Methods of Measuring Fluvial Sediment

by

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1. Sediment and the Fluvial Environment

As erosional and depositional agents, rivers are the cause of major landscape modification. The flow regime and sediment transport characteristics of rivers are systematically correlated to temporal and spatial changes in channel geometry and bed material size (Hey, 1987). As a result, land managers and researchers are interested in the response of erosion and sedimentation to changes occurring in fluvial systems. By predicting how land use will alter erosion and sedimentation rates, they can anticipate where sediment will be deposited, how long it will be stored, and how it will be re-mobilized (Reid and Dunne, 1996). The interactions between channel form, flow regime, and sediment transport aid in the determination of channel response to natural or man-induced changes (Hey, 1987). Alterations to the flow regime often affect sediment production and transport, while altered channel morphology occurs only through mobilization of sediment (Reid and Dunne, 1996). Therefore, an evaluation of sediment in the fluvial system is necessary to determine potential or existing channel responses to changes in land use.

The total sediment load refers to the sediment transport rate and is defined as the total amount of sediment passing through a given channel cross-section per unit of time (Shen and Julien, 1993). The load carried by natural streams is subdivided into dissolved load, wash load, and bed-material load. Dissolved load consists of material transported in solution. Wash load is composed of particles moving readily in suspension, which are finer than those usually found on the bed (generally < 0.062 mm). Bed-material load includes all sizes of material found in substantial quantities on the surface at the bottom of the stream (generally > 0.062mm). When particles move at velocities less than those of the surrounding flow by rolling, sliding, or saltation, the bed material is transported as bed load. However, when particles are transported and temporarily maintained in the main body of the flow by turbulent mixing processes, they are transported as suspended load. A significant amount of material supplied to streams constitutes wash load. The particles are so fine that almost any flow will transport them. The rate of supply is more constraining than is the transport capacity of flow in the movement of wash load. On the other hand, the transport of bed-material load is mainly capacity-limited due to the caliber of the coarser material. Dissolved load is the least dependent on the quantity of flow. It is very important from an environmental standpoint, but has little impact on channel form adjustment (Knighton, 1998).

Based on the type of total sediment load, several methods are available to evaluate the sediment component of a fluvial system. Such evaluations involve the development of particle size distributions, suspended sediment sampling, measurement of bedload transport, and the determination of changes in sediment storage. Numerous methods are available to conduct each of these evaluations. The method or combination of methods is dependent on the channel characterization and specific purpose of sediment evaluation.

2. Study Area

A sediment evaluation will be applied to Valley Creek, a third order stream located in Valley Forge National Historical Park in southeastern Pennsylvania. Valley Creek drains a 60.6 km^2 (23.4 mi^2) area, consisting principally of carbonate rocks, including limestone and dolomites. It is flanked by hills of less erodable crystalline rock, mostly quartzite, schist and gneiss. The stream has an average channel slope of 1.2% and is dominated by cobbles and gravel, with deposits of sand and silt. Bedrock is also present in some sections of the channel (Gutowski and Stauffer, 1996).

Over 75% of the entire length of Valley Creek is characterized as either runs or riffles, with more than half of the pool sites located behind a reconstructed mill dam. Near the covered bridge by Maxwell's Quarters, the channel changes substantially. The land is relatively flat upstream of the bridge. However, downstream of the bridge, the stream is forced into a narrow gorge between Mount Misery and Mount Joy. Several silted-up mill ponds once existed along this stretch. Their remnants form the existing high stream banks, which are unstable and easily eroded (Gutowski and Stauffer, 1996).

Peak discharge and runoff volume has increased in Valley Creek due to the increase in impervious surface area. Areas such as parking lots, roads, and roofs allow precipitation to flow quickly into the stream. The amount of land dedicated to residential, commercial, and industrial uses in the drainage basin increased significantly between 1970 and 1990. The result was a decrease in the amount of agricultural and open space land usage (Gutowski and Stauffer, 1996). For 1995, the 2-year peak discharge was estimated at 38.2 cms (1,350 cfs), while the 100-year peak discharge was estimated at 229.3 cms (8,100 cfs). Over the 300 year period from 1685 to 1985, the peak discharges were doubled, which is typical of hydrologic changes in a moderately developed watershed. These numbers were estimated using the SCS TR-55 (Urban Hydrology for Small Watersheds) graphical methods. Half of the increase occurred over the 100-year period from 1785 to 1885 when 40 to 50 percent of the watershed was deforested for agricultural use. The other half occurred between 1885 and 1985, with most of the increase occurring since 1970 when additional land was deforested and agricultural land was converted to residential, commercial, and industrial areas (Reed, 1991).

During active construction, sediment supply to channels can increase greatly (Knighton, 1998). Stream channel erosion can provide a substantial fraction of the sediment produced during urbanization. A comparison of gravel-bed rivers in paired urban and rural catchments of Pennsylvania led to the conclusion that erosion of the bed, banks, and hillslope sources upstream provide enough sediment to keep the bed material sizes of urban streams nearly similar to those of rural streams (Pizzuto et al., 2000). After a watershed has been developed, sediment yields should decline. However, channel response is variable due to the time scales of land use change in the drainage basin, as well as changes in hydrologic and sediment fluxes (Kondolf et al., 2001). In order to understand the effects of land use change on Valley Creek, a sediment evaluation needs to be completed. Knowledge of sediment transport through a fluvial system and of methods for evaluation of sediment storage and transport is necessary to determine channel responses to urbanization in the Valley Creek watershed.

3. Particle Size Distributions

Information on bed-material particle size is needed for a variety of qualitative and quantitative purposes. They include streambed monitoring, computations of flow hydraulics, and the advancement in understanding of stream processes. Such information can help predict channel form and stability, as well as analyze the source and travel distance of sediment (Bunte and Abt, 2001).

Bed-material particle size is computed by analyzing the frequency distribution of particle sizes within a bed-material sample. However, methods of measurement differ based on the bed-material characterization. Sampling sand-bedded streams is relatively straight-forward. It is usually not necessary to differentiate between surface and subsurface sediment. Therefore, grab samples can be taken from the bed, using a shovel as a sufficient sampling device (Bunte and Abt, 2001).

Gravel and cobble-bed streams typically involve a more complicated sampling process. The range of grain sizes is large, possibly extending over 5 orders of magnitude, from fine sand of 0.06 mm (0.02 in) to boulders of 4,000 mm (157.5 in) (Bunte and Abt, 2001). In many gravel and cobble-bedded streams, a coarse pavement or armor layer covers a finer substrate. Distinction between the two surfaces is difficult to recognize based solely on sediment texture. The difference between surface and subsurface sediment is tied to the flow regime and upstream sediment supply (Reid and Dunne, 1996). Sampling techniques depend on the bed-material strata to be sampled. Some studies sample particles exposed at the surface. Others sample the armor layer that extends to a depth of 1 or 2 large particles. In some cases, the armor layer is removed and the subsurface sediment is analyzed (Bunte and Abt, 2001).

Another complication for the sampling process in gravel and cobble-bed streams is the variability in particle-size distributions. While some streams may have a relatively uniform particle-size distribution over distances several stream widths long, others are composed of numerous areas with different particle-size distributions. The spatial sampling strategy is dependent on the study objectives and stream conditions. Spatially integrated samples involve systematic patterns over the entire area. Locations representative for a particular streambed area may also be sampled. Spatially segregated samples involve segregating the stream reach into sub-areas that can be sampled individually (Bunte and Abt, 2001).

Statistical precision is important to any study involving bed-material sampling. The statistical precision required by the study is used to determine such factors as the number of particles in the sample, sediment weight, or the number of parallel samples that need to be taken. Large sample sizes are often necessary to obtain a reasonable precision level. In a 1985 study of a complex gravel-bedded river by Mosley and Tidale, 50 30-kg (66.15 lb) samples were needed to determine mean grain size to within 20%. If precision were refined to within 10%, 228 samples would have been necessary (Reid and Dunne, 1996).

The final step in bed-material sampling is performing a particle-size analysis. In many cases, this is achieved by sieving the sample and selecting particle-size parameters and statistical analysis in conjunction with the study objectives (Bunte and Abt, 2001). While this final step is similar in the creation of most particle-size analyses, an abundance of bed-material sampling methods have been documented. Below is a description of several widely-used methods.

3.1 Surface Sampling

Bed-surface particles exposed on top of the streambed are collected by surface sampling. Surface sediment lacks a distinct vertical component, with the vertical extent equal to the diameter of the particle that is exposed on the surface at any given point. It can therefore only be measured by surface sampling methods and not by a volumetric sample (Bunte and Abt, 2001). Surface material is the primary interest in studies of flow resistance and surface coarsening (Church et al., 1987).

3.1.1. Wolman Pebble Count

Surface sampling is usually done with a grid or transect and is some variant of Wolman's technique (Wolman, 1954). A grid is established by either pacing or using lines or a tape. The sampling area is typically covered with 100 grid points, with a particle collected and measured at each point. However, the spatial scale of grid counts is flexible. Grid spaces are recommended to be twice the D_{max} (the particle size at which all others are finer than) in order to avoid double counting (Bunte and Abt, 2001).

Wolman proposed a heel-to-toe walk across the channel. In order to select a sample at random, the particle at the tip of the boot is selected while looking away. This method is often used because it requires little field equipment and can be done in wadable flows. However, there is a high possibility for operator bias against small particle sizes, such as sand. The computation of the fine part of a cumulative particle-size distribution has a statistical error that is more than twice as large as that for a D_{50} or D_{84}. However, this problem is negligible when all neighboring particles fall into the same size category, such as a sand patch. The operator can select one particle from a pinch of sediment taken from the streambed (Bunte and Abt, 2001).

3.2 Volumetric Sampling

Volumetric samples involve a predefined volume or mass of sediment that is removed from the bed. Samples are typically bulk samples that have been shoveled or scooped, size graded by mesh sieves and apportioned by weight (Church et al., 1987). They can be used to measure particle size in both the armor and subsurface layers.

The armor layer is a relatively coarse surface cover in comparison with the bulk subsurface mixture below. It can be formed by several processes, including the winnowing of surface fines, selective deposition of large particles and increased availability of coarse surface particles as part of equal mobility transport. The degree of armoring is used in such studies as streambed monitoring and sediment transport analysis. It is determined by comparing the D_{50} of the armor layer to the D_{50} of the subsurface sediment. The armor layer extends from the bed-surface plane down to the bottom side of the largest, or a frequently occurring large surface particle size. Samples should extend over the entire thickness of the armor layer (Bunte and Abt, 2001).

Subsurface sediment is found beneath the armor layer. It is controlled by the supply of fine sediment to the stream and local hydraulics. Size distribution of subsurface material is important to studies of sediment transport, fish spawning habitat and gravel resource appraisal. Before subsurface sediment can be sampled, the overlying armor layer needs to be removed. Church et al (1987) recommend clearing the surface sediment at least to the depth of the deepest-lying exposed grain. Sampling thickness of subsurface particles should be at least the same as the armor-layer thickness.

3.2.1 Bulk Cores

Bulk samples involve inserting a cylinder, also known as a barrel sampler, into the streambed. Bed material from inside the cylinder is extracted. The main advantage of barrel samplers is that a large sample can be obtained relatively easily (Lisle and Eads, 1991). They are designed specifically to collect volumetric bed-material samples in gravel-bed rivers because they allow sampling over a wide range of particle sizes and relatively large sample volumes. These samplers also retain suspended fines and can be used under submerged conditions (Bunte and Abt, 2001). However, the main disadvantages are that variations of gravel conditions with depth are difficult to measure and fine sediment settles into the bottom of the sampler as the coarser material is removed. In order to capture the fines, a sample of agitated water is taken from the cylinder and the concentration and grain size of the fine sediment are measured (Lisle and Eads, 1991).

Various versions of barrel samplers are documented, one of which is the cookie-cutter sampler. Also known as the gravel-cutter sampler, it was designed for use in coarse gravel and cobble bed streams. It is constructed from a 55-gallon drum that is cut in half. The barrel is fitted with handles and teeth are cut into the bottom so it can be worked into the streambed. When used in water depths that do not overtop the barrel, sediment is scooped out and poured into buckets. However, under submerged conditions, a rectangular sample box is attached to the downstream side of the barrel. The sediment is temporarily stored in this box, which has one open end and the other fitted with a fine mesh wire to retain fines (Bunte and Abt, 2001).

A second type of bulk core sampler is the CSU barrel sampler, which is a simplified alternative to the cookie-cutter sampler. It is constructed from a 30-gallon drum that is cut open on both ends. First, the barrel is slightly inserted into the bed material at the selected sampling location. Particles under the edge of the barrel are removed to allow the barrel to be worked deeper into the bed. All the particles within the barrel are removed, either by hand or with a scoop, until the pit has reached a predefined depth. In order to sample fine sediment, the water is swirled around in the barrel and a suspended sediment sample is taken. Under completely submerged conditions, the barrel is fitted with a cloth hood. Wearing a diving mask and a snorkel, the operator removes the sediment through a slit in the cloth (Bunte and Abt, 2001).

3.2.2 Freeze Cores

Freeze core samplers are designed to collect vertical sections of bed material bound by interstitial water to one or more probes driven into the bed. They extract a vertical section of undisturbed streambed material, extending from the surface into the subsurface. The stratification of bed-material remains intact, unlike the homogenization of streambed material that occurs when using barrel samplers (Lisle and Eads, 1991).

One or more pointed hollow rods with a 2 cm (.79 in) inside diameter are driven approximately 0.2m (7.9 in) into the streambed. They are injected with either liquid carbon dioxide or liquid nitrogen, which escapes through nozzles at the lower end of each rod. Pore water in the sediment adjacent to the rod freezes. The frozen core is then extracted from the bed for a particle analysis. Freeze cores typically weigh from 1 – 5 kg (2.2-11.0 lb) when sampled with liquid carbon dioxide, however this can be increased to 10 – 15 kg (22.0-33.1 lb) when sampled with liquid nitrogen (Bunte and Abt, 2001).

Freeze core sampling involves two main disadvantages, the first of which is created by pounding the rods into the bed. The stratification of the bed material may be disturbed as fine sediment is shaken deeper into the bed (Lisle and Eads, 1991). A second disadvantage is the irregular shapes of freeze core samples, depending on how far the freezing advanced outward from the rod. This can cause an irregular particle-size distribution of the sample. Retrieval of the rod may lose large particles that are only partially frozen to the core. A few large particles may also be frozen to the rod and dominate the sample mass, causing an underrepresentation of fine sediment (Bunte and Abt, 2001).

4. Suspended Sediment

The distinction between bed and suspended load is often highly debated. Most workers in the field consider suspended load to be the portion of the load created by the upward momentum in turbulent eddies in the flow. Bed load includes all sizes of sediment that move by sliding, rolling, or saltating on or very near the bed. However, as flow conditions change, particles can interchange between the bed and suspended load. A further subdivision of suspended load is known as wash load. This is the load that is composed of particles with such small settling velocities that they are held in suspension. These fine particles pass through river systems relatively uninfluenced by hydraulic conditions. However, high concentrations of wash load can affect the configuration of the bed and the overall rate of sediment transport (Leopold et al., 1964).

The transport of particles in suspension affects stream behavior and channel form adjustment. High concentrations of wash load reduce turbulence. The result is an increase in the viscosity of the flow and reduced settling velocities. Coarser grains and a larger bed-material load are transported during these high concentration periods. It was argued by Schumm [1960] that such concentrations cause channels to be relatively narrow and deep. Large suspended loads often lead to changes in stream course. They also have an impact on overbank deposition and the resulting floodplain development (Knighton, 1990).

Suspended sediment load contributes approximately 70% of the total load delivered to the world's oceans each year (Walling, 1987). Most of the suspended sediment is carried by relatively frequent events of moderate magnitude. Although there can be wide variations, the most effective discharge for transport has a flow duration of 0.3 – 5 % (1 – 20 days per year). This is the frequency with which discharges of different magnitude are equaled or exceeded. It becomes more frequent in larger basins. Individual catastrophic events may carry larger amounts of sediment. However, they occur so infrequently that their contribution to suspended sediment transport over the entire range of discharge is less significant (Knighton, 1998).

The main purpose of suspended sediment sampling is to determine the instantaneous mean discharge-weighted suspended sediment concentration over a stream cross section. The measured suspended-sediment discharge is computed by these concentrations combined with water discharge. Sediment concentration of the flow is determined by collecting depth-integrated suspended-sediment samples that define the mean discharge-weighted concentration in the sample vertical. Sufficient numbers of vertical samples must also be collected to define the mean discharge-weighted concentration in the cross section (Edwards and Glysson, 1999).

Suspended sediment samplers are designed to obtain a representative volume of the water-sediment mixture moving in the stream in the vicinity of the sampler. Although there are several versions of suspended sediment samplers, the sampling concepts are similar. The sampler is submerged with the nozzle pointing directly into the flow. Streamflow enters the sampler container through the nozzle, as air is exhausted. This process occurs due to the combination of positive dynamic head at the nozzle entrance, negative head at the end of the air-exhaust tube, and positive pressure due to a difference in elevation between the nozzle entrance and the air-exhaust tube. The sample in the container eventually reaches the level of the air exhaust. The flow rate drops, causing a circulation of the streamflow in through the nozzle and out through the air-exhaust tube. Coarser particles settle out because the water velocity flowing through the bottle is lower than the stream velocity. The concentration of coarse particles in the bottle gradually increases (Edwards and Glysson, 1999).

4.1 Depth Integrating Sampler

Depth integrating samplers continuously accumulate a representative sample from a stream vertical. The sampler is lowered slowly down to approximately 10 cm (3.9 in) from the top of the streambed. It is then raised to the water surface at the same speed. During this round trip, suspended sediment continuously enters the sampler, collecting a velocity, or discharge-weighted sample. The conditions for use of a depth integrated sampler are that the nozzle size must be at least 1.5 times the largest sediment size expected to enter the sampler. However, it must also be small enough that the bottle will not be two-thirds full after traversing the stream flow depth to prevent the entrance of excess sediment particles. If these conditions cannot be met, a second type of sampler, known as a point integrating sampler must be used (Shen and Julien, 1993). While many varieties of the depth-integrating sampler are available, a few of the most commonly used are described below.

4.1.1 DH-81

The DH-81 is a type of depth integrating sampler that is useful for sampling during cold weather conditions. The plastic sampler head and nozzle attach directly to the bottle, which eliminates a metal body. During colder conditions, the metal body would conduct heat away from the nozzle, air exhaust, and bottle, creating a more severe sampler-freezeup condition. The DH-81 can be used with 1/8 inch, 3/16 inch or 1/4 inch nozzles, as well as any bottle having standard mason jar threads. However, the size of the unsampled zone will depend on the bottle size used by impacting how close the sampler can get to the bed (Edwards and Glysson, 1999).

4.1.2 DH-59 and DH-76

These two lightweight samplers of 10.9 and 11.3 kgs (24 and 25 lbs) are designed for use in shallow streams with flow velocities up to 1.5 m/s (5 ft/s). They are the most commonly used for sediment sampling during normal flow in small and intermediate-sized streams. A round pint sample bottle is used in the DH-59, allowing sampling to within 11.4 cm (4 _ in) of the streambed. A quart container is used in the DH-76, which allows sampling to within 3 inches of the streambed. Intake nozzles can be interchanged when varying flow conditions are encountered and are available in 4.6 cm (1/8 in), 0.5 cm (3/16 in), and 0.6 cm (1/4 in) diameters. The DH-59 and DH-76 are preferred in the field because they are small, light, durable, and adaptable (Edwards and Glysson, 1999).

4.1.3 D-74 and D-77

These two heavier samplers are used when streams cannot be waded, but are shallower than about 4.6 m (15 ft). The D-74 is a 28kg (62 lb) sampler with a 61 cm (24 in) body that completely encloses the sample container. The sampler was designed to be suspended from a bridge crane or cableway by means of a standard hanger bar and cable-and-reel system (Edwards and Glysson, 1999). It is suitable for a maximum water depth of 5 m (16.4 ft) and a fluid velocity of 2.1 m/s (6.9 ft/s) (Shen and Julien, 1993). The D-

74 can be fitted with a round quart bottle, or with a standard pint milk bottle using an adapter. These containers allow the sampler to be lowered to within 10.1 cm (4 in) of the streambed. Nozzles of 4.6 cm (1/8 in), 0.5 cm (3/16 in) and 0.6 cm (1/4 in) are available which can be interchanged under varying flow conditions. They are aligned with the flow by tail vanes attached to the body (Edwards and Glysson, 1999).

The D-77 is 74 cm (29 in) long, weighing 34 kg (75 lb). A bronze casting is attached to the tail cone, with four sheet-metal vanes that orient the intake nozzle into the flow. A 3000 m^3 (3 liter) sample container is held in place by a spring clip on the bottom of the sample container chamber. The D-77 is a dramatically different design than the D-74 because it is constructed without a head assembly to cover the mouth of the container, where the intake nozzle is usually attached. In order to allow collection of a large volume sample at freezing temperatures, a cap, nozzle, and air-exhaust assembly is constructed of plastic and screwed onto the mouth of the sample container that is exposed at the front of the sampler. While only a 0.8cm (5/16 in) nozzle is recommended for the D-77, other available sizes include 0.62cm (1/8 in), 0.6cm (1/4 in), and 0.5 cm (3/16 in) (Edwards and Glysson, 1999).

4.2 Point Integrating Sampler

Point integrating samplers are designed to collect suspended load for a short duration at a given depth. They are more versatile than depth integrating samplers because they collect a representative suspended sediment sample at any point, from the surface of the water to within a few inches of the bed. These samplers also integrate over a range in depth. All point samplers are suspended with a steel cable, by which a current is supplied to the sampler head. An electrically activated valve samples points or portions of a chosen vertical location. Stream cross sections less than 9.1 m (30 ft) deep can be traversed in one direction at a time by opening the valve to depth integrate from either surface to bottom, or vice versa. When cross sections are deeper than 9.1 m (30 ft), a downward integration and upward integration can be collected in separate containers (Edwards and Glysson, 1999).

These samplers use a 0.5 cm (3/16 in) nozzle which should be greater than at least 1.5 times the largest sediment size to be collected. A solenoid-activated valve allows intake and exhaust passages to be activated on demand (Shen and Julien, 1993). The sampling procedure is similar to that of depth integrating samplers when the valve is activated. A pressure-equalizing chamber in the sampler body allows the point integrating sampler to be effective at a greater depth than the depth integrating sampler. It equalizes the air pressure in the container with the external hydrostatic head near the intake nozzle. This prevents the inrush of sample water that would occur when the intake and air exhaust are opened at depth. (Edwards and Glysson, 1999). There are 3 currently manufactured and widely used point integrating samplers, which are described below.

4.2.1 P-61 and P-63

Weighing 105 pounds, the P-61 can be used for point or depth integration at a maximum stream velocity of 1.8 m/s (6.6 ft/s). When the solenoid is not energized, the valve is in the nonsampling position. After energization, it is in the sampling position. A pint bottle is typically used with this type of sampler, which allows sampling to a depth of 54.9 m (180 feet). However, the sampler can be adapted to accommodate a quart bottle, which allows sampling to a depth of 36.6 m (120 ft) (Edwards and Glysson, 1999).

The P-63 is similar to the P-61, differing mainly by size and weight. At 90.7 kg (200 lb), it is better adapted to high velocity flows. The P-63 is 86.4 cm (34 in) long and cast bronze. Using either a quart or pint sized bottle, it has the same sampling depth as the P-61 (Edwards and Glysson, 1999).

4.2.2 P-72

Weighing at 18.6 kg (41 lb), the P-72 is a lightweight version of the P-61. This is due mainly to its cast-aluminum shell, rather than the bronze shell of the P-61. It also accommodates both the quart and pint sized containers, reaching a maximum sampling depth of 21.9 m (72 ft) with the pint container and 15.5 m (51 ft) with the quart container. However, it differs from the P-61 in that it can only be used at a maximum stream velocity of 1.6 m/s (5.3 ft/s), compared to 2.0 m/s (6.6 ft/s) (Edwards and Glysson, 1999).

4.3 Single Stage Samplers

Single stage samplers are designed to obtain sediment data on streams in remote locations and when rapid changes in stage make it impractical to use a depth integrating sampler. They are point samplers that sample at the point in the stream that the intake nozzle is positioned before a flow event occurs. Single stage samplers are also inexpensive. Multiple samplers can be used during a flow event to sample several elevations or times during the rising hydrograph (Edwards and Glysson, 1999).

Two types of single stage samplers are available, the US SS-59 (U-59) and US U-73. The U-59 is fitted with a pint milk bottle and a 0.5 cm (3/16 in) inside diameter air exhaust. Either a 0.5 cm (3/16 in) or 0.6 cm (1/4 in) inside diameter intake is constructed of copper tubing. These tubes are inserted through a stopper in the mouth of the sample container. The U-73 sampler is similar to the U-59, except that its design configuration solves many of the problems of the U-59. It can be used to sampler either a rising or falling stage, has no problem of condensation in the sample container, and has an exterior design that protects from trash and debris without additional deflection shields. The two types of single stage samplers are one with a horizontal intake and one with a vertical intake. Although they are not always interchangeable, under some conditions either type could be used. Streams carrying a considerable amount of sediment finer than 0.062mm (0.002 in) are sampled with the vertical intake sampler. The horizontal intake sampler is used to sample streams carrying significant amounts of sediment coarser than 0.062mm (0.002 in) (Edwards and Glysson, 1999).

The water-sediment mixture enters the sampler when the stream level reaches the elevation of the intake nozzle. Water continues to enter the sample bottle until it reaches the air exhaust tube. When the stream rises to the level of the exhaust port, air is trapped in the air exhaust and no flow can pass through to alter the original sample. However, the sample can be altered if a differential head exceeds the height of the invert. This description of the sampling process is idealized. Under normal conditions, the flow velocity and turbulence alter the effective pressure at the nozzle entrance (Edwards and Glysson, 1999).

In spite of its advantages, the single stage sampler has many limitations. Samples are collected at or near the stream surface and usually near the edge of a stream or near a pier. Therefore, adjustments must be made for vertical and lateral variations in sediment concentration during data analysis. Also, the time and gage height during which a sample was taken may be unknown. Last, the sampler may not result in intake ratios sufficient to sample sand, in spite of the many combinations of size, shape, and orientation of intake and air-exhaust tubes (Edwards and Glysson, 1999).

5. Bed Material Load

Bed material load is the most significant of the three components of load with regard to channel form adjustment. However, bed material load contributes the lowest percentage of the total load, with contribution of approximately 10% (Walling, 1987). A close relationship exists between channel form and the input-output conditions of sediment load within a reach. For example, the addition of mining waste invariably leads to channel form adjustments. Initial bed aggradation is followed by degradation once the sediment peak has passed (Knighton, 1999). With the variety of controls on channel form, there is no single, universally applicable relationship between morphology and transport (Emmett and Wolman, 2001).

In order to properly measure bed material transport, it is first necessary to understand what constitutes bed material and its relation to bed load. The sediment mixture of which the bed is composed is known as bed material (Edwards and Glysson, 1991). However, particles that roll, slide, or saltate along the bed once the entrainment threshold has been exceeded are known as bed load. In gravel-bed streams, rolling is the primary mode of transport. Saltation is restricted to beds composed of sands and small gravels, where grains hop over the bed in a series of low trajectories. Some particles can be transported as suspended sediment as they are carried upwards into the main body of the flow to be transported temporarily in suspension. One type of transport may dominate at any given stage. However, all modes of bed material transport can occur simultaneously over a wide range of flow conditions (Knighton, 1998).

Bed material transport is dependent on many variables, although it is predominantly a function of the transporting capacity of the flow (Knighton, 1998). Local and remote sources of supply interact with the sequence of flows. This creates temporal and spatial variability in transport at a section. In other words, sediment will be available at different times and in different places during an event. As flow rises, new sources are accessed. For example, channels with relatively high bar amplitude access sediment on the bar tops infrequently. On the other hand, most of the channel bed in wide, shallow channels may be accessed relatively rapidly (Sear, 2002).

One of the many variables in bed material transport is the development of an armor layer. When a channel is composed of heterogeneous grain sizes, the larger grains are more easily entrained due to their exposure to lift and drag forces. Finer grain sizes are more difficult to entrain due to hiding effects. Therefore, a stream must move the coarser half of its mean annual gravel load at precisely the same rate as the finer half (Parker, 2002). This challenges the traditional size-selective transport theory, which states that bed load size is directly proportional to displacement forces (Marion and Weirich, 2003). The armor layer is significant to bed material transport in that it limits the supply of material. The resulting sediment transport rate is lower than that predicted by capacity bed-load formulae (Knighton, 1998).

Another variable that affects bed-material transport is the addition of fine sediment sources to a channel. The supply of sediment to rivers can be increased by land disturbances, such as urbanization, fire, and agriculture. This additional supplied sediment is finer than that found in the river bed in most cases. A study by Curran and Wilcock [2003] found that increasing the sand content of a channel would result in a decreasing bed slope. This study led to the conclusion that the addition of a finer sediment supply can reduce the grain size of the bed and increase the river's transport capacity. This results in the counteraction of the tendency toward aggradation when sediment supply is increased.

The many variables involved in bed material transport make it difficult to measure. Errors are primarily associated with the sampling devices themselves, as well as the extreme temporal and spatial variations in transport rate (Knighton, 1998). A sample obtained at a given location may not be representative of the mean transport rate for an interval of time (Edwards and Glysson, 1999). The two main measurement techniques are direct and indirect. Direct methods involve some sort of sampling device placed on the bed. Indirect methods involve studies such as tracers or repeated channel surveys (Knighton, 1998). Any sampler chosen for a particular site should generally lie flat on the channel bed, with a nozzle opening two or more times larger than the maximum size particle to be sampled. However, these conditions are difficult to meet, particularly in coarse grained channels, when bed and flow conditions are not optimal. Under these circumstances, a combination of sampling methods may be used to sample all particle sizes transported. Even with changing transport rates and patterns, it is important to use the same type of sampler throughout the sampling duration in order to achieve consistent results (Ryan and Troendle, 1997). Many types of bed load samplers are available, each with their own strengths and weaknesses. Similar types of bed load samplers may collect substantially different amounts of sediment, due primarily to slight modifications in design (Ryan, 1998). Some of the most widely-known samplers are described in this section.

In order to identify the position and stability of transport zones, it is necessary to sample the entire cross-section over a variety of flows. The estimate of the mean transport rate becomes better as more vertical sample locations are used. However, the disadvantage is that the time required to sample each cross-section becomes larger with the addition of each vertical sampling location. The flow rate may also change before the sampling is complete. The commonly used method in gravel-bed channels is to sample a minimum of 20 equally-spaced points per cross-section. Two traverses are made per bed load sample, requiring 40 vertical measurements per sample. In narrower channels, fewer vertical sampling locations are usually required. Spacing between vertical sampling locations should be equal and approximately 15% of the channel width (Ryan and Troendle, 1997).

Sampling time and frequency are also important for evaluating bed material transport. The longer the sampler is held on the stream bed at each vertical, the better the measurement of mean transport rate at that point, but the longer it takes to sample a cross-section. A bed load sample is ideally collected in 1/2 to 1 hour during moderately fluctuating flow conditions. A sampling time of 30 to 60 seconds is recommended by the USGS for each vertical in gravel bed streams. The number of samples collected for a site is known as sampling frequency. Ryan and Troendle found that a minimum of 25 composite samples were usually required over a wide range of flows to define a transport function. These flows should range from low flow to roughly bankfull (Ryan and Troendle, 1997).

5.1 Helley-Smith

The Helley Smith is the most commonly used hand-held portable bed load sampler (Ryan, 1998). This pressure-difference bag sampler was designed for use in fine gravel beds. However, the United States Department of Agriculture (USDA) uses the Helley-Smith as a primary bed load sampler in steep, coarse-grained channels (Ryan, 1998). It traps coarse sand and fine gravels, from 2-10 mm (0.08-0.4 in) in size. The design is intended to trap all material traveling below the usual lower sampling limit of suspended sediment samplers (Sterling and Church, 2002).

The original version weighs 30 kg (66 lb) and is constructed of 0.6cm (1/4 in) thick cast aluminum. Its weight requires the sampler to be used with a cable-reel suspension system (Edwards and Glysson, 1999). The original Helley-Smith has a 7.6 x 7.6 cm (3 x 3 in) (inner dimension) intake and an expansion ratio (exit area / entrance area) of 3.22 (Ryan and Troendle, 1997). A 1.9 m^2 (295 in^2) polyester mesh sample bag is attached near the nozzle assembly. It has mesh openings of varying sizes (0.25 mm most commonly used) and is 45.7 cm (18 in) long. The sampler is designed to collect particle sizes less than 76 mm (3.0 in) at a maximum mean velocity of 3.0 m/s (9.8 ft/s) (Edwards and Glysson, 1999).

Other versions of the Helley-Smith are also available. A lighter, less expensive version has been developed and manufactured commercially. It is identical to the original, except that it is constructed of 16 gauge stainless steel, instead of 0.6 cm (1/4 in) cast aluminum (Ryan and Troendle, 1997). This “Sheetmetal” Helley-Smith also has an expansion ratio of 3.2. A second version of the original sampler is the US BLH-84. It is constructed of 0.6 cm (1/4 in) thick welded aluminum. Although it is similar in thickness to the original sampler, it has a smaller expansion ratio of 1.4 (Ryan and Porth, 1999). This sampler has a smaller hydraulic efficiency than the original Helley-Smith and doesn't draw in water the same way. It has a reduced flare, allowing it to fit more easily into the channel bottom and be less intrusive of the flow. A third type of sampler is the scaled up version of the original Helley-Smith. It has the same ratio and efficiencies as the original. However, it has an intake opening of 15.2 x 15.2 cm (6 x 6 in), allowing it to sampler larger particles. The main disadvantage is its unsteadiness in high flows and the difficulty of placing it on the bed. It is heavier, larger, and more disruptive of the flows. Sample sizes from this 15.2 x 15.2 cm (6 x 6 in) sampler are generally a factor of 5 or more larger than those from the original 7.6 x 7.6 cm (3 x 3 in) sampler (Ryan and Troendle, 1997).

The differences in sample design introduce significant changes in bed load collection rates. One laboratory test of the original 7.6 x 7.6 cm (3 x 3 in) sampler determined an average sampling efficiency of 160%, while field studies concluded an efficiency of 100%. This efficiency also varies with particle size. The original sampler has an approximate 150% efficiency for sand and small gravel, and 100% for coarse gravel. Higher efficiencies were generally found for the larger 15.2 x 15.2 cm (6 x 6 in) sampler (Edwards and Glysson, 1999). A study by Ryan and Porth [1999] found that samples collected with the original Helley-Smith were an average of 1.6 times larger than those collected by the US BLH-84. Samples collected by the Sheetmetal Helley-Smith were on average 1.8 times larger than those collected by the original sampler. Overall, the Sheetmetal Helley-Smith collected more material, the original Helley-Smith was intermediate, and the US BLH-84 had the lowest relative rate of transport of the three samplers. The study concluded that measured transport rates will vary depending on the sampler used. Some mode of calibration in needed in order to compare the results of the 3 samplers.

5.2 Pit Traps

Pit samplers, also known as slot samplers, are designed to intercept all material that would be in contact with the bed at the slot position. This material may be transported by rolling, sliding, or saltating (Sterling and Church, 2002). Openings are generally larger than the maximum hop length of saltating particles. Pit samplers are expected to be more accurate than other bed load samplers because they do not affect the flow. Various types of these samplers are available, which utilize either a vortex tube, a continuous conveyor belt, or a local weighing device (Laronne, 2002).

Simple pit traps accumulate material in an inner container that periodically requires emptying. This provides a composite bed load sample for all flows since the last emptying. Simple traps typically have round openings, so they are not sensitive to the effects of varying direction of the oncoming current (Sterling and Church, 2002). They can be installed in a streambed by a small field crew with shovels and buckets. The sampling container is buried flush with the bed surface. These types of samplers are limited to flows in which an operator can reach down to the stream bottom to empty the traps (Bunte et al., 2003)

A more complex, but preferred type of pit sampler is the Birkbeck bed load sampler, which weighs the mass of bed load that enters a slot. Water stage is independently monitored to account for variations. The sampler has a smooth cover to ensure the bed does not scour downstream of the samplers. It reduces friction and causes the flow to accelerate (Laronne et al., 2002).

The bed load trapping efficiency of pit traps is generally considered to be high, but they can also have highly variable sampling efficiency. They may be affected by water circulation within the trap and saltating particles overpassing the top (Sterling and Church, 2002). Sand and fine gravel may travel in suspension during high flow and skip over the trap opening. This is also possible with mid-sized gravel particles during a sufficiently high energetic flow. Sampling efficiency can also vary spatially, as flow energy increases at an uneven rate over a cross-section (Bunte et al., 2003). Sterling and Church found that a simple pit trap had a median 83% efficiency. During the highest flows, the upper limit of grain sizes to be relaunched from the sampler was 3-16 mm (0.1-0.6 in) and the maximum size of material in suspension was 3-4 mm (0.1-0.16 in). Pit trap efficiency should begin to decline at approximately 3-4 mm (0.1-0.16 in). Larger grain sizes result in high efficiency, while smaller grain sizes result in lower efficiency (Sterling and Church, 2002). The Birkbeck bed load sampler has a 100% hydraulic efficiency when sediment fill is small. It decreases to 90% when the container is filled 60% and to 66% when the container is filled 80%. This decrease in efficiency is caused by the generation of recirculation flow cells within the sampler as it fills (Laronne et al., 2002).

5.3 Tracer Grains

The use of tracer grains involves individual particles, which are collected, dried, painted, and replaced on the channel bed. These particles should represent a range of those found in the particle-size distribution of the channel bed. Spacing of the particles can either be equal, or randomly distributed along a cross section. Direction of the cross section is usually perpendicular to the flow direction. Each cross section is marked with rebar for relocation at a later date. After the intermediate axis of each grain is measured, the painted particles are pressed into the bed. Some particles are initially unstable when pressed into the bed by hand. However, they usually settle into a more stable configuration after they have been moved by the flow. The sizes moved by the range of flows are better determined by grains that move more than once (Ryan and Troendle, 1997).

After the testing period, particles are recovered and the distance moved off line is recorded. Recovery rate is influenced by the paint color of the particles. Particles with white, red and orange paint take on the tinge of unpainted bed particles, while particles painted blue, teal green or bright yellow are more easily recovered. Tree-marking paint helps particles retain color and resist abrasion longer than ordinary household spray paint (Ryan and Troendle, 1997).

The painted tracer method is used to detect motion of the coarsest particles on the stream bed, which are usually larger than those caught in portable samplers. However, there are limitations to the analysis of flow competence. The actual flow which moves the grain is unknown. It is generally assumed to be the highest flow achieved during the observation period. Particle recovery is also minimal due to abrasion of the paint and burial by other particles. For the best results, the painted tracer method should be used in conjunction with other sampling procedures (Ryan and Troendle, 1997).

5.4 Sediment Transport Equations

The advantage of using sediment transport equations is the prediction of transport under conditions other than the present. These equations are generally used only to compute the bed-material load. The washload depends on sediment supply. It must be calculated separately by constructing sediment rating curves and computing annual yields based on flow-duration curves. In gravel-bedded channels, sediment transport equations are primarily designed for bedload, as bedload tends to be the transport method for most of the bed material. Some of the common formulae available for gravel-bedded streams include the Bagnold, and Engelund/Hansen equations. The Parker equation is preferred among theoretical geomorphologists and provides reasonable predictions most of the time. However, few transport equations are appropriate for gravel channels with armored surfaces. Sand-bedded channels use equations referred to as “total-load equations” for calculation of bedload and the bed-material suspended load. Sand-sized sediment is usually partitioned between these two modes. These channels have provided the most comprehensively tested equations (Reid and Dunne, 1996).

The development of sediment transport equations is based on the premise that a specific relation exists between sedimentological parameters, hydraulic variables, and the rate at which bed material load is transported. The four principle approaches to the design of transport formulae are based on bed shear stress, stream discharge, stochastic functions for sediment movement and stream power (Gomez and Church, 1989). They range from the totally empirical to those based heavily on theory. Each equation is best suited for conditions similar to those used in its development. While no single transport equation has emerged as the definitive transport formula, their data requirements are very similar. Most require information on channel gradient, depth, width and sediment character. A few, such as the Modified Einstein and Toffaleti methods, involve suspended sediment methods (Reid and Dunne, 1996).

Formulas should be selected based on how well they have predicted loads in similar channels. An ideal equation would provide valid estimates for each channel in which it was tested. It would also provide consistent results for different operators on a single channel and provide valid estimates for all available data for a single channel (Reid and Dunne, 1996). Wilcock [2001] recommends calibrating a predictive model based on a small number of measurements of sediment transport rates. This would increase the accuracy by determining the reference shear stress, τ_r. By measuring transport rates, the error is reduced in determining the discharge producing τ_c (Wilcock, 2001).

While transport equations can be used as guides, none are completely accurate. They are based on the assumption that discharge remains constant for long periods. They also assume that downstream variations of depth and velocity are minor and that an infinite sediment supply of grain sizes representative of the bed material is available. These conditions are not met in most channels, particularly mountain channels (Reid and Dunne, 1996). Most sediment transport equations overpredict sediment flux by 2-10 times by failing to include surface coarsening and variations in the rate at which material is supplied and available for transport. Formulae can vary by an order of magnitude or more in their predictions (Booth, 2002).

5.5 Bedload Traps

Bedload traps sample gravel and small cobble bedload in a portable and cost-effective manner. The development of these traps was driven by the need of the U.S. Forest Service to accurately and easily measure the onset of gravel and cobble bedload transport in remote mountain streams. However, data collected with the traps can be used to determine cross-sectional transport rates and develop bedload transport rating curves in coarse-bedded streams. Bedload traps representatively collect all mobile gravel particle sizes, cause minimal stream bed disturbance, and are easily operated in wadable flows (Bunte et al., 2003).

The traps are constructed of a 0.3 x 0.2 m (1.0 x 0.7 ft)aluminum frame. A 0.9 m (3.0 ft) long net of approximately 25 liter volume and a 3.9 mm (0.15 in) mesh width is attached. The frame is anchored onto a ground plate at the stream bottom for the 1-hour duration of each sample (Bunte and Abt, 2003). The traps are typically installed with 1-m (3.3 ft) spacing across the stream that is easily wadable. As flow reaches the limit of wadability, a 3-person team and safety devices may be required (Bunte et al., 2003).

Bedload traps appear to have a satisfactory sampling efficiency. Particles that move onto the ground plate are usually transported immediately into the sampler, preventing inadvertent particle entrainment. Long sampling time reduces bias typically associated with short collection times. However, transport may be underestimated if the traps are allowed to fill beyond their capacity. When compared to the results of a Helley-Smith sampler, bedload traps resulted in steeper rating and flow competence curves. They are also unable to capture sand. The 3.9 mm(0.15 in) mesh only captures particles greater than 4 mm (0.16 in). Using a finer mesh would increase flow resistance and reduce sampling efficiency (Bunte et al., 2003).

6. Changes in Sediment Storage

An understanding of what happens to sediment after it enters a stream is necessary for understanding channel morphology. Erosion and deposition bring about changes in channel or reservoir morphology, as well as water quality. Analysis of potential changes requires the characterization of a channel under undisturbed conditions. A prediction is then made of how those characteristics will change with altered inputs. It is necessary to understand how much of each type of sediment is transported, where it is deposited, how it interacts with sediment in storage, and how the transport affects channel morphology (Reid and Dunne, 1996).

In order to evaluate changes in sediment storage, a channel analysis is typically required. Analyses include field measurements of channel characteristics, use of records from similar channels, definition of flow-duration curves, measurement of grain-size distributions, determination of mobile grain sizes, estimation of sediment transport rates, evaluation of historical and vegetation evidence for channel changes, and analysis of sequential aerial photographs (Reid and Dunne, 1996). Methods for several of these analyses have already been evaluated in the previous sections describing suspended load, and bed-material load. The remaining methods of evaluation are described below.

6.1 Aerial Photograph Analysis

One of the most valuable environmental records available is the interpretation of an aerial photograph sequence spanning approximately 50 years. Aerial photographs can be used to identify erosion and transport processes, measure or categorize process rates, and select sites for fieldwork. The most useful imagery occurs at scales larger than 1:24,000 (Reid and Dunne, 1996).

The first general step in analysis of aerial photography is to geo-reference all photos involved. Rectification projects data onto a plane and makes it conform to a map projection system. Orthorectification is a process which removes geometric distortion inherent in imagery. This distortion is caused by camera/sensor orientation, topographic relief displacement, and systematic errors associated with imagery. Orthorectified images represent ground objects in their true X and Y positions. Polynomial rectification can also be used to geo-reference imagery. This process involves using a currently geo-referenced image of an area as the basis for rectification of a separate image of the same area. In other words, the coordinate system of the geo-referenced image is transferred to the unrectified image. These applications are available using a geographic information system (GIS), such as ERDAS Imagine (ERDAS, 1997).

After the images have been geo-referenced, they are used to compare changes in channel morphology. The channel outline in all photos can be digitized using GIS. It can then be compared among the various years of imagery to evaluate changes in morphology (Laliberte et al., 2001). Total erosion or deposition can be calculated by measuring the area affected by particular processes, in conjunction with field measurements of sediment transport processes or erosion/deposition depth. A temporal sequence of aerial photographs can be examined to evaluate the progress of erosion or aggradation (Reid and Dunne, 1996).

6.2 Cross Sections

Cross sections are elevation transects surveyed from bank to bank. They monitor bed elevations over time with high precision and accuracy. Cross sections are measured perpendicular to the center line of the channel. A permanent fixture, such as rebar, is placed at each end of the cross section for relocation purposes. Resurveying of each cross section can typically be done in less than 30 minutes. The main disadvantage is that they do not document the depth of maximum scour. The bed may return to a higher level after it is scoured below its previous level. These short-term changes would not be detected by resurveying cross sections (Lisle and Eads, 1991).

6.3 Scour Chains

Scour and fill is best measured with scour chains. They measure the maximum scour depth occurring over a period of time. A chain is inserted vertically into a streambed. One end extends below the depth of anticipated maximum scour. The other end is draped over the bed surface. When the bed fills, the chain is buried. It stays on the surface as the bed scours. Maximum scour depth is determined from the length of the horizontal section of chain on the bed surface (Lisle and Eads, 1991).

Scour chains are installed using a probe constructed of pipes and pipe fittings. An eyelet is screwed into a section of the dowel, where one end of the chain is attached. The other end of the chain is threaded into the bottom of the probe and out through either a slot or one of the handles. The probe is tapped into the stream bed. A thin metal rod is inserted into the top of the probe and tapped against the dowel to hold it in place. The probe is then withdrawn, leaving the chain partially buried in the bed. The length of chain laid over the bed is measured and its elevation surveyed. Either flagging or a painted washer is attached to the end of the chain so it can be found later. The length of the chain lying over the original bed surface and that lying over the final bed surface is measured to determine maximum scour depth (Lisle and Eads, 1991).

Scour chains should be installed at regular intervals across a small number of cross sections. Lisle and Eads recommend placing the chains every _ m (1.6 ft) to 2 m (6.6 ft) across two to five cross sections. This placement allows monitoring of the changes in sediment transport over most of the full channel width. It also makes locating the chains more convenient. Locating chains at regular intervals across surveyed cross sections is the best way to relate scour-fill data to channel morphology (Lisle and Eads, 1991).

6.4 Measurement of Fine Sediment in Pools

Sediment load of a stream channel is often difficult to evaluate. The measurement of fine sediment volume in pools is a method to evaluate a channel's response to sediment additions. When sediment is added to a stream, the bed becomes more mobile at a given discharge. During high flows, all grain sizes of the bed have greater transport rates than they would if the sediment supply were smaller. When flow decreases, transport rates decrease, and fine sediment is winnowed from areas of the bed with high boundary shear stress. It is deposited in areas of low shear stress, such as pools. While the pools are covered in a layer of fine sediment, most of the remainder of the bed becomes armored. Deposits in pools are smaller when channels have a low sediment load and a less mobile bed. The fraction of pool volume filled with fine sediment is has been designated as V* by Lisle and Hilton (1991). It is directly related to the supply of sediment and the mobility of the channel (Lisle and Hilton, 1991).

The first step in measuring V* is to designate approximately 15 clearly definable pools in a reach with a relatively low gradient. In each pool the riffle crest and mean thalweg depth are measured to determine the residual pool, which is the pool that would remain if there were negligible surface flow. It is defined as the portion of the pool that is deeper than the riffle crest forming the downstream lip of the pool (Hilton and Lisle, 1993). Between 5 and 8 transects are placed at measured intervals across the pool. Water depth and fine sediment thickness are measured at a total of 30 to 60 locations. Next the residual pool volume (V_r) and fines volume (V_f) are computed. Scoured pool volume (V_{sp}) is the residual pool volume if fines were removed. It equals the sum of residual pool volume and fines volume. The fraction of pool volume filled with fines (V^*) is calculated as $V^* = V_f/V_{sp}$ (Lisle and Hilton, 1991).

The particular ranges of V^* cannot provide universal standards. However, Lisle and Hilton have found that channels with $V^* \leq 0.1$ contain fine bed material which is characteristically confined to small and discontinuous deposits in eddies. Outside of pools, a fine mode may not be evident among surface interstices. Channels with $V^* \geq 0.1$ generally have large patches of fines occupying much of the area of pools. Surface interstices may be noticeably filled and fine patches are evident elsewhere in the channel (Lisle and Hilton, 1999).

7. Sediment Sampling Methods Applicable to Valley Creek

An evaluation of sediment in Valley Creek is necessary to determine potential or existing channel responses to changes in land use. Evaluations of sediment in the fluvial environment include the development of particle size distributions, suspended sediment sampling, measurement of bedload transport, and the determination of changes in sediment storage. While numerous methods are available to conduct each of these evaluations, the method or combination of methods depends on the channel characterization and specific purpose of sediment evaluation. Valley Creek has a channel bed of predominantly gravel and cobble, with deposits of sand and silt. Over 75% of the stream is characterized as either riffles or runs, with more than half of the pool sites located behind a reconstructed mill dam (Gutowski and Stauffer, 1996). This description applies to the entire length of Valley Creek. The process of quantifying comparable statistics for the length of the channel within the park is currently underway. The amount of land dedicated to residential, commercial, and industrial uses in the drainage basin has increased significantly in the past 30 years (Gutowski and Stauffer, 1996). Chosen methods of sediment evaluation must be applicable to the channel characterization of Valley Creek.

7.1 Particle Size Distribution

Before constructing a particle size distribution for Valley Creek, several factors must be taken into consideration. While the channel is predominately gravel and cobble, it is composed of numerous areas with different particle size distributions. Some reaches consist of mostly gravel and boulders. Other areas, such as the reach directly upstream of the dam, are composed mainly of fine sand and silt. Therefore, a spatially segregated sampling strategy should be adopted, where the stream reach is divided into sub-areas that can be sampled individually. The armor layer must also be taken into consideration. In order to sample the particle size distribution of the subsurface sediment, the armor layer must first be removed. This would provide a bulk sample for categorizing the stored, but mobile sediment. However, removal of the armor layer from all samples would be extremely labor-intensive. Further discussion is needed for determining the extent of characterization of both surface and subsurface particle sizes.

The best method for creating a particle size distribution in Valley Creek would most likely be to use a freeze core sampler. A vertical, undisturbed section of the streambed could be removed and analyzed based in the armor layer and subsurface sediment (Lisle and Eads, 1991). However, this method is more labor intensive than others and the sampler may be difficult to obtain. If a freeze core sampler is unavailable, a cookie-cutter sampler would be the best choice. It was designed for use in coarse gravel and cobble bed streams. The teeth on the bottom make it easy to work into the streambed. The sampler can be used in submerged conditions and would retain fines during the sampling process. It is also constructed of materials that are relatively easy to find. The main component is a 55-gallon drum that has been cut in half (Bunte and Abt, 2001).

7.2 Suspended Sediment

The desirable result of suspended sediment sampling is the determination of the instantaneous mean discharge-weighted suspended-sediment concentration at a cross section. Combined with water discharge, it is used to compute the measured suspended-sediment discharge. The suspended sediment concentration of the flow is determined by first collecting depth-integrated suspended-sediment samples that define the mean discharge-weighted concentration in the sample vertical. Sufficient verticals are then collected to define the mean discharge-weighted concentration in the cross section (Edwards and Glysson, 1999). To achieve accurate results, samples would need to be taken from multiple storms. Samples would need to be taken for a variety of discharges, covering the rising and falling limbs of a hydrograph. While this approach is desirable, it cannot be done to the same level of detail in Valley Creek that would provide results to within +/- 30-40% of the correct value. More personnel would be needed than are available. These personnel would have to be available at all times in order to collect samples when storm events arise. However, the sampling strategy below can be applied to Valley Creek to produce an order-of-magnitude estimate of the actual sediment load of the watershed.

A point or depth-integrating sampler could be used during a limited number of small storm events. Suspended sediment in Valley Creek will be evaluated over varying flow conditions. Therefore, a versatile sampler should be used that can be operated under both low and intermediate flows. The best sampler for this purpose would be either the DH-59 or DH-76, two depth integrating samplers. Both are preferred in the field because they are small, light, durable, and adaptable. They are commonly used for sediment sampling during normal flow in small and intermediate-sized streams. However, the intake nozzles can be interchanged when varying flow conditions are encountered. The best locations to deploy these samplers are the foot bridge near Maxwell's Headquarters and the bridge at Wilson's Run. Their height above the channel is the smallest compared to other bridges, providing convenient sampling locations.

During a limited number of large storm events, single stage samplers should be used in Valley Creek. They are more practical than depth-integrating samplers when rapid changes in stage occur. The advantage is that they are inexpensive and multiple samplers can be used during a flow event (Edwards and Glysson, 1999). The installation of two single stage samplers is anticipated in Valley Creek. One will be located at the upstream USGS gage. Another will be installed near Maxwell's Headquarters for comparative purposes.

7.3 Bed Material Load

Measuring bed material load in Valley Creek should be done with a combination of methods. The best samplers are probably pit traps. They are generally thought to be more accurate than other bedload samplers because they do not affect the flow. Pit traps can be easily installed by a small field crew with shovels and buckets. However, they also have limitations. Trap operation can only occur during flows in which an operator can reach down to the stream bottom to empty the traps. They also have variable sampling efficiency. During high flow events, sand and fine gravel can skip over the trap opening. Particles can also be resuspended from the trap and lost from the sample (Bunte et al., 2003).

A Helley Smith sampler could also be used in Valley Creek. It traps coarse sand and fine gravel, from 2-10 mm (0.8-0.4 in) in size. However, these samplers also have varying sampling efficiency. A laboratory test of the original 7.6 x 7.6 cm (3 x 3 in) sampler determined an average sampling efficiency of 160%, while field studies concluded an efficiency of 100%. Efficiency also varies with particle size. The original sampler has an approximate 150% efficiency for sand and small gravel, and 100% for coarse gravel (Edwards and Glysson, 1999).

These samplers should be used in conjunction with estimates from sediment transport equations. However, a variety of these equations are available and the results are variable. Most sediment transport equations overpredict sediment flux by 2-10 times by failing to include surface coarsening and variations in the rate at which material is supplied and available for transport. Formulae can vary by an order of magnitude or more in their predictions (Booth, 2002). The most appropriate for Valley Creek need to be identified.

To determine the best bedload sampling strategy, several sediment-transport experts will be consulted, including Allan Gellis at USGS. Basically, a limited number of transport measurements will be taken to approximate how much sediment is traveling as bedload. The results will be used to estimate total annual sediment load. However, more focus should be placed on changes in sediment storage. The main efforts will be directed at sediment mobility and storage, in relation to other issues, including channel stability and filling of pools.

7.4 Changes in Sediment Storage

Measuring changes in sediment storage should also be done with a combination of methods. Aerial photographs should first be interpreted to identify erosion and transport processes and select sites for fieldwork. After these sites are located, cross-sections should be used to monitor bed elevations over time at the most intensive sampling locations. However, cross sections do not document the depth of maximum scour. To overcome this problem, scour chains should be installed at equally spaced intervals across the surveyed cross sections. This is the best method of relating scour and fill data to channel morphology (Lisle and Eads, 1991). At less intensive sampling locations, cross sections of banktops and baselines will be established. They will be resurveyed annually, or after a significant geomorphic event, which could include large storms, a season of high base flow, or freeze and thaw.

The most intensely sampled sites will be located at 5 reaches, with approximately 5 cross sections within each reach. These locations include a site near Maxwell's

Headquarters, at the USGS gage, at the long pool upstream of the dam, near Washington’s Headquarters, and at a geomorphically significant bend which is believed to be a considerable sediment storage location. Less intensive sampling locations will be determined based on areas of noticeable erosional and depositional activity.

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