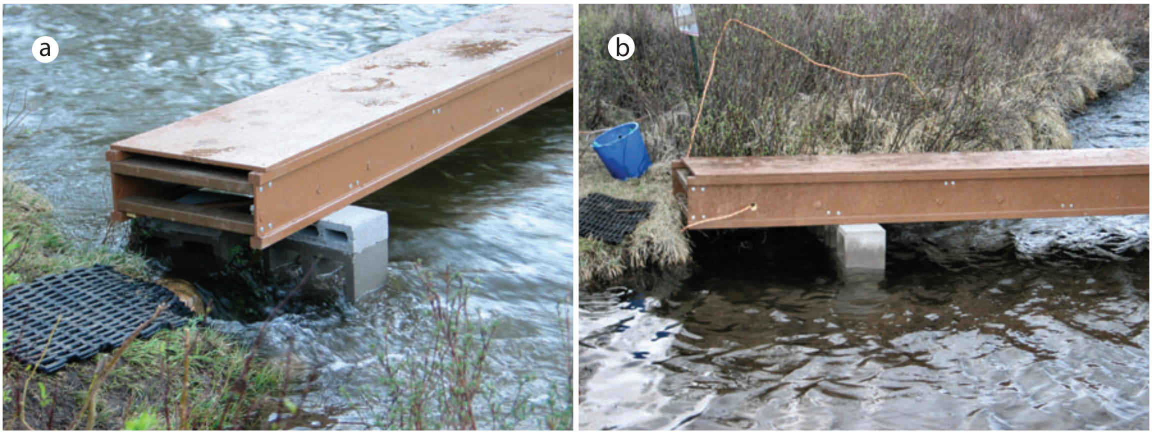

Figure 31—Details of the bankward side of the bridge resting on cinder blocks. Note the foot mats placed on the banks to protect vegetation at the location of repeated treading (a). The slack rope in (b) ties the bridge to a nearby tree.

the bridge as close to the water surface as is safely possible—approximately 0.5 ft (0.15 m). If the site is left over night, it may be necessary to prop the bridge up higher to ensure that floating debris will pass under the bridge and to allow enough space for an unexpected rise in flow. We recommend that one end of the bridge be tied to a tree or post in the bank so that if the bridge is swept off its cinder block supports, it will swing around and come to rest parallel to flow along the bank.

Figure 32—Close up of the footbridge used at Halfmoon Creek without decking (to show construction).

The footbridge shown in figures 30 and 31 was constructed using floor joists, 2 by 4 lumber, and plywood decking following the plans by Pitlick and Miller (1987) and Martinez and Ryan (2000). Two people assembled this footbridge in less than two days using handheld power tools (waterproofing took most of this time). Construction details for this bridge (fig. 32) are described in Bunte and Swingle (2005). Transportation of a 32 ft bridge requires a large truck or a trailer. The decking is installed after the bridge is in place across the stream (and removed before the bridge is pulled from the stream). Without the decking, two people can carry this bridge over a short distance.

CHAPTER 4.

Operation of Bedload Traps

Cleaning and Setting the Traps

Before they are deployed in the stream, bedload traps should be thoroughly cleaned each morning of organic debris adhering to the net from previous samples (fig. 33). Lay the bedload traps out on the bridge and, after they are thawed and partially dried, vigorously shake and brush them by hand, with a rag or a brush.

Figure 33—Laying out traps to be deployed for drying and cleaning out organic debris.

To set the traps on the ground plates, remove hose pieces, shaft collars, and the PVC pipes at the bottom of the stakes (fig. 34 a and b). Set the webbing loops on the frame to their approximate lengths and slide them over the stakes (fig. 34c). Slide the trap, complete with straps, down the stakes and set it on the ground plate (fig. 34d). Adjust the strap length for each trap such that the trap opening faces squarely into the

Figure 34—Six steps of setting the bedload traps onto the ground plates: Removing the hose pieces (a), removing the shaft collar (b), sliding the webbing loops over the stake (c), pushing the trap down onto the ground plate (d), checking the trap position (e), and fastening the shaft collar (f).

direction of flow, even if the ground plate and the stakes do not. Ensure that the entire bottom face of the frame is flush with the ground plate. Because each of the ground plate-and-stake assemblies differ slightly from each other, adjust the webbing strap loop length of a specific trap to fit a specific ground plate and stake pair. Traps should be numbered to coordinate placement with "their" ground plate.

Despite the individual fitting, ensure traps and straps are properly positioned on the ground plate before each sample is taken and re-adjust if necessary. Check the trap/plate contact by running a finger along the beveled edge of the trap and ground plate (fig. 34e). A gap between the frame and the ground plate must be corrected to prevent small particles from passing under the trap frame. Similarly, larger particles can bypass the trap laterally if the transition between ground plate and frame is not smooth, or if the frame is not oriented straight into the direction of flow.

After the trap is positioned satisfactorily, slide the shaft collars over the stakes, push them down to the top pair of webbing straps, and screw them tight to keep the straps in place (fig. 34f). Leave the ends of the nets untied until all traps are set. Figure 35 shows a trap properly seated on a ground plate. Depending on the distance between the traps and the force of flow, with practice, it takes only 1 to 2 minutes to install and secure a trap to a ground plate.

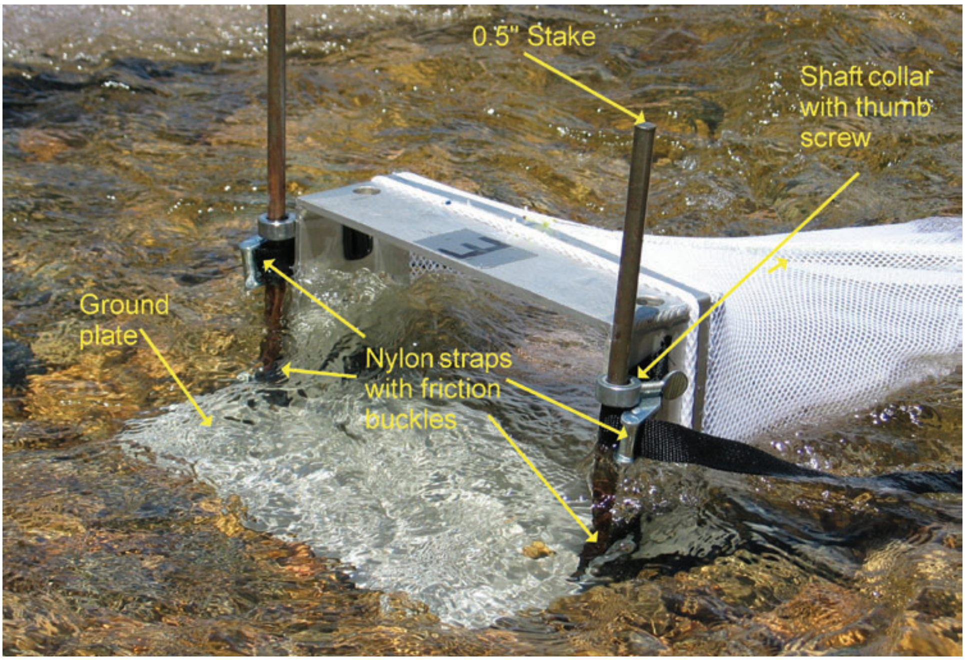

Figure 35—Detail of bedload trap mounted on a ground plate. Note that the net on this trap is not sewn onto the frame as is described in Chapter 2, but clamped around the frame with a metal band, a method not entirely successful.

Tying The Nets—Sample Interval Start

Tie the nets once all the traps are in place. Typically, two operators are employed to accomplish this task. Operator 1 should grasp the net and, if the trap has been sitting with an open net for some time, shake it to remove any bedload or debris already collected in the net. Operator 1 should then gather up the end and hold it between his/her hands while operator 2 ties the net with a cotton-covered clothesline. Two tight wraps of the cord around the net end, secured with a simple overhand knot and bow tie (like shoe laces), are sufficient to hold an entire net full of gravel. Two people tying the net take a little less than a minute per trap (fig. 36). Operator 2 should read the tying time for each trap from a watch worn on a string around the neck (a wrist watch interferes with neoprene gloves). The time at which traps were tied off (and later the time at which traps were emptied) must be recorded in order to compute sampling times which, in turn, are needed to compute transport rates.

Figure 36—Tying off a bedload trap at East St. Louis Creek (Photo courtesy of J. Potyondy, USFS Stream System Technology Center).

Recording Sampling Times

Written notes are difficult to take since both operators will have wet hands and may be wearing neoprene gloves when tying the nets. Therefore, operator 2 must remember the tying times for all traps and record them immediately after tying off the last trap. For a 60-minute sampling period, recording the time to the nearest minute generally provides sufficient accuracy (a maximum of 1.67 percent time error). Tying the nets takes approximately one minute per trap, so one usually needs to remember just four to six sequential numbers. We recommend having a table prepared in the field book for entering the tie-off times and having a field towel handy. Developing a routine can help. For example, always start at the same trap and refrain from conversation and distraction until the times are recorded in the field book. Alternative solutions for recording the tie-off times include having a dry assistant on land or using a voice recorder worn around the neck.

Bedload Traps Ready for Sampling

The authors have used bedload traps in a variety of settings. In figure 37, we provide an overview of different sampling sites with bedload traps installed in the streams at the beginning of the highflow season, ready for sampling.

Emptying Bedload Traps—Sample Interval End

After the sampling time interval is complete (generally one hour), empty the traps. Typically, samples are retrieved quickly from the back of the nets while the traps remain installed on their ground plates. Emptying the traps in the stream and retying them for the next sample allows continuous sampling throughout a day. Bedload traps may be removed from their ground plates and emptied on the bank if it becomes too dark to see or when large samples are collected at a site without a footbridge.

Without Footbridge

If traps are emptied in the stream, operator 1 grabs the net with gloved hands and strokes and shakes it to ensure that all material inside the net accumulates at the end (this usually happens by itself even when using long nets). The operator should also rub off any fine debris that is caught in the net, particularly close to the frame where most of the water exits the net. Long pieces of woody debris inside the net may need to be broken in place. Operator 1 holds the end of the net closed with one hand below the clothesline knot, and with the other hand, grabs around the net on the frameward side of the collected bedload (fig. 38). The bedload sample is thus contained between the two points of the pinched-off net. Operator 2 checks the time (the minutes of the hour) and unties the cotton cord. Both operators then maneuver the sample into a bucket brought by operator 2. Operator 1 releases the end of the net and shakes the contents into the bucket. The net is briefly released

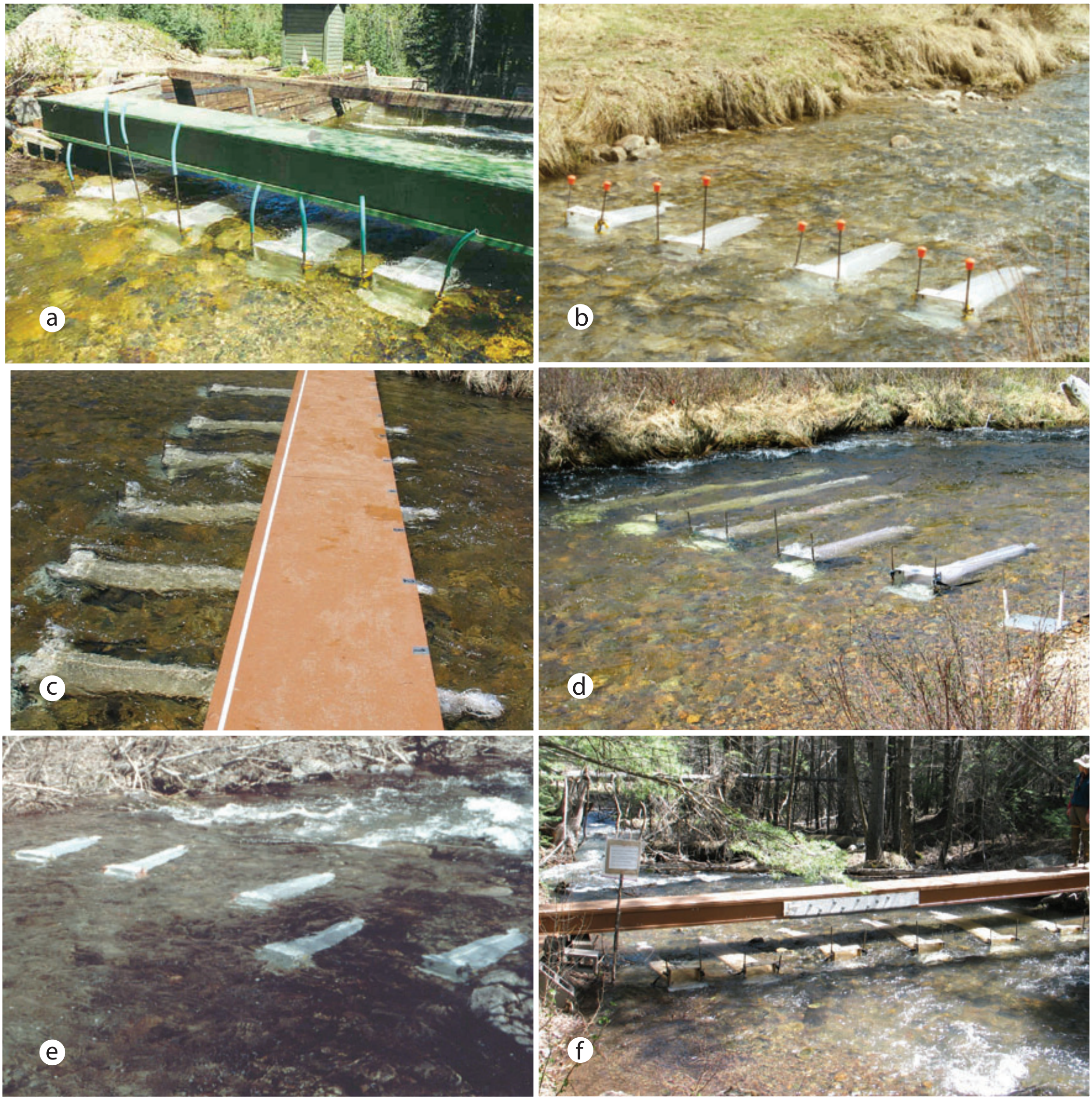

Figure 37—Four bedload traps installed in relatively small streams: East St. Louis Creek, CO (a) and Little Granite Creek, WY (b). Six bedload traps installed at a pool exit/riffle on the upstream side of the footbridge at Half-moon Creek, CO (d), and six bedload traps installed across the head of a point-bar (e). Five bedload traps installed in a pool exit at Cherry Creek, OR (e), where one of the traps had to be installed further upstream than the others because a large rock made installing that trap in line with the others impossible. Six bedload traps installed at the upstream side of a footbridge at Hayden Creek, CO (f).

Figure 38—Operator 1 holds the end of the net above and below the accumulated debris while operator 2 unties the net.

into the current (untied) to flush organic debris out of the trap before being retied and tossed back into the stream to start another sample. To reduce wading and to speed up the process, operator 2 can bring two buckets along to empty two neighboring traps in the same trip. The sequence in figures 39 a through d shows several steps to emptying bedload traps. The process described above is repeated until all traps are emptied and retied. It is important to use buckets with numbers that match the trap numbers.

Because the entire process of untying, emptying, and retying typically takes only about one minute per trap, the end of a sample and the start of the next sample are assumed to occur at the same time. Thus, only one value is recorded to denote the time of both untying and retying. However, if the process of untying, emptying, and retying cannot be done within a minute, the times for untying and retying need to be recorded separately. During the highest flows, sampling times may last for only a few several minutes, thus both tying and untying times should be recorded to the second for higher accuracy.

With Footbridge

We recommend using a footbridge together with bedload traps that have 5.5-ft long nets. The footbridge not only reduces the amount of treading and scouring on the bed, but is also a safer means of operating the traps at high flow when the wadeability limits are approached. A set of buckets appropriately labeled for each trap should be set out on the bridge next to the traps (fig. 40). We often put a few inches of water in the bottom of each bucket to help prevent the wind from blowing them off the bridge. Operator 1 stands in the stream upstream of the bridge,

Figure 39—Emptying bedload traps in the stream without a footbridge: grabbing the net (a), untying it (b), emptying the net into a bucket (c), and retying the net (d). Note: the persons in the right of each photo should be wearing wading belts!

Figure 40—Footbridge with buckets ready for emptying bedload traps.

grabs the net, and ensures the entire catch has moved toward the rear. He/she then grabs the end of the net above and below the sample mass and lifts the net end out of the water and onto the bridge. Operator 2 crouches on the footbridge, unties the net, and shakes the contents of the net into the bucket held slightly above the water by operator 1. The bucket is lifted onto the bridge and the net is retied (see the sequence of tasks shown in fig. 41). As the net is released back into the flow, operator 1 checks the traps for good contact with the ground plates. Operator 2 checks and remembers the tie-off time to record it later. When all traps are emptied, the buckets are removed from the bridge for sample processing.

The process of emptying and retying the net for the next sample occurs virtually in one step. Thus, bedload traps can collect samples back-to-back throughout the day and provide a continuous, hourly record of gravel bedload transport over the course of a workday. To prevent the nets from overfilling, sampling times must be reduced when transport volumes of organic debris and/or bedload are high.

Figure 41—Emptying bedload traps from a footbridge. Operator 1 grabs the net above the accumulated bedload (a) and lifts it out of the water and places the end of the net with the accumulated bedload onto the bridge (b). Crouching on the bridge, operator 2 unties the net and dumps the contents of the traps into a 5-gal bucket that operator 1 holds between himself and the bridge (c). Operator 2 places the sample bucket onto the bridge and reties the net (d).

Removing Bedload Traps From Their Ground Plates

In some instances, traps should not be emptied in the stream but rather removed from the ground plates, carried to the bank while the net is still tied, and emptied into the correspondingly numbered buckets on the bank. There are several instances where this may be necessary: 1) When working at a site without a footbridge, it can be difficult to empty large volume samples into buckets while the traps are fixed to the ground plate, particularly when using short 3-ft nets; 2) When transporting heavy buckets while wading at high flow, there is less danger of losing a sample when carrying traps back to the bank with the net still tied; 3) When taking a discharge measurement or Helley-Smith samples at the bedload trap cross-section in the middle of the day; and 4) When it is too dark to see after the last sample of the day. In this case, samples can be kept in the nets on the banks over night.

To remove the trap from the ground plate: 1) Remove the garden hose; 2) Unscrew and remove the shaft collars that hold down the straps; 3) Pull the trap off the ground plate, ensuring that the plate does not lift off the bed; 4) Place the PVC pipes over the stakes and fasten them with a shaft collar; and 5) Place the garden hose pieces over the stakes. Step 3 is shown in figures 42a through c and step 4 in figures 42d and e. Note that bedload traps should always be removed from their ground plates when operators are absent from the site for any length of time, particularly overnight when flows are typically highest in snowmelt regimes. Unattended sampling can overfill the traps and large woody debris might wedge in front of the traps. Sampled bedload volumes would be invalid in both cases, and damage might occur to the traps and/or the surrounding stream bed.

Sampling Time

Typical Sampling Time of One Hour or Longer

Gravel bedload particles move irregularly and particle sizes at the threshold of motion move infrequently. In an attempt to include irregularly and infrequently moving particles in the sample, bedload traps were specifically designed to facilitate long sampling times.

The typical sampling time for bedload traps at low and moderate transport rates is 1 hour. During this time, the operators can attend to other tasks, such as processing and bagging the previous hour's samples. At the lowest flows, 1-hour samples collected in bedload traps might comprise a few small gravel particles plus a few cups of organic debris. If transport rates are this low, sampling times can even be extended over several hours provided the flow is stable. However, the traps must be

Figure 42—Removing a bedload trap from its ground plate (see text for explanation).

checked periodically to confirm the net is neither filling nor clogged with organic debris. At moderate flows, 1-hour samples may comprise a cupful of gravel plus several quarts (several liters) of organic debris. As flows increase further, sample volume can amount to several gallons. One needs to check that the collected volume does not exceed the capacity of the sampler and reduce sampling times if needed (next section).

Shorter Sampling Times

At high transport of organic material or gravel

A 3-ft long net has a total volume of about 6.4 gal (25 liters) or 110 lb (50 kg) of gravel. Assuming a 40 percent fill level does not compromise the sampler efficiency (Emmett 1981), the bedload trap capacity is about 2.7 gal (10 liters) or 44 lb (20 kg) of gravel. Mountain gravel-bed streams with forested watersheds carry large amounts of coarse organic debris, particularly on the first rising limb of the snowmelt highflow. This material is collected in the bedload traps and may fill the net beyond capacity in less than an hour, even if gravel transport is miniscule (fig. 43). The largest sample volume collected in a 1-hour sample comprised 4.25 gal (16 liters), of which 0.6 cups (0.15 liters) were gravel. To avoid overfilling the net, which causes a reduction in sampling efficiency, sampling time must be shortened (Bunte and Abt 2005). Although longer nets can hold larger sample volumes, they are not necessarily suited for a longer sampling time because collected sample volumes may become unmanageably large.

Figure 43—Inappropriately large volumes of organic debris of up to 4 gal (approx. 16 liter) collected during a 1-hour sample in the bedload traps (upper left bucket).

Sampling time should also be reduced during times of high gravel transport. The highest measured transport rates occurred at flows > 130 percent of bankfull. At one site, bedload sheets formed during high flow and an entire layer of the bed about 10 cm thick was in motion. A 6-minute sampling time filled the 3-ft net (0.9 m) with 20 kg of gravel and cobbles (fig. 44). At another site, a 10-minute sample accumulated

Figure 44—Twenty kg of gravel and cobbles were collected in one of the bedload traps over a 6-minute sampling time when bedload sheets moved along the stream bed at Little Granite Creek, WY, in 1999.

24 kg of gravel and cobbles in a 5.5-ft net (1.65 m). Note that while the amount of organic debris is more or less evenly distributed across the stream, gravel transport rates can vary greatly over the stream width (Chapter 3, fig. 20).

In rapidly rising flow

Decisions regarding sampling time must be made in the field in response to current conditions of flow and sample volumes. A 1-hour sampling time may be too long when flow is rapidly rising. Discharge can easily increase by 10 to 15 percent within an hour on the daily rising limbs during snowmelt highflow. If the relationship between transport and discharge follows a power function with an exponent of eight or greater (typical of sampling results from bedload traps), a 10 to 15 percent increase in flow causes a doubling or tripling of the transport rate. A fast rise in transport rates during rapidly rising flow speaks against collecting full 1-hour samples because correlating transport rates with flow may be difficult. However, gravel transport in mountain streams often has a delayed response and does not immediately rise with increasing flow. In this case, a longer sampling time can be maintained. A compromise is to reduce sampling time to 30 or 45 minutes during rapidly rising snowmelt runoff, but shorter sampling times may be necessary during flashy rainstorm events.

Effect of Sampling Time on Measured Gravel Transport Rates

In coarse-bedded mountain streams, short-term transport rates typically fluctuate even during constant flow, and transport rates larger than average occur less frequently than those smaller than average (for example, Einstein 1937, Hubbell 1987). Due to this skewed distribution of short-term transport rates, sampling time has an effect on measured transport rates. This effect was quantified in an empirical study in which bedload traps were deployed for sampling intervals of 2, 10, and 60 minutes (Bunte and Abt 2005). At bankfull flow, transport rates estimated from 2-minute sampling were only one-sixth of the rates estimated using 1-hour sampling. The reason is that short-term samples are less likely to catch the infrequently occurring large transport incidents. The measured transport rates are, therefore, comparatively low and under predict the mean rate. The opposite effect occurred at low flows (about 30 percent of bankfull) when small gravel particles were just starting to move. Deployment over 2 minutes produced more samples with zero transport than a longer deployment. However, if gravel was contained in a 2-minute sample, the computed transport rates were higher than for samples obtained from longer deployment because the "catch" is assigned to a short sampling duration. Even when zero-values were included in the computation, transport rates estimated from 2-minute sampling times were four times higher during marginal transport than those from 1-hour sampling. Transport rates did not vary markedly between 10-minute and 1-hour sampling. Two-minute sampling resulted in a statistically significant flatter rating curve compared to longer sampling.

Ground Plate Readjustment During Sampling and Removal After the Highflow Season

Checking and Readjusting

Over the course of the highflow season, aggradation and/or degradation of the bed may occur around ground plates. This presents a problem to accurate sampling. If the bed scours, the plate can become pedestalled with bedload moving on either side of the trap. Eventually, a gap may form underneath the plate that permits sediment to pass unsampled below the trap. Aggradation of the bed presents the opposite problem. As the bed near the traps aggrades, the bed plane becomes higher than the surface of the ground plate. Simply scraping the ground plate free of overlaying material causes the plate to become located in a depression that is constantly filled with bed material falling down the inclined sides. In this situation, the bedload trap will collect material from an area that is larger than the width of the trap opening and overestimate the true transport rate. However, if the entire depth of the aggraded material remains mobile, and the material is transported in the form of bedload sheets, the ground plate should stay in its original position to yield accurate results.

In a degrading bed

To prevent incorrect sampling results caused by bed degradation, ground plates must be lowered to match the scoured bed plane. To lower a plate, pull it off the stakes and remove particles from under the plate until the plate matches the lowered bed plane. Reset the plate. As was done when the plate was initially placed on the bed, fill the interstitial spaces below the plate with smaller gravel. If wading behind the bedload traps scoured a trench where headcuts start to migrate between the traps, fill the trench with cobbles to prevent headcutting that pedestals the plates.

In an aggrading bed

To adjust the ground plate position in an aggrading bed, place a second ground plate on top of the bed material that covers the original plate. To do this, simply push the second plate down the stakes of the original plate. Bed disturbance is minimized by placing a second plate over the first. If the aggraded location experiences degradation at a later time in the highflow season, remove the second plate and use the original plate. An aggrading bed may be associated with the movement of bedload sheets. In this case, position the plates at the lower boundary of the moving bedload to sample the entire moving layer of bedload.

Removing Ground Plates and Stakes Using a Lever

At the end of the study, or possibly during ground plate placement (Chapter 3) or readjustment, the stakes driven into the streambed need to be removed. Sometimes, the stakes holding the plates can simply be removed by hand. At other times, a stake will not budge and a lever may be needed to pull it out (for example, use a 6-ft [1.8 m] long board or steel pipe). To grab the stake, fasten a 6-mm nylon rope loop to it using a prusick knot (see inset of fig. 45). Tie a webbing loop around the lever and connect it to the rope loop with a carabineer. Set one end of the bar on a rock on the stream bottom 2 to 3 ft away from the stake to be pulled. Place the webbing loop a few inches offset from the top of the stake such that when the lever is pulled up, the webbing loop sits vertically above the stake where it exerts the strongest pull on the stake.

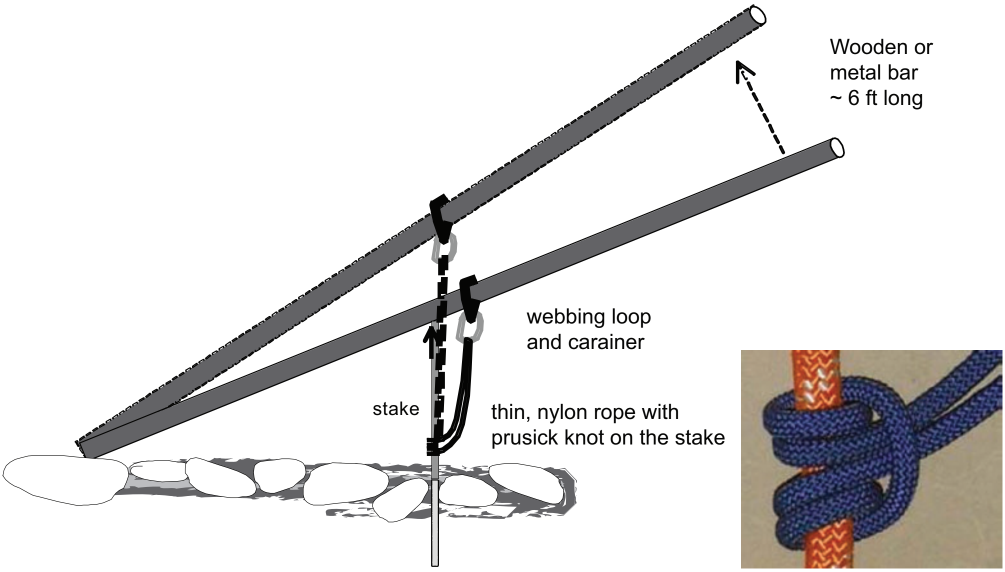

Figure 45—Using a wooden or metal lever to pull a stake from the stream bottom (left). Prusick (or prusik) knot (right, inset). Copied from http://storrick.cnchost.com/VerticalDevicesPage/Ascender/KnotPages/KnotPrusik.html

Ancillary Measurements

Bedload transport sampling is usually accompanied by a variety of field measurements including:

- Hydraulic measurements such as stage, flow velocity, flow depth, and discharge;
- Bedload sampling of sediment smaller than 4 mm using a Helley-Smith type sampler;
- A site survey, typically requiring longitudinal profiles along the banks and the thalweg, and one or several cross-sectional profiles; and
- Bedmaterial sampling, typically comprising a surface pebble count covering the reach and two or more subsurface samples at representative locations.

For more information on how to conduct these measurements, consult the literature on field methods, for example, Guy and Norman (1970); Dackombe and Gardiner (1983); Gordon and others (1992); Harrelson and others (1994); Ryan and Troendle (1997); Edwards and Glysson (1999); Bunte and Abt (2001a, b); and Ryan (1998, 2005).

Some of these measurements, such as surveying and bedmaterial sampling, are performed before or after the highflow season and are not discussed here. Hydraulic measurements and sampling fine-grained bedload using a Helley-Smith type sampler occur together with bedload trap sampling and can affect transport rates measured with the bedload traps. Similarly, measurements of stage, discharge, and Helley-Smith samples can be affected by the presence of bedload traps. Although mutual interactions between these measurements cannot always be completely avoided, operators need to be aware of the interactions and try to minimize them.

Stage

Two or more stage recorders and at least two staff gages should be installed per site. The water surface elevation often follows different temporal patterns within a reach due to secondary flows, standing waves, and local scour and fill of the bed. Locations less than 30 ft (9.1 m) apart can produce different hydrographs. Recording stage at several locations brings attention to this problem and provides an opportunity to adjust the measured hydrograph. Stage averaged over right and left bank, for example, may be a better indicator of flow than a single stage record, or a stage record from a given location may be representative of discharge for only a range of flow or part of the highflow season.

Although discharge associated with each sample might eventually be computed from the combined hydrographs of all staff gauges and water level recorders, at least two staff gages should be read and manually recorded with each bedload trap sample. Stage readings inform the operator of current flow conditions and provide a backup record in case water level recorders malfunction. For convenience, staff gauges should be installed close to the bedload trap site (fig. 46). However, the

Figure 46—Bedload trap sampling site with footbridge. Staff gauges and electronic water level recorders (inside the white PVC tubes) were installed upstream near both banks, conveniently close to the bridge, but were affected by the hydraulic resistance of the bedload traps.

presence of several bedload traps in a cross-section can pond the water upstream of the traps and elevate the water surface. This effect becomes more pronounced with increasing flow until bedload traps are inundated. Further inundation decreases the ponding effect. The upstream distance of ponding is short for steep gradient (step-pool) streams and typically does not extend beyond an upstream step. In lower gradient streams without steps, ponding of up to 0.5 inches (13 mm) was observed at a distance of 15 ft (4.6 m) upstream when bedload traps were just inundated [7]. The presence of ponding requires a trade-off: for convenience and ease of access, particularly if dense vegetation makes walking along the banks difficult, staff gauges should be close to the bedload trap cross-section. However, in order to be unaffected by the elevated water surface created by the presence of the bedload traps, staff gauges, and particularly water level recorders, should be well out of the way.

Operators should check whether ponding affects stage readings by comparing stage readings with and without bedload traps installed. If the presence of bedload traps increases the stage readings, a correction factor can be developed from the difference in stage readings with and without bedload traps in place, and that factor is applied to correct readings of stage for times when bedload traps are installed. Because the ponding effect decreases as bedload traps are overtopped by flow, the correction factor first increases with flow and then decreases for further increasing flow after inundation of the traps.

Ponding increases with the number of traps installed per cross-section. However, the trap spacing (Chapter 3) thought necessary to characterize the lateral variability of transport rates should not be increased to prevent ponding. The effects of ponding on stage readings can be corrected (see above) or avoided if gages are installed sufficiently far away from the bedload traps.

Discharge

Unless the study site is close to an agency-operated gauging station that provides a continuous discharge record, discharge measurements must be taken at different flows to determine a stage-discharge relationship. Discharge is ideally measured in a symmetrical cross-section. Such a cross-section may not be close to the bedload trap site, and the cross-section may become difficult to wade at high flow. If the study site has a footbridge, it may be used to take discharge measurements,

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[7] The authors have not evaluated if the increased water surface upstream of the bedload traps and the associated decrease in the local stream gradient and flow velocity affect measured bedload transport rates. If ponding decreased the bottom shear stress in front of the traps, a decrease in transport rates of fine gravel particles could be possible.

particularly if flows are deep and difficult to wade. Taking discharge measurements close to the bedload traps provides an opportunity to compare local flow hydraulics to local transport rates. However, if discharge measurements are taken at the footbridge, remove the traps during the measurements because the presence of the traps alters the vertical velocity profile. Measure discharge at the downstream side of the bridge because the presence of the ground plates increases the near-bottom flow velocity (Chapter 2). A distance of 4 to 5 ft (1.2 to 1.5 m) between the ground plates and the velocity verticals should ensure that velocity profiles have readjusted to the bed.

The most convenient time to take discharge measurements from the bridge is at the start of each work day (before the traps are installed) or at the day's end (after the traps have been removed). However, taking discharge measurements at the beginning or end of the day may diminish the range of flows at which samples can be collected with the bedload traps.

Helley-Smith Samples

A Helley-Smith sampler may be used with bedload traps if the study is interested in collecting pea gravel and sand, or if samples collected with a Helley-Smith sampler and bedload traps are to be compared [8]. A deployed Helley-Smith sampler from a footbridge may also permit sampling at flows that are no longer wadeable. However, finding a time and place to deploy the Helley-Smith sampler can pose a challenge. One option is to take Helley-Smith samples at the beginning or end of the day when bedload traps are not installed. Alternatively, Helley-Smith samples can be taken during bedload trap operation. To avoid effects of spatial differences in sampler location, as well as destabilization of the bed upstream of the sampler, bedload traps and the Helley-Smith sampler could be deployed within the same cross-section. The advantage is that both samplers can be deployed at the same time (provided care is taken not to step in front of the traps). However, sampling does not occur with the typical equal-width spacing if the Helley-Smith sampler is set into the spaces between the bedload traps. One needs to balance the possibility that a somewhat uneven spacing causes inaccuracies in the computed transport rates against the added labor of separate bagging needed for sampling at uneven spacing. Also, given the close proximity of the two samplers, they may affect each other's flow hydraulics and thus their sampling efficiencies.

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[8] Transport rates computed from a Helley-Smith sampler at all field sites were routinely found to be two to four orders of magnitude higher than those for bedload traps at moderate flows (about 50 percent Q_{bkf}). At bank full flow, transport rates from both samplers become similar (Bunte and others 2004b).

If a Helley-Smith sampler is deployed in a separate cross-section, sampling should be downstream of the bedload traps. Effects of upstream wading (when setting the traps) are avoided if Helley-Smith samples are collected before bedload traps are installed upstream. When using a footbridge, Helley-Smith samples should be collected at the downstream side. The streambed here is not, or only slightly, affected by wading (during discharge measurements). Alternatively, one might consider deploying the Helley-Smith sampler onto each ground plate for several minutes per plate [9].

Sampling Schemes and Required Operator Hours

The bedload trap researcher must decide when samples are to be collected during a day, how long sampling is to extend over the high-flow season, the number of daily and total samples, as well as the flow and transport rates to be sampled. These choices define the sampling scheme and depend on the study aim, as well as the degree of temporal and spatial variability of bedload transport.

Snowmelt regimes typically produce diurnally fluctuating flows. For Rocky Mountain streams with basin sizes of 3 to 23 mi^2 (8 to 60 km^2), flow decreases throughout the morning and reaches its daily minimum between 12 and 2 p.m. (12:00 to 14:00). Flow increases rapidly during the (late) afternoon and peaks between 7 and 10 p.m. (19:00 and 22:00). The differences between daily minimum and maximum discharge can be large: jumps from 75 to 125 percent or 100 to 150 percent of bankfull are possible within a few hours. Such changes in flow (Q) cause not only an immediate response in transport rates, but may also lead to high and variable transport throughout peak flow and the falling limb. Transport rates (Q_B) thus follow the hydrograph only approximately. Daily Q_B *vs* Q relationships typically have hysteresis patterns that change over the course of days and reflect changing conditions of sediment supply. Sequential hourly measurements of bedload transport between mornings and evenings typically show a rather well-defined Q_B *vs* Q relationship; however, repeatedly measured transport rates for the same discharge can vary over two orders of magnitude between days. Generally, the Q_B *vs* Q relationship is erratic during the lowest flows and becomes better defined during the highest flows.

[9] Placement of the Helley-Smith sampler onto the ground plates with bedload traps removed provides a better sampling result than obtained from setting the Helley-Smith sampler directly onto the stream bed (Bunte and others 2005).

Understanding bedload transport processes and evaluating how a stream responded to disturbance or mitigation effects are common study aims. Common approaches may involve establishing a bedload transport rating curve, analyzing transported particle sizes, computing annual load, and comparing measurements over time. Accurately determining rating curves, bedload particle sizes, and annual loads requires representative sampling that takes into account the daily and seasonal variability of bedload transport. Ideally, the complex relationship between bedload transport rates and flow in a snowmelt highflow regime would be characterized by sampling all flows to produce a continuous temporal record of bedload transport rates over the highflow season. However, such a sampling approach constitutes a large logistical effort with several crews and is usually not feasible. A compromise is to sample during daylight hours, use one crew, and schedule sampling to include daily low and high flows as well as part of the daily rising and falling limbs. The aim is to approximate the information obtained from a continuous record as best as possible while keeping a logistically feasible sampling scheme.

Intensive 1-Hour Sampling Throughout a Day

Transport rates around peak flows are usually highest and most important for estimating annual load. Daily field work should therefore be scheduled to sample those rates. However, including peak flows in the evening, daily falling limb of flow in the morning, and low flow around noon makes for a long field day that lasts from 9 or 10 a.m. (9:00 or 10:00) to 8 or 9 p.m. (20:00 or 21:00) when it becomes too dark to work without artificial lighting.

Bedload traps that are emptied at 1-hour intervals and collect back-to-back samples lend themselves to providing time series records of gravel transport. Two people can operate six or more bedload traps at one field site, and about eight hourly bedload trap samples can be collected in an 11- to 12-hour day, plus a few Helley-Smith and/or discharge measurements. The time between sample collections is used to process samples (Chapter 5) collected in the previous hour, take stage readings, and take notes.

Collecting eight consecutive 1-hour samples still leaves much of the day unsampled, particularly on the early falling limb during which transport rates may be high and variable (for example, Bunte 1996, Gottesfeld and Tunnicliffe 2003). High transport rates were also reported for the falling limbs of storm events (for example, Lisle 1989, Rickenmann 1994). These findings suggest that trends and relationships observed during the beginning of an event (or day) may change over time. In order to obtain at least qualitative information of bedload transport during unmeasured times, one should consider installing an automated device such as a hydrophone.

Covering the Highflow Season

Daily hysteresis patterns of the Q_B *vs* Q relationship typically change over the highflow season, and relationships between transport rates and flow typically differ between the rising and falling limb of the highflow season. Sampling should therefore not be limited to a partial season. Moreover, extending sampling over (almost) all days of the highflow results in a large sample size. Rating curves can be better defined and segregated into increments that best describe specific times or flows when more data points are available. Bedload samples that are collected over the entire highflow season—almost as a time series—are particularly important when using a summation approach to compute annual loads (Chapter 5).

Some methodological studies require neither sampling over the entire highflow season nor keeping a detailed daily record. For example, sampling simply at different transport rates suffices if the study compares two devices that each collect instantaneous transport rates or compares the effects of different deployment times. In this case, the stream simply serves as an outdoor flume.

Representative Sampling for Rating Curve and Annual Load Estimates

Intensive sampling that covers most days of the highflow season still may not collect samples at times or flows most crucial for establishing rating curves or computing annual load. In order to improve the representativeness of samples, operators should try to understand the temporal patterns of flow and transport and on that basis, ensure that sampling includes all flows and the highest transport rates.

For example, an understanding of the temporal variability of bedload transport at the field site allows operators to better identify times that are most important to sample and times that could be skipped with minimal loss of important information. In order to gain some insight into the temporal patterns of an ongoing Q_B *vs* Q relationship during field work, an operator could visually estimate the gravel volume collected at one of the bedload traps and assign it to one of five classes that each increase by approximately one order of magnitude: 1) A few small particles, 2) 1 tablespoonful, 3) ½ cup, 4) 1 quart, or 5) 1 pail. These volumes could be plotted in the field book versus stage or over a hydrograph.

When establishing a rating curve, operators should also ensure that a sufficient number of samples are collected within all increments of flow. The distribution of flows and gravel transport rates over a snowmelt highflow season is typically skewed. Low and moderate flows and transport rates occur over much longer portions of the highflow season than peak flows and the highest transport rates. Sampling only between 8 a.m. and 4 p.m. misses peak flows in a snowmelt regime. Keeping a list of sampled flows and trying to sample all increments of flow evenly will help increase the representativeness of the collected data.

Collecting samples at the highest transport rates is crucial when the study aim is to compute a rating curve and annual load. The day of peak flow (or a few hours of it) may easily transport 50 to 80 percent of all gravel transported over the highflow season, although the highest transport rate may not coincide exactly with peak flow. Inaccuracies in the prediction of the maximum transport rates cause large errors in annual load predictions. Sampling the highest transport rates—those that occur infrequently but carry the overwhelming majority of all gravel moved within a highflow season—requires special effort. The question "Were the highest flow and transport rates measured?" is vexing because one normally does not know until a day or two later, when stage has receded, whether the highest flow and transport rates have occurred.

The statistical evaluation of the correlation between bedload transport rates and discharge (in other words, the Q_B *vs* Q relationship) requires absence of serial correlation between consecutive samples. Sampling at a preset daily time, for example, 8 a.m. or 5 p.m., may satisfy this requirement but restricts sample collection to either the daily falling or rising limbs of flow. Most likely, morning and afternoon samples produce different bedload transport rating curves. Sampling at random times throughout the highflow season also satisfies the statistical requirement of regression analysis, but appearing at the site at truly random times is logistically infeasible. Even if the randomness referred to daylight hours only, taking isolated measurements is not a good use of time when using bedload traps that take time to set up and take down, while back-to-back sampling easily produces a time series of measurements. In addition to obscuring the complex temporal patterns of the Q_B *vs* Q relationship over a day and the course of the highflow season, the collection of isolated samples leads to a number of other problems. The lack of a daily time series takes away an opportunity for quality control: one cannot evaluate whether a specific sample might be an outlier in an otherwise typically well-defined Q_B *vs* Q relationship of sequential 1-hour measurements. Collecting isolated samples also results in a far lower sample size which, given the high variability of transport rates, leads to larger scatter in the computed bedload transport rating curve than semi-continuous sampling. One can always elect not to use certain data for a rating curve if they do not meet some preset requirements, but to do this evaluation, one needs to understand the temporal patterns of transport as thoroughly as possible.

Effort in Time and Labor for a Field Season

Intensive sampling requires a large work effort—both in the field and in the lab—that needs to be budgeted. The most effective use of budgeted time is probably achieved by employing a two-person crew that works 11- to 12-hour field days. Working repeated long field days requires suitable nearby accommodation (for example, a rented house). At the highest flows when sample volumes become too large to be processed between 1-hour samples, a third person may be needed temporarily to help with sample bagging if the 1-hour sampling interval is to be maintained (even though the actual sampling time may need to be reduced).

The time and effort needed over the field season increases with the duration of the highflow, the magnitude of the highest flows, and the size and number of the samples collected. Table 1E in Appendix E provides estimates for work hours required for a 2-week field season with low highflows and a 4-week field season with large highflows. Two person crews working 12-hr days for 6 to 7 days per week over a 4-week highflow period accrue a total of 624 work hours. A third person needed temporarily during the highest transport rates or when installing a footbridge adds another 30 to 40 hours. Washing samples that exceed the capacity for field processing requires extra time, up to 100 hours, after the field work (Chapter 5). Half the field work hours (312 for a two person crew) are required for a short, 2-week highflow season with low peak flows and no extra time for help during the highest flows or for sample washing. The pre-field work hours of scouting, site selection, and setting up the field site, as well as the post-field work tasks of taking down a site and storing and maintaining gear, do not depend on the duration or magnitude of the highflow and amount to about 170 hours for a two-person team. Not included in this budget is the time needed for pre and post highflow measurements such as surveying the site, sampling the surface and subsurface bed material, and traveling to the field site.

Intensive sampling over a field season can produce a large number of samples. A daily average of seven samples adds up to almost 200 samples over a 4-week highflow season. This amounts to 1000 bags if five traps were used. About half as many samples are collected in a 2-week highflow season. The time for sieving those samples is estimated at 260 hours for a 4-week season with high discharges and large samples, whereas only half of those hours may be needed for a 2-week highflow season with low peak flows and fewer large samples (See Chapter 5 for effort and time of lab sieving). Thus, depending on the magnitude and duration of the highflow season, the total number of work hours may range between 600 and 1200.

Operator Safety and Comfort

Operating bedload traps can be challenging, with a variety of tasks to be accomplished quickly and accurately in cold, wet, and sometimes dangerous situations. Wading safety was discussed in Chapter 3 and Appendix D. Additional suggestions for keeping operators functioning at their best are discussed in Appendix F.

CHAPTER 5.

Sample Processing and Computation of Transport Rates

Samples collected with the bedload traps need to be processed before transport rates can be computed. Processing includes removal of organic debris, bagging, drying, and sieving. Organic removal and bagging typically occurs in the field and drying and sieving at home and in the lab. The importance and effort required for sample processing should not be underestimated. Roughly ½ to ¾ of the daily sampling effort must be dedicated to sample processing.

Removing Coarse Organic Material

Amounts and Composition

In forested watersheds, a large proportion of the sample volume collected with bedload traps may consist of coarse organic material (fig. 47). The amount of organic debris increases strongly with flow, particularly during the first rising limb of the snowmelt hydrograph, when organic debris comprises up to 99 percent of the entire moist bulk sample volume (Bunte and Swingle 2003a). The largest volume of organic debris

Figure 47—4.5 gal of organic debris was collected in a 19-minute bedload trap sample.

collected during a 19-minute sample in a bedload trap was 4.5 gal (17.5 liters). This sample volume filled the net beyond capacity. The sampling time was too long given the stream conditions (fig. 43).

In Rocky Mountain streams, organic debris includes whole or partial cones from conifer trees, conifer tree needles, willow and alder leaves, twigs and sticks, wood and bark pieces, grass, moss, algae, elk and deer droppings, aquatic insects, and caddis fly cases. The debris, particularly at high flows, may also include small fish, drowned bugs, ants, and earthworms.

Advantages of Field Processing

Separating the organic debris from the inorganic sediment is quite labor intensive, particularly when the organic fraction is large. Ideally, this is done by washing the lower density organic material from the higher density bedload immediately after the sample is collected during the 1-hour interval between trap servicing. Advantages of field processing are that the stream can be used for the large amounts of water needed for washing, and the organic material collected can be recycled into the stream. Washing at the stream site also avoids having to haul voluminous and heavy samples back to the lab, to clean up a considerable mess in the lab (do not try washing samples in a kitchen sink), and deal with smelly, decaying organic material after sitting for weeks in the bag.

As a stopgap measure, if it's raining hard or the amount of organic material is too large to be processed during the time between two samples, the collected material can be stored, unprocessed, in labeled Ziploc bags. However, bagging unprocessed samples is not recommended as the standard procedure because of the considerable effort that goes into labeling, filling, transporting, and storing a large number of heavy, leaking Ziploc bags filled with organic debris and gravel. In practice, one can wash some samples on the spot and store others. Early evening samples collected during rapidly rising flow are likely to contain the largest amount of organic material. One can often catch up with washing these samples the next morning when the organic load is relatively low on the daily falling limb of flow.

Washing Procedure

Washing a large number of samples requires setting up a work space. This is the procedure we use: Sit on a camping stool in front of a 5-gal bucket with a metal bowel on top of it. Place three buckets on your side. One bucket contains water for washing the samples, one serves as a repository for the washed out organic debris, and one holds the bagged samples. Place cartons with different sizes of Ziploc bags, a Sharpie marker, and a field book for notes within easy reach on top of a plastic

Figure 48—Washing samples in the field: the work space.

tub. Place the buckets containing unwashed samples along your other side (fig. 48).

To separate organic material from the inorganic bedload, pour the entire sample (organics plus gravel) into the metal bowl placed on top of one of the 5-gal buckets (fig. 49). Cover the mixture with water and gently stir. Stirring stratifies the sample so that the relatively heavy gravel particles fall to the bottom of the bowl while the less heavy organic material remains near the top (most of the organic particles are too waterlogged to float). With a rubber spatula, carefully push the

Figure 49—The sample is poured into a metal bowl for washing (a). The sample is covered in water and stirred with a rubber spatula (b). Organic material is decanted and discarded.

Figure 50—Bedload particles are retained in the bowl, from a small sample (a) and a larger sample (b).

organic particles to the bowl rim and decant. Decanting into a bowl that fits on top of a bucket or a household sieve ensures that an inadvertently discarded particle can easily be retrieved without rewashing the entire sample. Repeat the process of covering the sample with water, stirring, and decanting organic material a few times to remove all organic material from the bedload sample (except for a miniscule residue with a dry weight that is insignificant compared to the gravel weight). The gravel particles remain in the bottom of the bowl (fig. 50) and are bagged in Ziploc bags of suitable size. Bags are labeled and collected for transport offsite. Wash the samples that are too large to be washed in one batch in smaller portions. Some samples may contain so much organic debris that washing in small quantities is inefficient. Place the sample (or a portion of it) into another 5-gal bucket, cover it with water, and stir. Again, the agitation allows the heavier inorganic material to fall to the bottom of the bucket. Remove the top layer of organic material using a large wire spoon (Asian kitchen supply) (fig. 51). After the volume of the total sample is reduced to a few liters, hand-wash the remainder of the sample in a bowl (see above) or bag it for later washing. The organic material removed from the sample is either returned to the stream or collected for further analysis if it is of interest to fisheries biologists and aquatic ecologists.

Washing After the Field Season

At some point, the number and volume of samples collected at high flows may exceed the capacity of what can be washed during the time period between two samples. Bag these samples to wash them later at the field site after the highflow season or in a different location (a backyard usually) using a similar setup as in the field. Washing samples in the lab or in a sink is not recommended.

Figure 51—Washing a sample with large amounts of organic material using a big wire spoon.

If the sample volume in each of the five traps amounted to four 1-gal (3.9 liter) bags per sample, collecting seven samples results in 140 bags for one day. Assuming large sample volumes were produced during 3 days, 420 bags would need to be washed. At about 15 minutes per 1-gal bag (3.9 liter), washing 420 samples takes a little over 100 hours.

Drying, Sieving, Weighing, and Removing Mud Flakes

A brief description of sieving considerations, referring specifically to bedload trap samples, is provided below. See Bunte and Abt (2001a) for more details and general information regarding sieving and particle-size analyses for gravel samples.

Air Drying

Samples from the bedload traps contain gravel 4 mm and larger. Particles this size can be air-dried in their bags, which is an advantage considering that hundreds of bags might be collected over a highflow season. Small sample volumes of less than half a cup can dry indoors in their opened bags within a few days. If the weather is hot and dry, opened sample bags placed outside will dry within a few days (keep samples out of rain and prevent them from being knocked over). The drying process can be expedited if the samples are poured onto a flat surface and placed in the sun. Dry samples in the lab during cold, rainy, or humid weather.

Field Sieving

Large samples may be too heavy to transport from the field to the lab when working at a remote site. The weight is greatly reduced by sieving cobbles and large to medium gravel particles in the field. Once air dried, pass these particles through a 0.5 *ø* size template and record their number per size class. The weight per size class can be measured at the site using plastic shopping bags and an accurate hanging scale (0.1 to 10 kg range, perhaps a finer scale as well). If field weighing is not possible, estimate the weight of particles in each size class from the number of particles per size class using the following regression:

$$m_i = 0.00289 * D_i^{\ 3.00} \qquad (2)$$

where m_i is the average mass (in grams) of a particle in the i^{th} sieve size, and D_i is the diameter of the square-hole sieve on which the particles were retained when using 0.5 *ø* size classes[11]. For example, the average mass (g) of particles retained on the 32 mm sieve is $32^{\ 3.00} *$ 0.00289 = 30,768 * 0.00289 = 94.7 g. Eq. (2) was derived as the mean of 11 sets of fluvially transported gravel collected in Rocky Mountain streams with basin areas of 3 to 23 square miles (8 to 60 km^2). Note that the mass of disc-shaped or elongated particles may span a factor of up to about ±5 of the average particle mass per 0.5 *ø* size class. Equation (2) applies to gravels and cobbles of mainly ellipsoidal (or compact-bladed) shape. Exponents and coefficients of Eq. 2 showed no systematic variation with the bedmaterial D_{50} size, basin area size, or predominant rock type[12].

Lab Sieving

Samples from the bedload traps are usually sieved in the lab using standard square-mesh sieves in 0.5 *ø* units[13]. The smallest 0.5 *ø* particle size-class that can be collected with the bedload traps and a

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[11] Equation 2 is not applicable for particle diameters measured with a ruler.

[12] River gravels containing large amounts of exceptionally light or heavy rocks, such as tufa or ores, were not included in the analyses.

[13] Round-hole sieves or rulers are not recommended because the resulting size distributions cannot be directly compared to those from square-hole sieves that are typically used for fine gravel and sand.

3.6 mm mesh width net is 4 to 5.6 mm. However, flat particles with a 4 mm *b*-axis may escape through the net because the mesh holes tend to have a rhomboic shape. Thus, when comparing fractional transport rates, the 4 to 5.6 mm class may be slightly underrepresented. Some particles of the size class 2.8 to 4 mm are usually present in the sample, but these particles are excluded from further analyses because they are not sampled representatively. Pour the samples that contain particles of several size fractions onto sieve stacks and place the stacks into a sieving machine (mechanical shaker) for 15 minutes. Weigh sieved size fractions and enter results into prepared forms. Using two shakers and four sieve stacks, an experienced two-person team can sieve and weigh two moderately large samples (in other words, the entire sample fits into a sieve stack) in 15 minutes, permitting the processing of up to eight samples per hour. Small samples of one or a few tablespoons in volume typically comprise only a few size classes and can be sieved more quickly by hand than by a machine, requiring 1 to 5 minutes per sample depending on the volume. If intensive sampling resulted in 1000 bags (7 samples/day over 28 days = 200 samples times 4 to 6 traps) of which 700 were classified as moderately large, sieving would require about 90 hours for the large samples, 15 hours for the small samples, plus 15 hours for miscellaneous lab tasks. This requires a total of 120 hours each for two workers. The lab effort is approximately cut in half for a 2-week highflow with relatively low peak flows that might produce 500 sample bags of which 200 are moderately large.

Mud Flake Removal

The cobble and gravel bottom of some streams has a crust of hardened mud that flakes off into pieces ranging from several mm^2 to several cm^2 in size (fig. 52). These may become mobile at the beginning of high

Figure 52—Bedload sample containing a large quantity of mud flakes.

flow and accumulate in bedload samples. However, crust pieces have sedimentary and transport properties different from those of gravel bedload. Whether to include them as part of the measured bedload depends on the study goal. We have not found a better way to remove crust pieces from the sample than by picking them off the sieve (which is painstakingly slow).

Computation of Transport Rates From Bedload Trap Samples

Instantaneous Gravel Bedload Transport Rates

Due to the uneven spacing of bedload traps across the stream and the potentially different sampling times for each trap, mass transport rates (Q_B) are computed for each bedload trap individually. To compute the total transport rate for an array of four traps across the stream, sample mass collected at trap 1 (m_{s1}) is divided by the trap width (w_s) and the sampling time at trap 1 (t_{s1}) then multiplied by the section of stream width represented by trap 1 (w_{i1}). These computations are repeated for all four traps, and partial transport rates are summed across the active stream width to obtain the total bedload transport rate.

$$Q_b = \frac{m_{s1} * w_1}{w_s * t_{s1}} + \frac{m_{s2} * w_2}{w_s * t_{s2}} + \frac{m_{s3} * w_3}{w_s * t_{s3}} + \frac{m_{s4} * w_4}{w_s * t_{s4}} \quad (3)$$

where m_s is the sampled bedload mass in each trap, w is the portion of the stream width represented by each trap, w_s is the width of the traps, and t_s is the sampling duration. The representative section of stream width for each trap typically extends from the trap in question halfway toward its left and right neighbors. Near the bank, the width boundary depends on the potential for local bedload transport at a specific flow. A stream width section with very shallow flow over grass or a still water wake behind a log protruding into flow is not included in the representative segment of stream width. Should bedload transport occur at such locations at higher flow, they are included in the active stream width. The sum of all stream sections equals the active stream width. The transport rate per unit width (g/m*s) is obtained by dividing the cross-sectional transport rate by the active stream width.

Instantaneous gravel transport rates computed from bedload trap samples can range over many orders of magnitude, between the very onset of gravel motion to fully developed gravel transport. A sample with one 4 mm particle in one of the traps corresponds to a transport rate on the order of 0.00001 g/s, and this marginal transport typically starts at 25 to 35 percent of bankfull flow. Near bankfull flow, transport rates may range between 0.1 and 100 g/s depending on the size of the stream, sediment supply, and the erodibility of the bed.

Annual Gravel Load

Sampling schemes most appropriate for computing annual load have been discussed in Chapter 4. Either a rating curve approach or a summation of hourly/daily loads can be used to compute annual load. Accuracy and precision of both approaches increase not only with the number of measurements available, but particularly with an increased density of measurements collected during the highest flows. The uses and limitations of the two methods when processing bedload trap data are explored below.

Rating curve approach

- If sampling did not cover most of the highflow season, a rating curve approach is likely to be the only option for computing annual load. However, if the rating curve is poorly defined, due to high scatter or sampling over a small range of observed discharges, a total transport estimate is likely to be erroneous and should not be attempted.
- Different rating curves may have to be established for portions of the hydrograph, particularly for the rising and falling limbs because of hysteresis effects.
- A rating curve estimate of annual load requires a correction for an inevitable statistical bias. Several methods exist to compute a correction factor (Cohn and others 1989; Duan 1983; Ferguson 1986, 1987; Koch and Smillie 1986), which are evaluated in Hirsch and others (1993). For rating curves obtained from a large number of bedload trap samples collected over the entire highflow season, bias correction factors computed from Ferguson (1986, 1987) and Koch and Smillie (1986) typically assumed a value between 1.5 and 2.0.
- Annual load computed from a rating curve approach is sensitive to the length of the time increments used in the analyses when based on steep rating curves with exponents of 8 or larger (typical of bedload traps). For pronounced daily fluctuations of flow (with approximately 8 hours of rising and 16 hours of falling flow), annual load computed from hourly time increments is larger than the load computed for mean daily flows (Bunte 2002).

Summation approach

- A summation procedure requires an almost complete time series of bedload transport measurements over the highflow season. Transport rates measured (and interpolated) for hourly increments are then added over the course of a hydrograph.

- A summation approach is likely to yield a higher accuracy in annual load estimates than a rating curve approach (Bunte and Swingle 2003b; Walling and others 1992; Walling and Webb 1981, 1988), but again, availability of samples for the highest flows and transport rates is essential.

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Appendix A: Sampling Intensity of Bedload Traps Compared to Typical Helley-Smith Sampling

Sampling intensity quantifies the percentage of the bedload collected in a sample compared to the transport that moves through the cross-section during the time period of sampling. Sampling with bedload traps collects a far greater proportion of the gravel passing a site than sampling with a Helley-Smith-type sampler. For bedload traps, all samplers are deployed side-by-side and collect samples simultaneously. For a Helley-Smith-type sampler, an operator may work for almost 1 hour to collect a sample (for example, sampling at 20 verticals for 2 minutes each), but the sampling time is only 2 minutes.

Relative sampling intensity I_r can be defined as the ratio of actual to potential sampling intensity. Actual sampling intensity I_{act} is the product of actual sampling time (in other words, the time at which the sampler is in ground contact t_s) multiplied by the width and number of samplers (or sampling verticals) used. Potential sampling intensity I_{pot} is the product of either a desirable sampling duration t_{tot} or the worktime of an operator collecting the sample and the active stream width w_{act}.

$$I_r = \frac{I_{act}}{I_{pot}} = \frac{n_s * w_s * t_s}{w_{act} * t_{tot}} \qquad \text{(A1)}$$

where n_s is the number of samplers or sampling locations per cross-section and w_s is the sampler width.

For snowmelt highflows and low to moderate gravel transport, a 1-hour sampling time is desirable for representative measurement of infrequently moving particle sizes. For a 1-hour sampling time, relative sampling intensity obtained when deploying six bedload traps at Halfmoon Creek was:

$$I_r = \frac{I_{act}}{I_{pot}} = \frac{n_s * w_s * t_s}{w_{act} * t_{tot}} = \frac{6 * 0.3 \text{ m} * 60 \text{ min}}{7.8 \text{ m} * 60 \text{ min}} = 0.23 = 23 \text{ percent} \qquad \text{(A2)}$$

By contrast, relative sampling intensity for samples collected with a 3-inch Helley-Smith sampler (sampling at 15 locations for 2 minutes each) was

$$I_r = \frac{I_{act}}{I_{pot}} = \frac{15 * 0.076 \text{ m} * 2 \text{ min}}{8.0 \text{ m} * 60 \text{ min}} = 0.0048 = 0.48 \text{ percent} \qquad \text{(A3a)}$$

based on a desirable sampling time of 60 minutes, or

$$I_r = \frac{I_{act}}{I_{pot}} = \frac{15 * 0.076 \text{ m} * 2 \text{ min}}{8.0 \text{ m} * 35 \text{ min}} = 0.0081 = 0.81 \text{ percent} \quad \text{(A3b)}$$

based on the 35-minute work time during which the operator was busy collecting the sample. Averaged over all sampling sites to date, sampling intensity obtained by bedload traps 1 ft (0.3 m) wide spaced at increments of 2 to 7 ft (0.6 to 2.1 m) within the active stream width and when deployed for 1 hour was 24 percent (table 1A). This means that 24 percent of the bedload passing the site during the time of the operator's presence was collected. A typical scheme for a 3-inch (0.0762 m) Helley-Smith sampler deployed for 2 minutes per location spaced 0.5 m apart yields sampling intensities of 0.5 percent based on a desirable 60-minute sampling time, or 1 percent based on the operator's worktime. In the first case, sampling intensity of the bedload traps exceeds that of the 3-inch Helley-Smith sampler on average by a factor of 52, in the second case by a factor of 28.

Table 1A—Relative sampling intensity ($I_r = I_{act}/I_{pot}$) for bedload trap and Helley-Smith[a] samples collected in different studies.

	Sampling intensity (%)					
	Sampling time				Number of	
	Helley-Smith		Bedload traps	Active stream	HS-verticals	Bedload traps
Stream	**1 hr**	**work time[b]**	**1 hr**	**width (m)**	**per cross-section**	
St. Louis Cr.	0.51	1.02	23.8	6.3	13	5
Little Granite Cr.	0.37	0.56	14.5	12.4	18	6
Cherry Cr.	0.46	0.73	25.0	6.0[c]; 9.4[d]	17	5
East St. Louis Cr.	0.45	1.35	33.3	3.6[c]; 5.1[d]	9	4
Little Granite '02	0.52	1.24	22.2	5.4	11	4
Halfmoon Creek	0.48	0.81	23.0	8.0	15	6
Hayden Creek	0.58	1.00	25.7	7.0[c]; 6.5[d]	15	6
mean for all sites	0.48	0.96	23.9		14	5

[a] 3-inch Helley-Smith sampler deployed for 2 minutes per vertical
[b] the time the operator was busy collecting a Helley-Smith sample, in other words, (number of HS verticals + 1)*2
[c] cross-section for bedload traps
[d] nearby cross-section for Helley-Smith samples

Appendix B: List of Components for Making Bedload Traps

A bedload trap costs approximately $200 to 300 to construct, not including the time for buying materials or arranging the work to be done. Hardware amounts to 25 to 30 percent of the total cost; labor costs account for the remaining 70 to 75 percent.

Table 1B—Items to purchase for making one bedload trap.

- Aluminum stock, 4 inches wide, ¼ inch thick, 42-inch long strip
- Ground plate, aluminum sheet 1/8" thick, 16 inches by 12 inches
- 2 cold-rolled steel stakes, 4 ft long with sharpened tip
- Netting material: depending on length of the net (See Appendix C)
- Spool of nylon yarn (thread about 1 mm thick)
- Set of carpet/upholstery sewing needles
- Cigarette lighter to sear the ends of the nylon yarn
- 4 webbing straps, 1-inch wide, 2 ft long, with sturdy metal friction buckles
- 4 plastic tension buckles, 1 inch wide
- Cotton-covered clothesline, 2 to 2.5 ft per trap
- 2 metal shaft collars, 5/8 inch (16 mm) inside diameter, with thumbscrews, and
- 2 pieces of PVC pipe, 8 inches (0.2 m) long (used when frames are not on the ground plate)

Appendix C: Details of Ordering Netting Material

Netting material can be purchased from Delta Net and Twine Company, Inc. (*www.deltanetandtwine.com*). Select the netting listed in the highlighted row of Table 1C for a 3.6 mm mesh width opening. This information is provided for the user's convenience, not for endorsement of this company as the sole distributor.

The price of netting material is computed by weight. With a weight of approximately 1 lb per 3 ft of netting material 8 ft deep (wide), a 16-ft long piece (enough for 4 or 8 traps depending on the length of the net) weighs 16/3 = 5.33 lb. At a cost of $8.00/lb, the total price for the netting material is 5.33 * $8.00 = $42.64, so the material price for a 3-ft long net is $5.33 and $10.66 for longer nets.

Table 1C—Netting sizes of bulk nylon knotless Raschel (from the Delta Net and Twine 2002 catalog).

Twine size	Mesh size[a] (inch)	Mesh size[a] (mm)	Mesh opening[b] size (approx.) (mm)	Depth[c] of netting (ft)	Approx. stretched ft to lb	Price per lb[d] 1-24 lb ($)	Price per lb[d] 25-100 lb ($)
210d/9	**3/16**	**4.7**	**3.6**	**8**	**3.0**	**8.00**	**7.50**
210d/15	1/4	6.4	5.8	8	3.3	8.00	7.50
210d/18	3/8	9.5	9.0	8	5.5	8.00	7.50

[a] This measure of mesh size includes one of the netting sides and is therefore larger than the mesh opening size.
[b] Mesh opening size is the open mesh space. This measure is not included in the manufacturer's catalog.
[c] Depth = knitted width
[d] as of Jan. 2005

Appendix D: Wading Safety, Use of Safety Devices, and Wading Risk

Wading Safety

Wading, especially during high flows, is inherently dangerous. Operators must use caution when wading and observe safety measures. Field work of this type should only be undertaken by groups of two or more people. Wearing a belt with chest waders that prevent water from filling the waders in case of a fall is essential even at moderate flows. To reduce the risk of slipping, the wading person should move their feet close to the stream bottom. Each step should be taken deliberately and slowly, one step at a time. Stepping onto slippery rocks or into gaps between large rocks should be avoided. The wading person should move sideways, facing upstream, when wading becomes difficult. A sturdy pole or staff can help to maintain footing. Two people holding hands may be more stable than a single person, especially if only one person moves at a time. When encountering unsafe conditions, the wading person should turn back. Walking backwards a few steps until reaching shallower or slower flow may be easier than turning in a tricky spot.

Use of Safety Devices

Safety devices and practices not only make wading safer but extend "wadeable" conditions to higher flows. Safety practices include wearing a life vest, holding on to a safety line tied across the stream (fig. 53) and, as an extreme measure, wearing a climbing harness and being belayed by a person holding a belay rope on the bank (fig. 54). Several practices can be used together. Wearing a dry suit might also be advantageous in flows difficult to wade.

In the event a person has lost their footing and cannot easily get up, the person should float on their back, feet downstream, and use their arms to steer to a location with shallower water and less flow velocity where it is possible to crawl to the bank. The person should not attempt to stand up in fast moving water. If a foot gets caught on the stream bottom, fast flow can push the person under water. The safest and fastest way out of a stream may not be the closest bank but the nearest shallow bank. When floating downstream, locations should be avoided where a person may be pinned against an obstacle, such as undercut rocks,

Figure 53—Safety devices used by operators at high flow in Little Granite Creek. Notice the life vests and the safety rope fastened across the stream.

Figure 54—Operating bedload traps in poorly wadeable flow. Hazardous downstream flow conditions warrant increased safety measures such as life vests, climbing harnesses, and ropes for each operator's belay. Crossing the ropes should be avoided and operators should be experienced in handling belays. Photo courtesy of Winema National Forest, Klamath Falls, OR.

strainers, downed trees, and deep holes. For more information, check web sites regarding river recreation, fly fishing, and river rescue[14].

The Wading Risk

To evaluate whether or not a flow is wadeable, one should not only consider the risk of slipping and falling, but also the consequences of losing one's footing. While a swim may be exhilarating in warm weather and a safe reach, cold water, bulky waders, the absence of potential rescuers, as well as the presence of hazardous objects downstream, such as rapid flow, undercurrents, downed trees, snags, sharp metal, and wire pose the danger of injury and drowning. Thus, each person and each field crew should carefully assess not only the immediate dangers of wading (for example, high and fast flow, a slippery bed, a small body stature), but also the consequences of lost footing and being swept downstream.

[14] For example, see the Safety Code of American Whitewater at: http://www.american-whitewater.org (accessed 12-20-06).

Appendix E: Estimated Work Time for One Field Season

Table 1E—Work effort in total hours for all field personnel combined.

Tasks, crew size, hours	**2-week highflow season with peak flows < Q_{bkf}**	**4-week highflow season with peak flow > Q_{bkf}**
Scouting for site selection, setting up and taking down the site: 2 person crew, 10 hrs/d, 8 days	160	160
1 extra person when setting up and taking down a footbridge	8	8
Field work: 2 person crew, 12 hrs/day, 6 to 7 days/week	312	624
1 extra person during highest flows	0	36
Washing samples after field work	0	100
Drying and transporting samples	10	20
Lab sieving, 2 person crew	120	240
Storage and maintenance of gear	10	10
Total work hours per season	620	1198

Appendix F: Field Equipment and Operator Gear When Using Bedload Traps in Mountain Gravel/Cobble-Bed Streams

Work Assignment

Use of bedload traps involves a variety of different tasks, such as installing ground plates, setting and emptying the traps in the stream, washing and bagging samples, taking notes, etc. While all tasks can usually be accomplished by all operators in unchallenging situations, cold temperatures, marginally wadeable high flows, time pressures, and the requirements of multi-tasking put a stress on everyone. Assigning each operator a limited set of tasks based on their skill set is recommended. One operator, for example, may be skilled at sample processing or note taking, while the other is better suited to wading at high flows or lifting and moving heavy objects. Following an established routine helps accomplish the tasks and avoids mistakes, particularly in stressful situations.

Field Gear

Using bedload traps requires not only the items immediately associated with the bedload traps (table 1F), but also a relatively large amount of field gear (tables 2F and 3F), much of which is necessary for sample processing in the field as well as for personal protection (table 4F) due to the relatively cold and high radiation environment of mountain streams. The lists provided below attempt to be comprehensive—not all items may be needed in every study. Not all of the gear may need to be purchased—some of the gear such as buckets, tubs, and ropes may be found in the general field gear storage area or in someone's garage. Equipment typically used in fluvial field studies can perhaps be borrowed from a university or government agency (table 2F). Specialty personal field gear, such as waders and paddle jackets, were evaluated in tables 5F and 6F.

Protective Clothing Suggestions

Water temperature at snowmelt highflows in Rocky Mountain streams is typically 32 to 50°F (0 to 10°C). Air temperature fluctuates greatly, freezing at night and rising up to 50 or 60°F (10 to 16°C) during the day, occasionally reaching 80°F (27°C). Protection from the cold and wet, as well as the sun, is essential for making it through a long day of field work.

Gloves

Neoprene gloves are necessary when in contact with the water for more than a few seconds at a time, even on relatively warm days. Neoprene gloves work well for the operator setting and emptying bedload traps, but are less suitable for the operator tying and untying the bedload traps (neoprene gloves limit the operator's dexterity, are cumbersome to put on and off, and wear out quickly). Partially rubberized cotton knit gloves (available in gardening and hardware stores) are better suited for tying the nets. Repeated contact with the cold water and handling wet gear all day roughens and dries out the skin. Wearing rubber gloves helps to reduce this problem.

Waders

When working in deep, fast, and cold water during long days in the field, waders are an important part of an operator's outfit and should be carefully selected. Table 5F provides the authors' evaluation of different waders with respect to various requirements. As flow and temperature conditions change within a highflow season, it may be useful to have several waders at hand, at least one pair of hip waders and one pair of chest waders per operator. Hang waders upside down and dry them out at room temperature each night.

Jackets and Gravel Guards

An operator will need a waterproof jacket for installing ground plates and setting and emptying the traps. A nylon paddle jacket is adequate for cool weather or short exposure to the flow. A neoprene paddle jacket with a front zipper is warmer and easier to take on and off (table 6F). When the operator's arms are under water, water leaks through the neoprene cuffs of the paddle jackets. The degree of leakage and coldness to the arms can be reduced by wrapping wrists and forearms with neoprene gravel guards[10]. All clothing worn underneath waterproof clothing should be moisture wicking and fast drying (for example, polypro).

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[10] Gravel guards are pieces of neoprene approx. 6 by 18 inches (0.15 by 0.46 m) in size with a velcro closure. They are designed to be wrapped around the ankle to prevent sand and fine gravel from entering wading boots worn over stocking foot waders.

Table 1F—Bedload traps and their components.

- Bedload traps with netting, straps, and buckles
- Cotton cover clothes line to tie off net
- Ground plates
- Stakes
- Stake driver
- Shaft collars with thumb screws

Table 2F—General field gear for fluvial studies.

- Measuring tape, 50 to 100 ft long
- Engineer's hammer or small sledge hammer
- Chest waders
- Hip waders and irrigation boots
- Life vests
- Nylon climbing rope (50 to 100 ft) for safety line
- Gravelometer (template) in 0.5 phi increments
- Accurate hanging scale

For ancillary measurements:

- 2 staff gauges
- 2 stage recorders
- 4 metal fence posts and fence post driver
- Equipment for discharge measurements (for example, current meter and top setting rod)
- Sampling frame for pebble counts
- Surveying equipment
- Helley-Smith bedload sampler

Table 3F—Items needed for operating 4 bedload traps.

- Paddle jackets
- Rubber and/or rubberized gloves
- Work gloves
- Neoprene gloves
- 4 plastic buckets, 5 gal (color 1)
- 4 plastic buckets, 5 gal (color 2)
- 4 plastic buckets, 5 gal (any color, 3 for washing samples, 1 spare)
- 1 mid-sized terry cloth field towel
- 1 metal bowl, 9 to 10 inch diameter, crimped
- 1 metal bowl, 12 inch diameter with rim to fit onto a 5-gal bucket
- 1 clear plastic measuring cup (2-cup size)
- 1 large wire spoon (Chinese kitchen ware)
- Rubber spatulas, large and medium size
- Ziploc bags (starter kit: more may be needed)
    - Snack size, carton of 100 (enough for 25 samples)
    - Quart size, 2 cartons of 50 (enough for 25 samples)
    - Gallon size, 2 cartons of 40 (enough for 20 samples)
- 2 Sharpie markers (new)
- 1 pack of mechanical pencils (half a dozen or so)
- 1 water resistant field book
- 1 note book
- 2 camping stools
- 2 camping chairs
- 2 plastic tubs, 25 to 30 gal, for storing gear
- 1 plastic mantled cable with end loops, 20- to 25-ft long, and padlock to secure gear
- Several large- and medium-sized tarps to protect gear and operators from rain
- Assortment of short ropes and string
- Assortment of plastic shopping bags
- Surveyors flags and flagging
- Several stakes of rebar of different length, always handy
- Duct tape, always handy
- Silicone gel, for example, Aqua seal, to repair leaky waders, jackets, gloves…
- Piece of plexi glass, about 1 ft^2, for viewing under water
- Several homemade signs to mark the study site, with brief explanation
- Tool kit, nails and screws, baling wire

Table 4F—Personal items needed for field work.

- Field hat and warm cap
- Sun glasses
- Sun screen lotion, chap stick
- Insect repellent
- Hand lotion, liquid bandaid or super glue
- First aid kit
- Layered clothing, particularly polypro long underwear and other quick-drying clothing
- Change of clothes (if one set gets wet)
- Footwear besides waders (for example, tennis shoes, hiking boots)
- Several pairs of thick socks
- Rain gear
- Head lamps
- Easy to read digital sports watch, worn on a string around the neck
- Camera
- Cooler with food
- Several water bottles
- Plenty of snacks

Table 5F—Authors' evaluation of wader properties.

	Hip waders	Chest waders			
Desired quality	**Irrigation boots; hip waders**	**Gore-Tex (fly fishing) bootfoot**	**Neoprene stocking foot**	**Thin rubberized or nylon bootfoot**	**Heavy weight rubberized or nylon bootfoot**
Wadeable flow depth	Less than thigh high	Deeper than thigh high			
Protection from cold water	Good	Little	Little to moderate	Moderate	Good
Operator wading agility	Very good	Good	Good to moderate	Moderate	Restricted, esp. when oversized
Allowing bending and squatting	Some restriction	Moderately restricted, needs to be oversized			Restricted
Wear and tear resistance	Robust; punctures easy to patch with silicone glue	Delicate; patching with silicone glue?	Leaky at stocking foot; punctures easy to patch with silicone glue	Robust; punctures easy to patch with silicone glue	
Avoiding sweatiness	Moderate	Good	Poor		
Ease of putting on or taking off	Easy	Moderate	Cumbersome	Moderate	Moderate

Table 6F—Authors' evaluation of two types of paddle jackets.

Desired quality	**Nylon, pullover**	**Neoprene, front zipper**
Water tightness along cuffs	Neoprene cuffs are easy to put on and off, but are leaky; arms become wet under water. Gravel guards worn on forearms reduce leakiness and improve cold protection	
Water tightness along front	Water can enter around the neck and along the zipper	
Protection from cold water	Poor	Good
Ease of putting on or taking off	Cumbersome	Moderate

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