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I am submitting herewith a thesis written by Joshua S. Rogers entitled "Comparison of underwater video mapping and pebble count measurements in determining stream channel substrate." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Wildlife and Fisheries Science.

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Vice Provost and
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(Original signatures are on file with official student records.)

Comparison of underwater video mapping and pebble count measurements in determining stream channel substrate

A Thesis
Presented for the Master of Science
Degree
The University of Tennessee, Knoxville

Joshua S. Rogers
August 2008

Acknowledgements

I would like to thank my major professor, Dr. Ray Albright, for his incredible guidance and patience. There is no way I would have been able to do this without him. I would also like to thank Dr. Paul Ayers for his work prior to and during this research. Without him this thesis would have never been born. Thank you to Dr. Larry Wilson for returning that first phone call left by some kid and then helping him find a home here in FWF. Thank you to my beautiful wife for being a source of encouragement and love throughout these past two years. Lastly, I give praise to my Lord and Savior, Jesus Christ. His sovereignty put me here and His grace has kept me here. He has taught me more during this time than I ever would have imagined. Streams and stones have filled my life for two years, but praise God for the one that is eternally important...“the Living Stone.”

1 Peter 2:4-10

Abstract

GPS videography has been used to capture substrate data with post-processing efforts being made to characterize streambed particle distributions. Advantages of this method include less field time, minimal streambed disturbance, convenience of post-field processing, and digitally stored data which can be used with GIS when geo-referenced. The question being asked is ‘what are the drawbacks of this method and how accurate are the data.’

Current video mapping techniques were used to capture stream channel substrate footage in three distinct float patterns. All data were geo-referenced by embedding geographical coordinates to each frame during recording. Post-processing of the video data included a comparison of three methods used to “retrieve” samples from the video: time interval, distance interval, and visual estimation. These data were compared to the data gathered by three distinct pebble count transects: thalweg, zig-zag, and proportional. The accuracy and efficiency of both methods - video and field – were tested by comparing them to a frame method used as a control. Data were compared by particle size, diameter size class, and percent distribution of substrate.

The proportional pebble count data proved to be significantly different at $\alpha=0.15$ from the frame data for particle size. No one method of pebble counting showed itself to be more accurate than the others. Significant differences at $\alpha=0.15$ were found between video data and frame data for all three retrieval methods. Visually estimating data proved to be significantly different for measurements of cobble while video distance and time interval data showed significant differences in small gravel. Particle measurements from video data proved to be more time consuming and less accurate than current pebble count techniques.

Although visual estimation of video data shows less precision than pebble counting methods, it maintains the video-mapping benefit of reduced field time by allowing quick analysis of data in the laboratory. When performing large scale substrate classifications, the use of an underwater video mapping system can provide: 1) reconnaissance data of locations for more accurate substrate analysis and 2) a quick method of detecting substantial changes to the streambed over long distances due to land use effects or natural phenomena.

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Chapter 1: INTRODUCTION

Defining the Stream

Stream channel substrate is an important facet of lotic systems establishing a link between a stream and its physical and biological characteristics (Diplas and Fripp, 1992; Faustini and Kaufmann, 2007). Therefore, to correctly understand these stream characteristics one must understand the stream substrate. Substrate is a product of weathered material within the watershed that is carried to the stream by the force of gravity and runoff. Once in the water column, it is characterized as either suspended sediment or bed sediment. Suspended sediment is that which is carried along by the upward momentum of turbulent eddies in the flow. Bed sediment is that which is moved by sliding, bouncing, or rolling along the stream bottom. Sediment transport is a function of stream power which is dependent upon the velocity, width, depth, slope, and channel roughness of a stream (Leopold et al., 1964). As stream power increases, more sediment and larger sediment is carried downstream. Once the needed power to move a particle is lost, then the particle becomes stationary. In this way, sediment is picked up, moved, and redistributed throughout the wetted channel during differing flows. When wishing to define specific effects of a stream one must go to that which is the stream's foundation which is the substrate.

Importance in Stream Equations

Substrate is collective in that it is identified as a grouping of particles on the streambed. The behavior of these groups of particles is significantly more important than that of a single particle due to the natural variability of particle size in most streams (USDA, 1996). It is important, therefore, to group particles into size classes based on their characteristics. Particle size distribution is a crucial variable in determining a stream's flow and channel structure and, therefore, is used in a number of differing sciences. Crowder and Diplas (1997) noted that a variety of river-related characteristics can be calculated with accurate estimations of particle distributions of a streambed. For example, distinct substrate size classes are frequently used for flow resistance evaluations (Hey and Thorne, 1983) obtained through equations that characterize bed roughness (Diplas, 1990) and riverbed stability (Neill, 1968). Bedload transport calculations must be made from accurate estimations of representative particle sizes (Almedeij and Diplas, 2003).

Ecological Impact

Particle size distribution determines the potential diversity and quantity of biota within a stream's ecosystem. The survival of most freshwater benthic organisms depends on a precise balance of particles to be present. This is because the assemblage of certain sizes of particles is used in determining habitat quality (Roper et al., 2002; Faustini and Kaufmann, 2007). Streambed particle composition can have important effects on fish populations, especially salmonids (Whitman et al., 2003). For example, stones of approximately 20 cm (mean diameter) are preferred by juvenile Atlantic salmon during their winter habitat selection (Rimmer et al., 1983). Kondolf and Wolman (1993)

compared sizes of salmonid spawning gravels and found that between-species variation exceeds within-species variation, so different species have preferred size ranges for spawning gravels.

The composition of streambed particles affects the entire life cycle of certain fish species by influencing spawning habitat (Bjornn and Reiser, 1991), embryo survival (Chapman, 1988), fry habitat (Cordone and Kelly, 1961), and invertebrate food supplies (Alexander and Hansen, 1986). Slight increases in the deposition of fines (< 2mm) can decrease intergravel dissolved oxygen concentrations (Kondolf, 1997) and negatively impact all species in the zone of increased deposition. Stream channel substrate can also have secondary effects by influencing biota outside of the water column. Stream geomorphology was shown to influence fish abundance and, therefore, control the quality of belted kingfisher foraging sites and brood weights (Sullivan et al., 2006).

Describing Land Use Effects

Dietrich et al. (1989) demonstrated that particle size distribution was one of the first channel characteristics to change in response to land management activities. Increased land management activities anywhere in a basin have the potential to negatively affect the composition of the streambeds within the streams of that watershed (Whitman et al., 2003) by increasing the amount of fine material being deposited. However, particle distribution measurements can be used to detect these cumulative watershed effects (Potyondy and Hardy, 1994; Bevenger and King, 1995; Schnackenberg and MacDonald, 1998). Regulations on the legal amount of sediment that can be taken from or placed in a stream are enforced by agencies like the Environmental Protection Agency (EPA). For this reason, many monitoring protocols use survey methods designed to sample streambed particles in an endeavor to prove compliance or noncompliance of federal and state laws (Roper et al., 2002).

Surface Substrate Sampling

Bed material can contain two substrate layers: pavement (or armor), and subpavement (Dietrich et al., 1989; Fripp and Diplas, 1993). Sampling each layer independently is important because of the influence that the individual layers have on the stream, its processes, and its effect on the biological component found therein (Hey and Thorne, 1983; Diplas and Fripp, 1992; Fripp and Diplas, 1993; Green, 2003). Surface substrate sampling can be used to interpret the gravel assemblage for the pavement, but not the percent of fines associated with the subpavement (Kondolf and Li, 1992). Streams with predominantly coarse (i.e., gravel or larger) bed material are most often sampled using particle counts to determine particle size distribution (Faustini and Kaufmann, 2007). For the remainder of this paper, sampling substrate of the pavement layer is what will be addressed.

Variants

Several sampling methods have been developed over the years for determining particle size distribution. Determining the population of particles in a stream is unfeasible because every particle present cannot be measured. Therefore, sampling efforts focus on providing the most efficient and robust measurements attainable from a reasonable

sample size of the population. Sampling of surface bed material can be extremely demanding of time and resources if a specified accuracy is to be achieved (Hey and Thorne, 1983; Mosley and Tindale, 1985). Wolman (1954) introduced a method, now referred to as the Wolman pebble count, which has become the common protocol for most particle measurement studies (Harrelson et al., 1994; Schnackenberg and MacDonald, 1998; Green, 2003; Olsen et al., 2005). It was originally developed as an alternative to bulk sampling because of the difficulty in obtaining sufficiently large bulk samples in coarse bed material (Rice and Church, 1996; Kondolf, 1997). Wolman (1954) sampled a preset number of particles (approximately 100) along a transect in a homogeneous population in order to determine the D_{50} value. The D_{50} is the median diameter or the particle size at which 50% of the sample is finer. It is used as the keystone percentile diameter of the “typical” substrate. Wolman’s method was done by walking along a transect, stopping at equally spaced intervals, and retrieving the sample located at the end of the observer’s boot. Variants of this technique include hybrid methods (Diplas and Fripp, 1992), zig-zag transect methods (Bevenger and King, 1995), frame methods (Bunte and Abt, 2001), and visual estimation methods (Latulippe et al., 2001).

Variants of the Wolman pebble count are often designed to address the sampling and observational errors of substrate measurements (Hey and Thorne, 1983). Variability can affect the detection of a change in particle distribution (Olsen et al., 2005), but variability is a part of all sampling protocols (Ramsey et al., 1992; Clark et al., 1996) and should, therefore, not be used in justifying the removal of measurements made under these variances (Roper et al., 2002). Even still, to be useful for a study objective, substrate measurements should be accurate and of minimum variability when deriving particle size distributions (Bunte and Abt, 2001).

Common Errors

Sampling

Sampling errors can develop when samples for percentile values are taken from insufficient sample sizes (Hey and Thorne, 1983; Rice and Church, 1996; Green, 2003). Sampling errors can cause the inability to detect differences in substrate distributions when comparing measurements from different seasons or different streams. Wolman (1954) identified 100 particles as sufficient enough to provide accurate and repeatable measurements of the D_{50} . This is because the D_{50} can be most consistently estimated with 100 particles in streams that have a normal particle size distribution (Rice and Church, 1996; Green, 2003; Olsen et al., 2005). However, Mosley and Tindale (1985) only collected sample sizes of 70 from subareas within a stream reach in order to combine other subarea collections for the total sample size. To accurately determine percentiles other than the D_{50} , sample sizes up to 200 – 400 particles have been advised (Fripp and Diplas, 1993; Rice and Church, 1996).

Brush (1961) calculated that a sample size of 60 would be sufficient to reduce error among different observers and the work of Hey and Thorne (1983) showed that significant differences were not present between observers for sample sizes as small as 30. Sampling error decreases with increased sample size, but observer error (from

individual bias) becomes increasingly significant (Hey and Thorne, 1983). When more particles are randomly sampled from a population, the closer one comes to determining the true mean of that population. However, observer error stays the same no matter what the sample size. Therefore, in relation to increased sample size, observer error will contribute more to total error than will sampling error. As noted by Bunte and Abt (2001), increasing the sample size is only beneficial upon the elimination of observer bias. When comparing sampling results from studies using different sample sizes only a small error will be produced (Green, 2003), but may be compounded with the random error and observer bias already present to increase the total error. Therefore, to reduce total error, a sampling procedure should use the same number of samples each time.

Observer

Observer error can occur from two major biases: particle selection, and particle measurement. Particle selection bias is seen in the step preference and selection of a preferable stone size of individual observers. When walking across an uneven surface, the observer has a tendency to be cautious with their steps in order to keep from falling or possibly hitting a rock with their shin. Thus, large, slippery cobbles and boulders are sometimes avoided, biasing the count toward fine particles (Bunte and Abt, 2001). Also, observers are more likely to slightly shift their walking line near overgrown banks in order to avoid a difficult sample under dense foliage (Bunte and Abt, 2001). For the same reason, the deepest parts of a pool may be excluded. When using multiple observers, bias can appear due to different step lengths or boot sizes. This can generate a different sampling frequency of particles which has the potential to produce serial correlation errors (Hey and Thorne, 1983; Wohl et al., 1996).

Preference toward particles of a certain size is often unavoidable when the observer views the sampling area under foot. Larger particles may stand out more to the observer and therefore make them bias against fines, but if a stone is too large to pick up and handle with ease, then it may be “unintentionally” avoided biasing the observer against large particles (Bunte and Abt, 2001). To eliminate this bias, the observer can close or avert their gaze and take a “blind” sample (Wolman, 1954; Leopold, 1970) or use a grid or frame (Bunte and Abt, 2001) which allows the observer to visually identify the selected particle. However, both of these methods can still produce error. Using the blind sample technique, observers may allow fast water currents to carry or push their finger away from finer material and into larger rock directly downstream (Marcus et al., 2005). Using the grid method, observers may still incorrectly select a particle not directly under a fixed point (Rice, 1994) especially with particles smaller than fine gravel (< 8 mm).

Another problem with particle selection is the inability to correctly sample fine particles due to observer finger size (Marcus et al., 1995; Fripp and Diplas, 1993). Observers may have difficulty determining which particle to measure if particles are smaller than their fingertip. Kondolf (1997) suggested using a portion of the fingertip (e.g., right corner of the fingernail) for particle selection when multiple particles are touched at the same time. The literature does not convey an overall consensus on the smallest particle size that can be accurately selected and measured. Suggested cutoffs are 2 mm (Wolman, 1954; Kellerhals and Bray, 1971), 4 mm (Kondolf and Li, 1992;

Kondolf, 1997; Olsen et al., 2005), 8 mm (Bevenger and King, 1995; Schnackenberg and MacDonald, 1998), and 15 mm (Fripp and Diplas, 1993). The problem is further enhanced when sampling is done in cold water due to decreased sensitivity of the observer's finger from numbing (Bunte and Abt, 2001). Wearing gloves has been suggested to help solve this problem. Marcus et al. (1995) showed that wearing gloves did not affect the results of pebble count data at $\alpha=0.05$ significance level. Not being able to accurately measure the fine sediment can force truncation at this size range and underestimate the overall size of percentile values (Fripp and Diplas, 1993; Green, 2003).

Errors associated with particle measurement arise when observers do not measure a particle accurately when using a ruler or by visually estimating the size. By having seven individuals measure the same 60 particles, Marcus et al. (1995) was able to demonstrate that particle measurement did play a role in observer bias; three of the seven had measurements that were significantly different ($\alpha=0.05$) than measurements made with calipers. Hey and Thorne (1983) used a gravelometer to assess stone sizes which reduced observer error. However, error associated with the use of gravelometers or templates is detected when comparing streams with different geomorphologies because streams predominated with shale will have fractured rocks that are thin and are able to slide through openings easier than round stones (Hey and Thorne, 1983).

Comparison

Olsen et al. (2005) studied the affect of observer variability (i.e., particle selection and particle measurement) and site variability and found that "environmental heterogeneity is a greater source of variability than differences among observers when the monitoring objective is to compare differences among streams or riffles or to monitor change over time." Roper et al. (2002) measured physical stream attributes at six stream sites and found that variation among streams accounted for 80% of the total variation for 10 of the 13 attributes measured including D_{50} , percent fines, and pool-tail fines. This is important to note because pebble counts are often used in large scale stream monitoring efforts (Bevenger and King, 1995; Schnackenberg and MacDonald, 1998; Kershner et al., 2004) and one would need to know if variations appeared because the compared sites were actually different or if it was just observer bias. To reduce variation among streams, Roper et al. (2002) suggested stratification, using permanent sites, and incorporating analysis of covariance into comparisons.

Comparison errors may also come from comparing different techniques. Whitacre et al. (2007) compared different monitoring protocols on the same streams and showed that the majority of measurable attributes were statistically different. The significant differences included D_{50} values and percent fines. These differences were concluded to arise from the multiple approaches of measurement used for each attribute.

The time of year that surveys are conducted between different stream reaches is also a possible source of comparison error. If pebble counts are performed on stream reaches from different watersheds at different times of the year, then particle size distribution comparisons may not be accurate due to changing base flow levels and land use effects (Larsen et al., 2001). To reduce the error associated with seasonal variability, one must be able to revise the timing of repeated sampling if changes in the watershed occur (Olsen et al., 2005).

Photography and Videography

As technological advancements have been made in the fields of photography and videography, scientists have incorporated these into their various disciplines. Some of these innovations have been able to provide better quality data than traditional methods. An example is the conventional use of repeat cross-sections to monitor the three-dimensional form of gravel-bed rivers over time. The location, spacing, and frequency of these surveys are generally based on the practicality and cost associated with the work (Westaway et al., 2003). Researchers have therefore integrated the use of aerial photogrammetry and image analysis to quicken this process while providing more accurate data (Winterbottom and Gilvear, 1997; Brasington et al., 2000; Westaway et al., 2003; Carbonneau et al., 2004).

Close-range photographic techniques have been used for particle size studies by sedimentologists and geomorphologists for many years (Whitman et al., 2003). Researchers have investigated the complex structure of riverbeds by using this method of photogrammetry to produce high quality and high-density data for examining particle distributions of exposed gravel surfaces (Graham et al., 2005) and submerged substrate for potential fish habitat (Carbonneau et al., 2003; Whitman et al., 2003). When one is able to digitize these images, the stream channel substrate measurements become, theoretically, more representative than pebble count surveys because all traceable particles can be measured and the bias for the selection of larger particles is eliminated (Whitman et al., 2003).

Videography has been used for the viewing of underwater substrate. Kvernevik et al. (2002) used an underwater video system to map the sea floor off the coast of Malaysia. This method provided a fast, easily repeatable method that proved to be helpful to coral reef conservation efforts in developing countries. Duizendstra (2001) placed underwater cameras on bedload samplers in order to better understand the morphological behavior of the armor layer of the Common Meuse in the Netherlands. The cameras provided information about the particle size distribution, roughness, and condition of the armor layer. Fiscor (2005) used both an underwater mapping system as well as a surface water mapping system to characterize suitable habitat for endangered mussels in East Tennessee, USA. The attributes able to be characterized with this method included: flow characteristics of the river (pool, run, and riffle), river depth, substrate classification, embeddedness of the substrate, and the presence of coal contamination.

Frezza et al. (2003) used videography to directly characterize fish communities and streambed particle sizes. Their design of a portable underwater camera was developed as an alternative to electrofishing surveys for investigating stream and river fish communities. Streambed particle sizes were measured manually to be compared to video data. No significant difference was found between measured particle sizes from the video and field data when using their quadrat method (where transect lines were perpendicular to stream flow). When using the line method (where they manually guiding the camera from bank to bank in a zig-zag pattern), only one of the nine sites proved to be significantly different when comparing video and field data. In this instance, video data showed an increase in fines.

Underwater video mapping has benefits in a number of areas. When characterizing streambed particle sizes, the sampling efficiency and accuracy can be

improved due to the permanence of videos/photos and the capabilities of current software (Whitman et al., 2003). The video permanence allows for later review of data by the same observer to gauge the repeatability of interpretations (Frezza et al., 2003). This permanence also enables multiple observers to review the same exact data to test for observer variability (Whitman et al., 2003) This is not possible in pebble count methods due to the fact that a particle's original position is changed when sampled, even with the observer's careful efforts of replacing the particle for the next observer. Other benefits of video mapping include sampling ease (i.e., no burdensome rocks to lift), ability to collect data in colder months (within the temperature ranges of the electrical components), minimal streambed disturbance, ability to collect data alone, convenience of post-field processing, areal stream channel capture, and reduced field time.

Reduced field time is not only a cost saving benefit, but also a monitoring benefit. It has been proposed that for fluvial habitat modeling of aquatic species one must extend their measurements to the scale of the entire river (Fausch et al., 2002). Using traditional pebble count methods, the area in which can be sampled is limited by the amount of time needed to acquire the grain size measurements (Carbonneau et al., 2004) making large reaches impractical to measure. When examining the effects of stream channel substrate from wild fire, Potyondy and Hardy (1994) and Wells et al. (1979) showed that increases in fine sediment only last one to two years before returning to pre-fire conditions. This small window of opportunity for fieldwork can be caught when using a method as quick as video mapping.

The limitations of using videography in streams are primarily based around the visibility of particles. Streams with levels of high turbidity would prevent viewing of the substrate as would the presence of high amounts of periphyton. Moving the video too fast over the substrate (either over shallow water or in fast current) can create a blurred screen, although, some of this may be eliminated when viewing camera angles that are not directly facing the stream bottom. Also, some correction can come from using software that allows for slow-motion play of the video footage. Lack of light in deep water areas can darken the streambed and prevent substrate measurement, but the use of artificial lighting while filming can help remedy this problem. The limited view of the camera can affect the largest measurable particle, depending on the depth of the water (e.g., a 600 mm particle may be fully visible at three feet water depth, but not at one foot). Also, camera shots are limited to the wetted perimeter of the stream, but many pebble count surveys will measure all particles in the streambed (i.e., wet, dry, and protruding out of the water). Perspective errors can occur when a particle is partially covered by another or when the intermediate axis is not visible due to particle orientation. Outside of viewing problems, processing time and equipment cost may also be possible limitations to the research.

Objectives and Hypotheses

A number of large scale stream monitoring protocols require particle count measurements to be made. Traditional Wolman pebble counts and its variants can become time consuming. For this reason, many of these protocols use multiple observers to perform the work. Studies have suggested that, when monitoring changes at a specific location, it is hard to reduce variability between observers below 10 to 15 percent

(Marcus et al., 1995; Bunte and Abt, 2001; Olsen et al., 2005). Wohl et al. (1996) suggested using a single observer to conduct all pebble counts, so that observer variability would be minimized. As pointed out by Olsen et al. (2005), this may reduce variability, but would be impractical for large scale studies or studies that are continuous over time. Using a system of underwater video mapping could give a single observer the ability to quickly gather data in the field which could be analyzed on a more convenient schedule in the laboratory. Current underwater video mapping methods need to be investigated to determine if they are a reliable source of substrate information.

The primary research objective of this study was to compare underwater video mapping patterns of stream channel substrate to in-stream grid measurement techniques, using a frame measurement as a control. The null hypothesis was that video mapping data, grid measurement data, and frame measurement data would not differ in their means at $\alpha=0.15$ in regards to the substrate particle size, diameter size class, and percent distribution. Secondary objectives were: 1) to identify the most accurate float pattern for video mapping, and 2) to identify the most accurate grid measurement technique. The null hypothesis for secondary objective number one was that the float patterns would not differ in their means at $\alpha=0.15$ in regards to the substrate particle size, diameter size class, and percent distribution. The null hypothesis for secondary objective number two was that the grid measurement techniques would not differ in their means at $\alpha=0.15$ in regards to the substrate particle size, diameter size class, and percent distribution.

Chapter 2: METHODS

Study Site

Location and Selection

The study site was a portion of Abrams Creek in the Great Smoky Mountains National Park (GSMNP) in TN, U.S.A. The Abrams Creek headwaters flow from the mountains surrounding the Cades Cove area within the northwest section of the GSMNP. The stream flows westward towards the park boundary and then flows south providing, for all practical purposes, a natural boundary line for the rest of the western portion of the park. Abrams Creek eventually leaves the park and empties into Chilhowee Reservoir. The particular stream site chosen for this study was a section of stream approximately 1400 meters in length beginning at latitude W -83.93227 and longitude N 35.61019. This section of Abrams Creek was chosen for two primary reasons:

1) Channel Design

Under normal flows, this section is both wadeable and floatable. If the stream was too deep, then a pebble count could not have been conducted. If it was too shallow, then the kayak used for video mapping would not have been able to float the stream.

Abrams Creek is also a gravel/cobble dominated stream which is appropriate for a pebble count, since surface particle size distribution is measured in streams where the bed material is predominantly coarser than gravel (Faustini and Kaufmann, 2007).

2) Accessibility

The location for this section of Abrams Creek begins adjacent to Abrams Creek Campground and flows along the road for the majority of the site. There was no back country hiking that had to be done, so the equipment was only carried a short distance to the water's edge. The accessibility also allowed us to drive close to the lower end of the site to pick up the kayak after each of its runs. All video data was able to be collected in a single morning, owing to the stream accessibility.

Design and Profile

Once the site was selected, three 300 meter reaches were identified, each containing the three habitat units used in the study: pool, riffle, and run. The beginning and end of each habitat unit were given Global Positioning System (GPS) latitude and longitude coordinates. This provided reference points throughout the study. The three stream reaches were named Camp, Station, and Bridge because of their locations by the campground, adjacent to the ranger station, and a log foot bridge crossing, respectively (Figure 1). The gradient and riffle cross-section of each reach were surveyed using a Lasermark LMH-GR laser level, elevation rod, and multiple measuring tapes. All measurements were made to 0.3 cm. Gradient and cross-section graphs can be found in Appendix A

Abrams Creek GSMNP

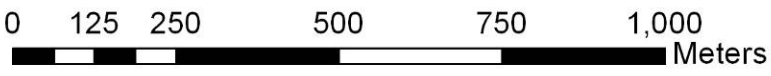
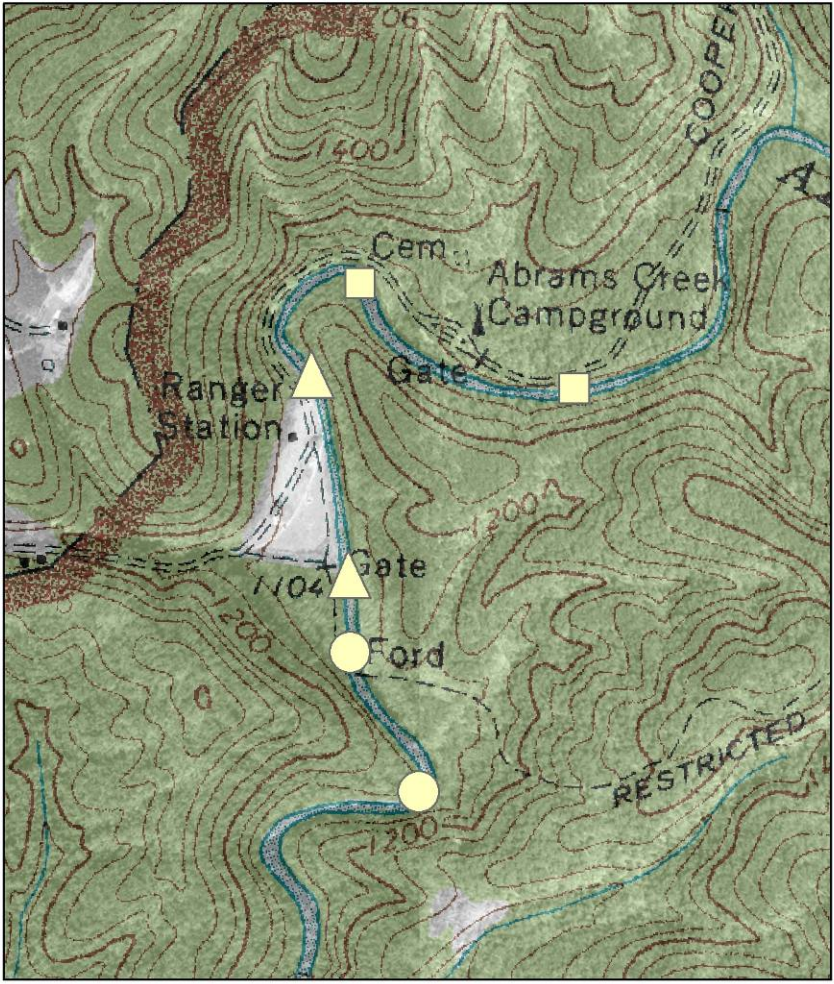
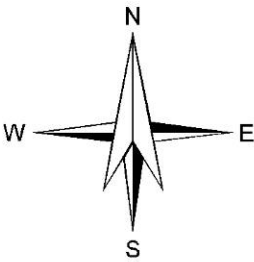
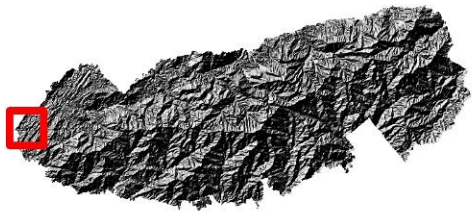


Figure 1. Abrams Creek study site. Study reaches are identified by shapes: Camp Reach (between squares), Station Reach (between triangles), and Bridge Reach (between circles)

Video Mapping

The Underwater Video Mapping System (UVMS) was originally designed to perform coral reef surveys (Legoza, 2002). This method was adapted to better fit a canoe by Fiscor (2005). For this study, the canoe adaptation of Fiscor (2005) was converted to fit a kayak. Equipment used consisted of two Dropshot 20/20 hull-mounted underwater video cameras (one viewing straight down and one at an angle to the substrate) and two underwater laser pointers mounted 196.85 mm apart, one on either side of the vertically facing camera. These were placed in a Wilderness Systems Tarpon 100 kayak. A weather-proof case located at the rear of the kayak housed three Sony Digital DVD video recorders, a Garmin GPS 18 receiver, and a Video Mapping System 200 (VMS 200) (Figure 2). The GPS recorded geographical coordinates directly onto the video footage. GPS data was gathered with an average dilution of precision (DOP) value of 3.0. The DOP value is used to describe the geometric strength of satellite configuration on GPS accuracy. The lower the DOP value the better. DOP values between 2.0 and 3.0 are considered to be excellent. Having GPS data allowed for the location and speed of the kayak to be determined on a frame-by-frame basis while watching the video. This particular video mapping method has been used to conduct habitat mapping in the Big South Foothills National River and Recreation Area, the Great Smoky Mountains National Park, and the Obed Wild and Scenic River (Ayers, 2007a, b, and c).

Field Methods

Each reach of the study stream was floated with three different float patterns: thalweg, along-the-bank, and zig-zag (Figure 3). The thalweg run followed the main flow of water, which will often indicate the deepest part of the channel. The along-the-bank run was performed by staying on a course about 3-5 feet away from the left bank (facing downstream). This datum was analyzed with the thalweg video datum as a method that could be compared to the proportional particle count data. This combined analysis is considered the proportional video method for the rest of this paper. The zig-zag float pattern consisted of the kayak moving downstream from wetted edge to wetted edge on roughly 45 degree angles. Each time the front of the kayak touched a bank, it was turned and we flagged the bank and took a GPS point as a reference. All video data were collected on the morning of 13 June 2007 by Dr. Paul Ayers of the University of Tennessee department of Biosystems Engineering and Technology.

To aid in the calibration of the lasers during the analysis measurements, white ceramic tiles (107.95 mm square) were placed at various depths along the thalweg of the Camp reach. This provided a “particle” of known size when watching video footage that could be compared with the width between the lasers at different depths to assure accurate measurements.

Post-Processing

Data gathered from the UVMS was geo-referenced using Pix-Point/Geovideo software from Red Hen Inc. This allowed all gathered GPS and video data (taken on one second intervals) to be mapped using ESRI ArcView Geographic Information System 9.2 (GIS). Attribute tables were created in this process allowing the beginning and end of



Figure 2. The Underwater Video Mapping System (UVMS). Abrams Creek GSMNP, TN, June 13, 2007.

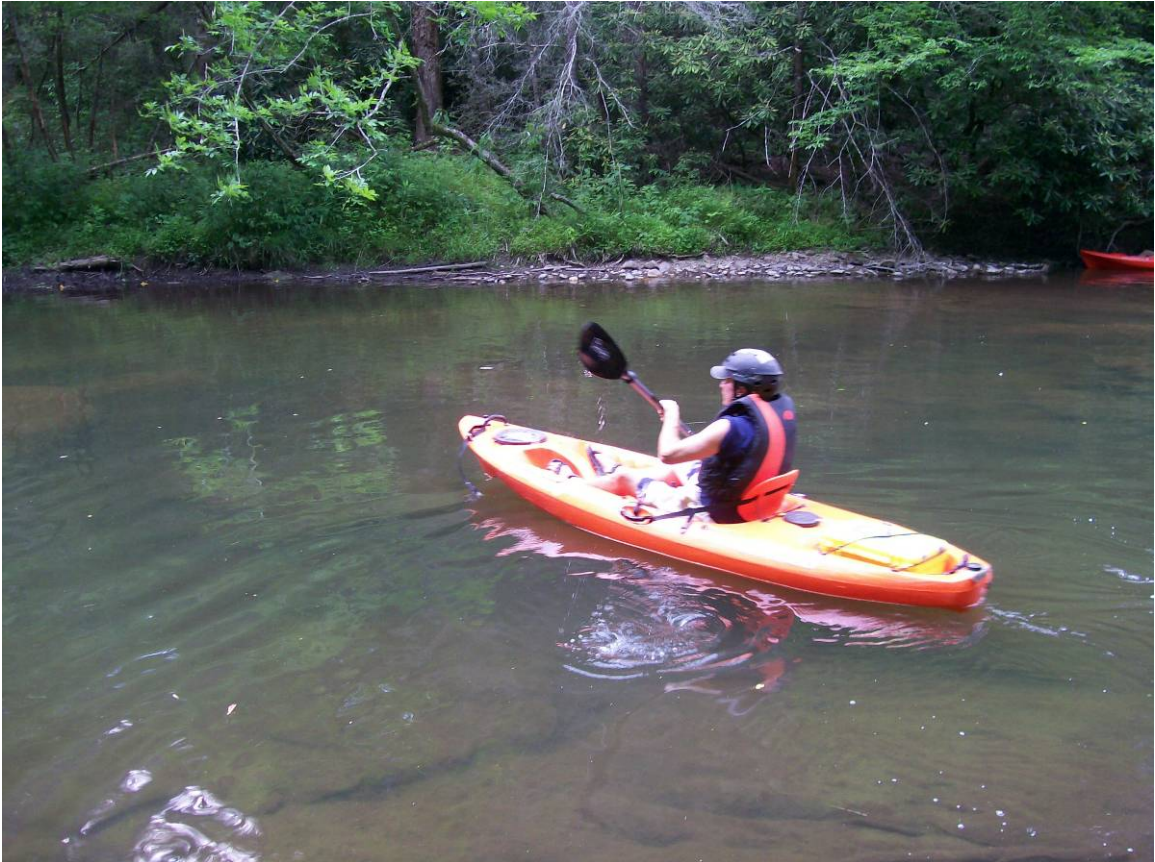


Figure 3. Performing a zig-zag float pattern. Abrams Creek GSMNP, TN, June 13, 2007.

each reach and habitat unit to be identified. Once identified in GIS, the video tape recorder (VTR) times corresponding to these locations were used as starting and stopping points when watching the video. Video playback occurred on a laptop with image output on an external flat screen monitor. A DVD player called AVS DVD was used for the playback. This player was chosen because: 1) it permitted reverse and forward playback at $\frac{1}{4}x$ and $\frac{1}{2}x$ normal speeds, 2) it allowed stepping with frame-by-frame action, 3) it was able to return to the same location for each VTR time, and 4) the user interface was easily controlled.

In order to extract particle measurements from the video, a template for a viewing monitor had to be constructed. Template construction was based on the laser pointers' viewed distance apart on the computer screen. When water depth increased, the lasers *appeared* closer together at the middle of the screen, and when water depth decreased, the lasers *appeared* to be farther apart near the screen edges. However, because they were mounted parallel to one another, distance between laser pointers remained 196.85 mm. This known distance provided a reference for the measurement of particles on the streambed. Two blank sheets of acetate film were taped together, cut to fit the dimensions of the viewing monitor, and fastened to the screen. This template was then calibrated while viewing the Camp reach thalweg video because this video included the images of the ceramic tiles. The Camp reach thalweg video was played and laser point and tile locations were marked on the template using permanent marker (Figure 4). Points were identified for all depths where the laser points were still visible. Another template was constructed of two blank acetate sheets and was used to draw best-fit lines for both laser location marks. These lines were connected in the center of the screen (Figure 5). The spot at which the lines crossed was used as the sampling point for video measurements. Distances between the marked laser point locations were measured on the template. Conversion factors were added to the best-fit lines as hash marks between the known laser locations. The suspected intermediate axis of a particle (Figure 6) measured from the video was multiplied by the corresponding conversion factor on the template. The conversion factor was determined based on the laser location in that given frame. All particle size measurements were made from the video footage captured by the vertically-faced camera because it captured the laser pointers' positions. The UVMS also provided a side-mounted camera that could be used in shallow water conditions when the vertical camera did not provide good substrate visibility. This camera was not used for substrate size determination in this study.

Substrate particles were randomly selected from the video based on two step series: time and distance. Time steps were determined from the total amount of time that the video recorded data between the start and finish of each study reach. The reach time was divided by 100 to give the needed time step interval that would yield 100 sample points for each video run within each study reach. For example, if the thalweg run for the Camp reach took 500 seconds to record, then the time step between each point would be five seconds. Distance steps were determined from the total distance that the kayak traveled between the start and finish of each study reach. This distance was divided by 100 to give a distance interval that would yield 100 sample points for each run. An example of this would be if the total traveled distance was 1000 meters, then the distance step between each point would be 10 meters. To be able to compare to the proportional

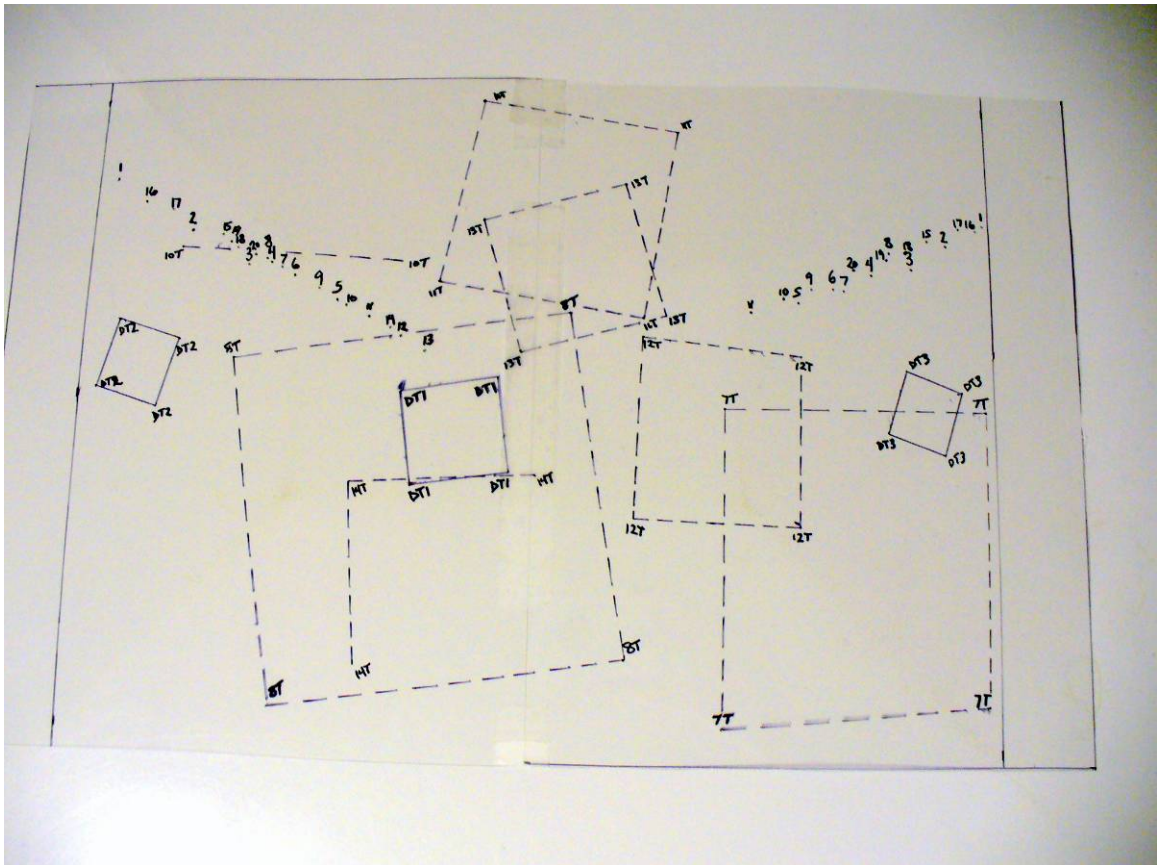


Figure 4. Calibration sheet for video sampling in the laboratory. Dashed lines represent selected ceramic tiles that matched a marked laser point location and which were used to calibrate the depth conversion factors.



Figure 5. Acetate template sheet with conversion factors. Sheet is overlaid on a monitor showing video of substrate. A laser point can be seen on the left of the screen at about the 0.79 conversion factor. The AVS DVD player control panel can be seen at the center of the screen below the sample point.

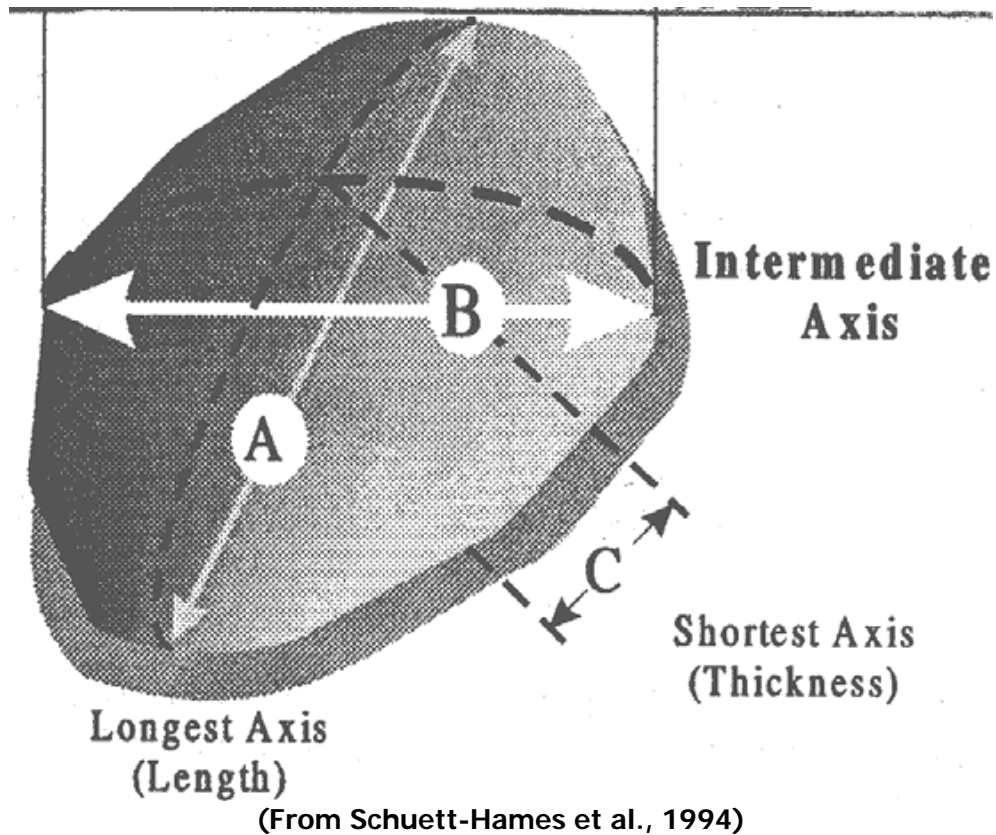


Figure 6. Defining the intermediate axis of a particle.

pebble count method, the along-the-bank video data were only divided by 50 for time and distance and then analyzed with the thalweg video data that was resampled with time and distance steps that were divided by 50. The time and distance steps were determined for each run (i.e. thalweg, along-the-bank, and zig-zag) for all three study reaches, generating a total of 1800 sample measurements needed from the video data.

At the selected time step or distance step on the video, the particle under the cross-hair point of the best-fit line intersection was identified as the sample particle. The diameter of its intermediate axis was measured in millimeters on the screen by a cloth tape (Figure 7). Its on-screen diameter and the corresponding conversion factor was recorded. The depth-corrected diameter, that was the actual diameter, was calculated as a product of the conversion factor and the intermediate axis measured on-screen. If a particle was indistinguishable, then a replacement had to be taken. Replacement points were found by stepping the video forward (or backward) in three frame intervals until a measurable particle was found. Appendix B displays the video mapping data generated from measuring particles on the screen.

A visual estimation method of the substrate was also analyzed from the video for each study reach. These types of data matched what had typically been extracted from the video runs in the past. An observer would watch the video for a study reach and visually estimate the proportion of the substrate by the size classes listed in Table 1. The

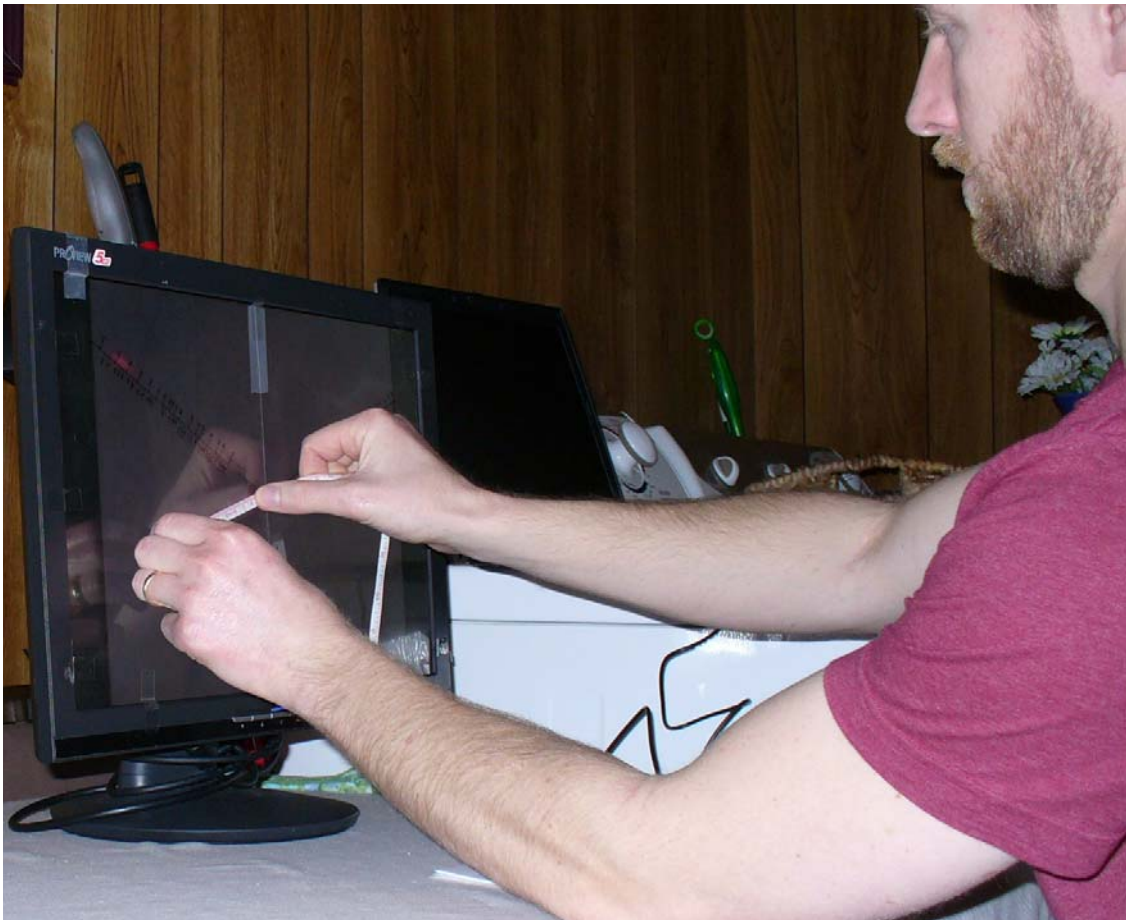


Figure 7. Measuring a particle on the external monitor. The calibration sheet can be seen taped to the monitor screen. A soft, flexible ruler was used to measure the suspected intermediate axis in mm.

Table 1. Size classes used for visual estimation of video data

Substrate	Size (mm)
Fines	< 2.0
Small Gravel	3.0-10
Large Gravel	11-100
Cobble	101-300
Small Boulder	301-600
Large Boulder	> 600
Bedrock	

observer would record the amount of VTR time that a substrate size class dominated the viewing screen. The vertically-faced camera was the primary source of data, but in very shallow, fast moving water, when this view became too blurred, the diagonal camera view would be analyzed. This could be done because the reference laser pointers were not as crucial since a conversion factor was not being determined. Particles were being placed into size classes through estimation and no particle measurement had to be made. Appendix B displays the video mapping data generated from the visual estimation method.

Particle Count

Particle counts were conducted in each of the three reaches using three different techniques: thalweg, zig-zag, and proportional. The three techniques used for the particle counts are described below:

1) Thalweg

The thalweg is the deepest portion of the stream channel, often indicated by where the most flow is located. Starting on one end of a reach (preferably the downstream end to prevent sediment disturbance that could obscure the substrate), a transect line followed the thalweg to the end of the reach. Based on observer step size and reach length, the spacing was every 3 to 5 steps between measurements to achieve a representative 100 sample size.

2) Zig-Zag

The zig-zag transect was adapted from Bevenger and King (1995). The observer followed the same line as the kayak from wetted edge to wetted edge. The transect length increased with this method, so the distance between steps also increased; every 5 to 7 steps a particle was measured to achieve a representative 100 sample size.

3) Proportional

The proportional method was sampled by habitat unit based on the percentage of the reach that the habitat unit comprised. Ten transects were created

from wetted edge to wetted edge using a tape measure placed perpendicular to the stream flow at the designated sampling sites. For example, if 40% of the reach was riffle habitat, then 4 of the 10 transects were placed in riffle habitat. Ten particles were measured along each transect for a total of 100 particles from the entire study reach. To prevent measuring the transitional habitat units, the first and last transects (per habitat unit) were measured 10.7 meters in from the end of the last habitat unit and 10.7 meters in from the beginning of the next habitat unit. The remaining transects needing to be taken in that habitat unit were evenly spaced throughout the unit to prevent bias transect locations or correlation between transect measurements.

The “blind-toe-count” method was used to perform particle selection. For this method the observer closed or averted their eyes, placed their forefinger at the end of their boot, and blindly selected the first particle that their finger contacted. For particles located in pools deeper than the observer’s waist, a diving method had to be used. To dive for a particle, the observer placed a metal, yard-long ruler at the end of the boot where the forefinger would have been placed. Leaving the rod in this position, the observer dived to retrieve the particle located under the ruler.

Once a particle was selected it was measured along the intermediate axis, or b-axis, since this is the axis that would best represent the spherical shape of the particle (Krumbein, 1941; USDA, 1996). All rocks have three axes perpendicular to each other, with the intermediate axis being the one of median length (Figure 6). Fine grain samples were recorded as sand or muck and given a value of 1.0 mm. If a sample point consisted of coarse sand, then a pinch of sample was taken and the average sized particle measured. If the sample was too large to be picked up, then it was measured in place. If the sample was too embedded, preventing the observer from picking it up, then the particle size and embeddedness (%) were estimated. Sample measurements were recorded in millimeters and placed in size classes based on the Wentworth Scale (Table 2). All counts were performed by the same observer to reduce bias and error.

The sample size for each method was 100 particle measurements. This sample size was shown by Wolman (1954) to give reproducible results when a single observer performed the counts. Whenever bedrock was encountered, it was recorded as such and another point was taken as a replacement. Replacements were obtained by taking another step along the same transect and within the same habitat unit where the bedrock was encountered and blindly selecting another particle. Particle count data were collected between 12 June and 23 June 2007. Appendix B displays the descriptive statistics for the particle data.

Control

A frame method was implemented as a control against which the float video data and particle sampling data could be compared. The frame design and sampling method were adapted from Bunte and Abt (2001). Polyvinyl chloride (PVC) 1120 piping, 25 mm outside diameter, was used to construct a sampling frame that was 101.6 cm square at the outside edges (Figure 8). The sampling frame was filled with sand to add the needed weight to help the frame sink and to keep it from moving while in the water. This grid

Table 2. Wentworth* pebble size classes

Particle	Size Class	Millimeters
Fines/Sand	Fine-Coarse	< 2
Gravel	Very Fine	2-4
	Fine	5-6
	Fine	7-8
	Medium	9-11
	Medium	12-16
	Coarse	17-22
Cobble	Coarse	23-32
	Very Coarse	33-45
	Very Coarse	46-64
	Small	65-90
	Medium	91-128
	Large	129-180
Boulder	Very Large	181-256
	Small	257-362
	Small	363-512
	Medium	513-1024
	Large	1025-2048
Bedrock	Very Large	2049-4096

*From Wentworth, 1922



Figure 8. Design of PVC sampling frame. The frame was placed on the stream bank to provide a clearer picture of the design. Measurements were taken in stream.

design created a frame that was both mobile and easily handled. Four elastic bands were used to create four cross-hair points within the frame. The bands were attached to the PVC pipe using o-ring clamps to allow for ease of adjusting the distance between the cross-hairs. The distance between the cross-hair points was based on the D_{95} size for the reach being sampled. The D_{95} is the particle size at which 95% of the sample is finer.

Sample sizes for the frame were determined for each reach based on an equation from Hey and Thorne (1983). Zig-zag and proportional log base two data (i.e., standard deviation) were combined for individual reaches and used in the equation. The equation allowed for the assigning of a sample size, N , for a prescribed level of accuracy, d , given the standard deviation, s , of the t-value for $n-1$ degrees of freedom of the initial sample size, n , at a given site:

$$N = [(ts)/d]^2$$

Table 3 shows how the sample size for each reach was determined. The t-value for the 95% confidence range was used for the Camp reach. The t-value for the 90% confidence range was used for the Station and Bridge reaches due to the time required to take the number of samples at 95% confidence level. However, the number of samples taken exceeded the number needed providing a level of confidence greater than proposed. An accuracy of 15% was used for all sample size determinations. This is because the sample sizes grow extremely large as the accuracy levels are lowered. For example, at 10% and 5% accuracy (with all else the same), the Bridge reach sample sizes would have been 1203 and 4593, respectively.

Based on the needed number of particles to be sampled per study reach, 20 to 21 transects were run perpendicular to the stream flow using a tape measure. These transects were placed in evenly spaced increments, indeterminate of habitat unit. Along a transect, the frame was placed in evenly spaced increments while facing upstream. This spacing of transects and frames lessened the likelihood for overlapping of the frame and double counting of a particle. Once the frame was placed in the proper position, with one of the square's sides parallel to the tape measure, particles could be retrieved and measured.

Table 3. Sample sizes for each study reach taken with the frame method.

	n	d	St.Dev	t-value	# of samples needed	# of samples taken
Camp	200	15	2.06	1.960*	401	420
Station	200	15	2.54	1.645	429	540
Bridge	200	15	2.90	1.645	560	644

*Based on the 95% confidence level

To sample a particle using the sampling frame, the observer used visual identification to select the particles directly under each of the four cross-hair points. Facing upstream, the observer would select the particle on the top left and then work counter-clockwise around the frame for the rest of the samples. This method removed some observer bias by preventing the observer from selecting larger or smaller particles based on their partiality (Marcus et al., 1995). The elasticity of the bands allowed for natural removal of the particles from within the frame, preventing the problematic removal and realignment of the frame after each sample. Particles were measured in millimeters along their intermediate axis (Figure 6). Particles that were large enough to touch multiple cross-hair points (i.e., multi-counting) were only counted once, but the missed point or points were sampled at the cross-hair's adjacent corner. This increasingly became a problem as the Bridge reach was sampled due its high percentage of bedrock. Bedrock counts were recorded, but because of their lack of a numerical measurement they were not counted as a sample to be analyzed. Therefore, that particle count was resampled at the adjacent corner as mentioned above. If no other sample could be taken in the frame due to multi-counting, then the frame was flipped 180 degrees upstream so as to place the frame on the other side of the tape measure. This new frame position was sampled (counter-clockwise starting on the top left cross-hair point while facing downstream) until a measurable particle was obtained. Frame data was collected between 22 June and 6 July 2007. Appendix B displays the descriptive statistics for the frame data.

Data Analysis

Statistical Analysis Software (SAS) 9.1 was used to analyze all data. A SAS 9.1 macro procedure and Shapiro-Wilk from ProcUnivariate were used to determine normality of all sample groups. If data were from a normal distribution, then a one-way Analysis of Variance (ANOVA) was performed to determine if a significant difference was present. When only comparing two groups, the ANOVA test is reduced to a two-sample *t*-test. If data were from a non-normal distribution, then ANOVA could not be used because normality is one of the assumptions. The Wilcoxon Rank Sum test, some times referred to as the Mann-Whitney *U* test, was performed to determine if a significant difference was present in the nonparametric data. For this test, data are ranked from highest to lowest value and given a ranked number, in order to make comparisons. Since this is a test on the ranks of the data, normality of data is not necessary. An alpha value of 0.05 was used for normality tests and an alpha value of 0.15 was used for statistical comparisons. The alpha value is the reference probability of the assigned level of statistical significance. It states up front, what risk you are willing to take in making a Type I error. A Type I error is made when the alternative hypothesis is accepted as true when it is actually false. For $\alpha=0.15$, statistical significance is concluded if the obtained p-value is less than 0.15. Typical alpha values are 0.01, 0.05, and 0.10. Due to the natural variability in performing pebble count measurements, a higher alpha value was chosen.

Chapter 3: RESULTS

Data from the pebble count, video time/distance step intervals, and the frame control were analyzed by particle size, diameter size class, and percent distribution. The visual estimation method was only analyzed by percent distribution because no measurement of a particle's intermediate axis actually occurred, but only placement into a size class. The pebble count methods and video particle-measurement methods each had sample sizes of 100 per reach. The frame measurements had sample sizes of 420, 540, and 644 for the Camp, Station, and Bridge reach, respectively. The total number of particles actually measured was 4304. The total number of particles counted (including replacements due to bedrock encounters and/or visibility limitations) was 5294. Nearly one-fourth of the measured particles came from replacement points.

Measurements

Particle Size

For particle size, the data were grouped as frame, pebble count proportional (PCP), pebble count zig-zag (PCZ), pebble count thalweg (PCT), video distance proportional (VDP), video distance zig-zag (VDZ), video distance thalweg (VDT), video time proportional (VTP), video time zig-zag (VTZ), and video time thalweg (VTT). Each group consisted of the combined data for all three study reaches. A comparison of each groups' means and standard deviations are shown in Table 4 with the difference in size from the frame (i.e., control) indicated. Detailed descriptive statistics can be found in Appendix B. Particle size data were from a non-normal distribution for all comparisons. Significant differences were found at $\alpha=0.15$ when comparing video measurements to the frame measurements (Table 5).

Table 4. Comparison of particle size means and standard deviations from data collected on Abrams Creek GSMNP, TN, June-July 2007.

	Mean Size (mm)	Standard Deviation	Difference From Frame Mean (mm)
Frame	107.01	149.30	NA
PCT	123.19	235.53	+ 16.18
PCP	139.38	273.63	+ 32.37
PCZ	116.05	170.42	+ 9.04
VTT	53.17	70.49	- 53.84
VTP	60.50	72.51	- 46.51
VTZ	47.75	53.28	- 59.26
VDT	59.00	62.49	- 48.01
VDP	69.93	72.82	- 37.08
VDZ	61.23	61.47	- 45.78

Table 5. Comparison of p-values for each method tested against the frame control for the variable 'particle size' at $\alpha=0.15$.

Method	p-value	Significant Difference
Pebble Count Thalweg	0.2818	No
Pebble Count Proportional	0.9295	No
Pebble Count Zig-Zag	0.7444	No
Video Time Thalweg	<0.0001	Yes
Video Time Proportional	<0.0001	Yes
Video Time Zig-Zag	<0.0001	Yes
Video Distance Thalweg	0.0001	Yes
Video Distance Proportional	0.0300	Yes
Video Distance Zig-Zag	0.0013	Yes

Diameter Size Class

Diameter size class charts, based on the Wentworth scale (Table 2), were generated for the frame control method and for each particle count method by run (i.e., proportional, zig-zag, and thalweg) and by study reach. An example of how a diameter size class chart was constructed is shown in Figure 9 for the frame control of the Camp reach. All diameter size class charts are given in Appendix C.

Diameter size class data were grouped as frame, pebble count proportional (PCP), pebble count zig-zag (PCZ), pebble count thalweg (PCT), video distance proportional (VDP), video distance zig-zag (VDZ), video distance thalweg (VDT), video time proportional (VTP), video time zig-zag (VTZ), and video time thalweg (VTT). Each group consisted of the combined data for all three study reaches. Diameter size class was statistically tested as the variables D_5 , D_{16} , D_{35} , D_{50} , D_{65} , D_{84} , and D_{95} . Table 6 shows the p-values, at $\alpha=0.15$, for the comparison of each grouping and each variable when tested against the frame control. Table 7 has the same notations corresponding to the p-values of Table 6, but gives the average size in millimeters for each of the diameter size class variables. Figure 10 is a diameter size class chart comparing the different methods for the zig-zag run of the Camp reach. It illustrates the general trend for all methods and runs (i.e., thalweg, proportional, and zig-zag) shown by the data in Table 7.

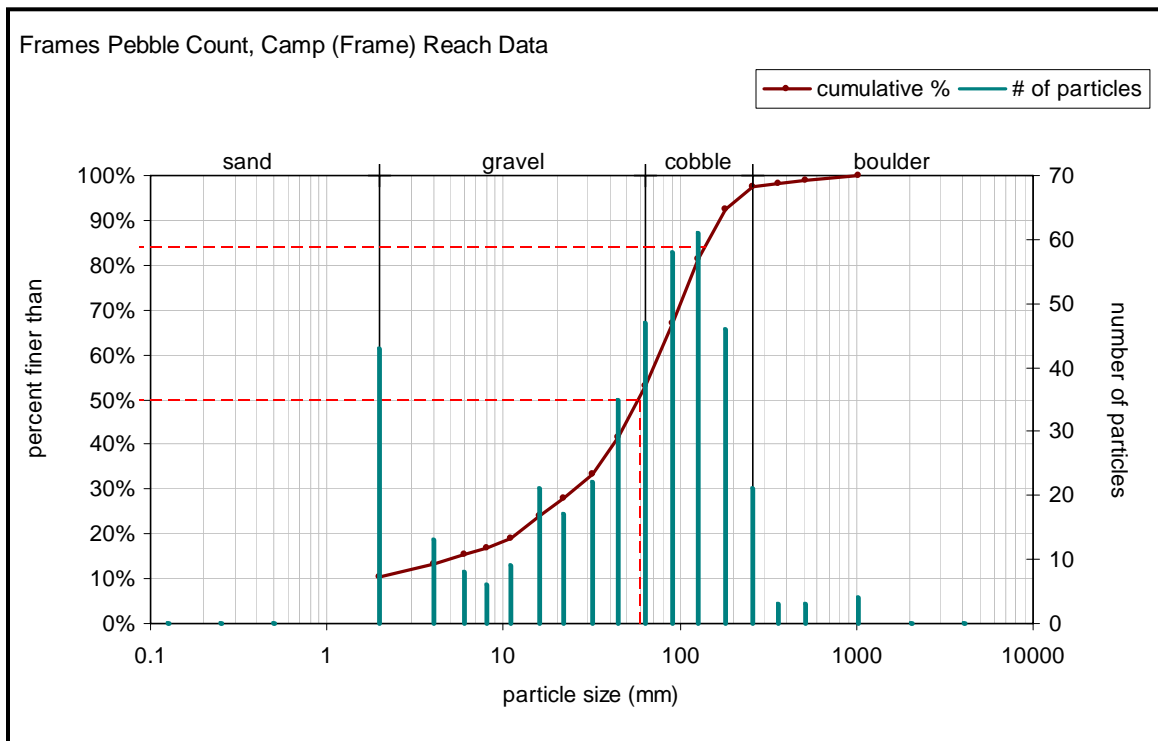


Figure 9. Diameter size class chart for the frame method on the Camp reach. Abrams Creek GSMNP, TN, 22 June 2007. Classifications are based on the Wentworth scale.

Table 6. Comparison of p-values for each method, tested against the frame control for the variables of ‘diameter size class’. P-values that are italicized and underlined are from data with a non-normal distribution. P-values that are bolded are significantly different than the frame control at $\alpha=0.15$.

Method	D5	D16	D35	D50	D65	D84	D95
PCT	<u>0.3173</u>	0.2866	0.1939	<u>0.2683</u>	0.7421	0.7843	0.9417
PCP	0.7376	0.6434	0.6974	0.0413	0.8825	1.0000	0.2848
PCZ	0.0890	0.2036	0.3065	<u>1.0000</u>	0.8351	1.0000	0.7845
VDT	0.1084	0.3543	0.2567	0.0092	0.0213	0.0452	<u>0.1212</u>
VDP	0.0993	0.5021	0.5209	0.1260	0.2016	<u>0.1840</u>	<u>0.3537</u>
VDZ	0.0352	0.4358	0.0849	0.0233	0.0618	<u>0.0765</u>	<u>0.1157</u>
VTT	0.2791	<u>0.6625</u>	0.0132	0.0099	0.0135	0.0418	0.0933
VTP	0.0550	<u>0.6579</u>	0.0118	0.0293	0.1306	0.0626	<u>0.1642</u>
VTZ	0.2943	0.2139	0.0116	0.0006	0.0067	0.0269	<u>0.0765</u>

Table 7. Comparison of average sizes (in millimeters) for each method, tested against the frame control for the variables of ‘diameter size class’. Numbers that are italicized and underlined are from data with a non-normal distribution. Numbers that are bolded are significantly different than the frame control at $\alpha=0.15$.

Method	D5	D16	D35	D50	D65	D84	D95
Frame	1.3	5.0	27	61	102	190	390
PCT	<u>1.4</u>	8.1	38	<u>66</u>	107	180	400
PCP	1.4	7.0	31	68	104	190	630
PCZ	1.7	8.3	37	<u>70</u>	106	190	443
VDT	1.8	3.4	20	39	63	113	<u>183</u>
VDP	1.9	3.8	21	48	82	<u>137</u>	<u>213</u>
VDZ	1.6	3.7	18	43	70	<u>123</u>	<u>183</u>
VTT	1.5	<u>2.4</u>	7	21	54	110	180
VTP	1.5	<u>2.6</u>	8	32	72	123	<u>197</u>
VTZ	1.5	2.7	9	27	49	103	<u>163</u>

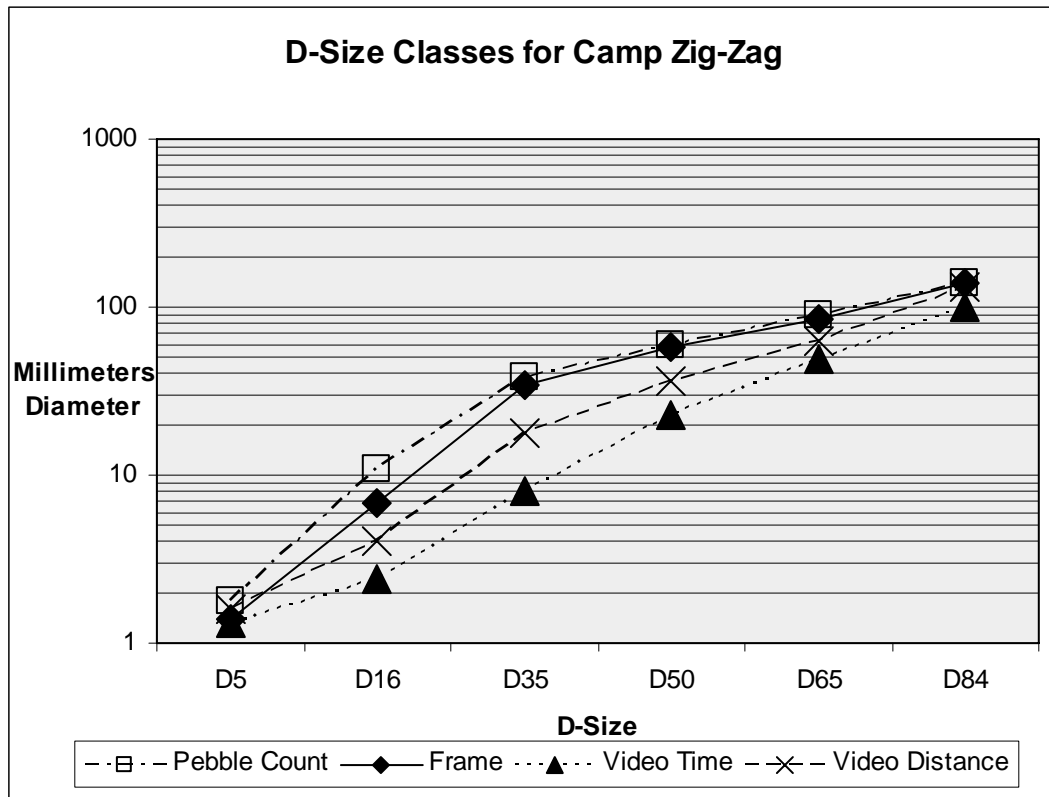


Figure 10. Comparison of diameter size class variables for the Camp reach zig-zag technique.

Percent Distribution

The percent amount of fines, small gravel, large gravel, cobble, small boulder, large boulder, and bedrock, as according to the visual estimation scale of Table 1, were determined for all methods of data collection when comparing the visual estimation technique with the others. The percent amount of fines, gravel, cobble, boulder, and bedrock, as according to the Wentworth scale of Table 2, were determined for all methods of data collection when the visual estimation technique was not included. Wentworth scale comparisons included two separate analyses of data: with bedrock counts and with bedrock replacements. Percent distribution data were grouped as frame, pebble count proportional (PCP), pebble count zig-zag (PCZ), pebble count thalweg (PCT), video distance proportional (VDP), video distance zig-zag (VDZ), video distance thalweg (VDT), video time proportional (VTP), video time zig-zag (VTZ), video time thalweg (VTT), visual estimation proportional (VEP), visual estimation zig-zag (VEZ), and visual estimation thalweg (VET). Each group consisted of the combined data for all three study reaches.

Table 8 shows the p-values, at $\alpha=0.15$, for the comparison of each grouping and each visual estimation variable (i.e., fines, small gravel, large gravel, cobble, small boulder, large boulder, and bedrock) when tested against the frame control. Figure 11 is a radar chart that compares the different methods for the proportional run of the Camp reach. It illustrates the general trend for all methods and runs (i.e., thalweg, proportional, and zig-zag) shown by the data in Table 7.

Table 9 shows the p-values, at $\alpha=0.15$, for the comparison of each grouping and each Wentworth variable (i.e., fines, gravel, cobble, boulder, and bedrock) when tested against the frame control. Table 10 shows the p-values, at $\alpha=0.15$, for the comparison of each grouping when tested against the frame control in the Wentworth scale with bedrock replacements.

Time Investment

The ability to quickly gather data with the UVMS is one of the major benefits. However, laboratory analysis of the data must also be factored into the time expenditure. Therefore, it is important to make comparisons between each of the methods in regards to the time it takes to perform them. Exact times for each method are listed in the tables found in Appendix B.

To perform the frame control measurements, the average amount of time spent in stream was 556 minutes per study reach. This is considerably longer than any of the other methods, but it must be noted that four to five times as many particles were being measured using this method. The average amount of time per study reach to perform a pebble count using the proportional, zig-zag, and thalweg runs was 158 minutes, 89 minutes, and 74 minutes, respectively. This was the total time needed for these methods since no laboratory analysis was needed.

When collecting data using the video distance step technique, the average time per study reach spent analyzing in the laboratory was 160 minutes, 182 minutes, and 174 minutes for the proportional, zig-zag, and thalweg runs, respectively. Yet the total time investment must include the time needed to collect the data while on the kayak. The

Table 8. Comparison of p-values for each method tested against the control for the variables of ‘percent distribution’ from the visual estimation scale. P-values that are italicized and underlined are from data with a non-normal distribution. P-values that are bolded are significantly different than the frame control at $\alpha=0.15$.

Method	Fines	Small Gravel	Large Gravel	Cobble	Small Boulder	Large Boulder	Bedrock
PCT	0.5391	0.8007	0.9588	0.8678	1.0000	1.0000	0.9141
PCP	0.7877	0.3305	0.9783	1.0000	0.4676	0.1469	0.9538
PCZ	0.0535	0.2051	0.8865	1.0000	0.8203	0.8149	0.9146
VET	0.4776	<u>0.0636</u>	0.4779	0.0007	<u>0.0636</u>	0.3486	<u>0.1840</u>
VEP	0.0335	1.0000	0.8091	0.0033	0.2144	0.4785	<u>0.2683</u>
VEZ	0.0161	0.1570	0.9462	0.0181	0.3739	0.3712	0.4912
VDT	0.0411	<u>0.0765</u>	0.2716	0.2241	<u>0.1967</u>	<u>0.0593</u>	<u>0.0636</u>
VDP	0.0996	0.0020	0.5786	0.7465	0.2464	<u>0.0593</u>	<u>0.0636</u>
VDZ	0.0111	0.0002	0.2052	0.2835	0.1234	<u>0.0593</u>	<u>0.0636</u>
VTT	0.7014	0.0026	0.8593	0.0856	<u>0.1642</u>	0.1481	<u>0.0636</u>
VTP	0.0158	0.0030	0.8980	0.8593	0.1234	0.1481	<u>0.0636</u>
VTZ	0.4512	0.0005	0.3913	0.0184	<u>0.0636</u>	<u>0.0593</u>	<u>0.0636</u>

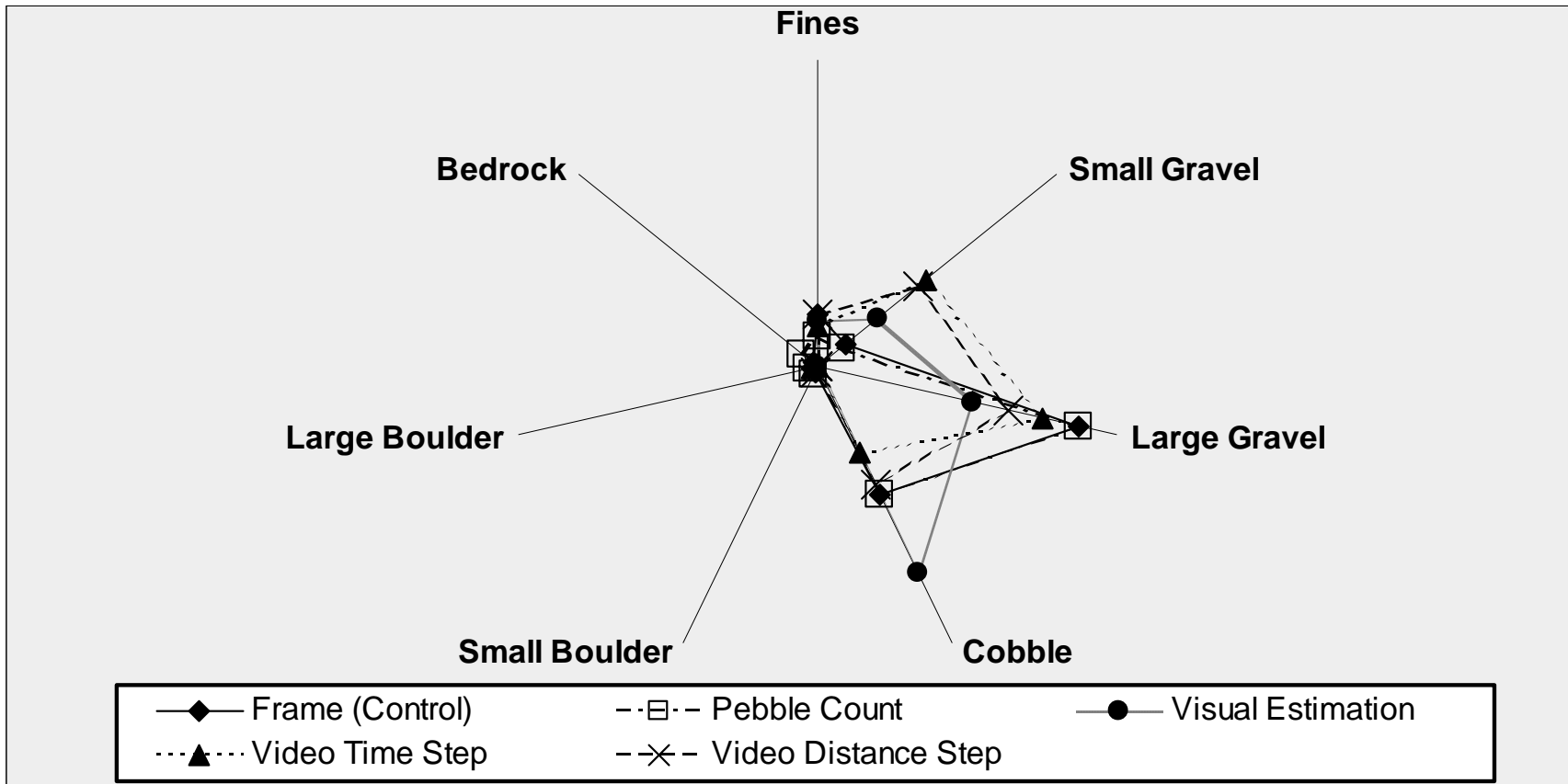


Figure 11. Comparison of percent distribution variables, from the visual estimation scale, for the Camp reach proportional run.

Table 9. Comparison of p-values for each method tested against the control for the variables of 'percent distribution' from the Wentworth scale. P-values that are italicized and underlined are from data with a non-normal distribution. P-values that are bolded are significantly different than the frame control at $\alpha=0.15$.

Method	Fines	Gravel	Cobble	Boulder	Bedrock
PCT	0.5391	0.8329	0.7638	0.8541	0.9141
PCP	0.7877	0.6578	0.7747	0.6745	0.9538
PCZ	0.0535	0.7244	1.0000	1.0000	0.9146
VDT	0.0411	0.0131	0.8058	<u>0.0636</u>	<u>0.0636</u>
VDP	0.0996	0.0590	0.3688	0.1462	<u>0.0636</u>
VDZ	0.0111	0.0334	0.7072	0.0749	<u>0.0636</u>
VTT	0.7014	0.0114	0.3500	0.0993	<u>0.0636</u>
VTP	0.0158	0.0372	0.8676	0.1145	<u>0.0636</u>
VTZ	0.4512	0.0085	<u>0.1967</u>	0.0749	<u>0.0636</u>

Table 10. Comparison of p-values for each method tested against the control for the variables of 'percent distribution' from the Wentworth scale with bedrock replacements. P-values that are italicized and underlined are from data with a non-normal distribution. P-values that are bolded are significantly different than the frame control at $\alpha=0.15$.

Method	Fines	Gravel	Cobble	Boulder
PCT	<u>1.0000</u>	0.7247	0.3384	0.8611
PCP	0.7813	0.6008	0.9508	0.8293
PCZ	0.0779	0.0671	0.7913	0.8917
VDT	0.0559	0.0045	0.1338	<u>0.0636</u>
VDP	0.0918	0.0476	0.8581	0.0918
VDZ	0.0734	0.0208	0.6105	0.0491
VTT	0.4012	0.0027	0.0335	0.0640
VTP	0.0866	0.0264	0.4127	0.0732
VTZ	0.2729	0.0021	0.0110	0.0491

average time needed to float one of the 300 meter study reaches was 7 minutes for the thalweg run, 19 minutes for the zig-zag run, and 23 minutes for the proportional run. The proportional run time is the addition of two separate float pattern times: the thalweg run time and the along-the-bank run time.

When collecting data using the video time step technique, the average time per study reach spent analyzing in the laboratory was 200 minutes, 212 minutes, and 305 minutes for the proportional, zig-zag, and thalweg runs, respectively. The thalweg run analyzing time was larger than the other methods because it was the first set of data analyzed and the learning curve associated with taking measurements off of the video monitor added time to the process. The time spent on the kayak was the same as from the video distance results since both video distance and time techniques were performed on the same video sets.

Visual estimation techniques also used the same video sets, so the float times are the same. The average time needed per study reach to analyze the video data with this method was 31 minutes, 38 minutes, and 14 minutes for the proportional, zig-zag, and thalweg runs, respectively. In most cases, the observer could expect to spend twice the amount of recorded time (i.e., VTR time) in the laboratory analyzing the data through visual estimation.

The time expenditures being compared in this study are not the best representation of the benefits of the UVMS. The Abrams Creek study site was easily accessible and only 1400 m in total length. This was very accommodating in performing the pebble count surveys, but did not allow the UVMS to demonstrate its time saving advantages. When performing a field study, one must consider the travel time to reach the study site. This is especially important when working in remote sites that are hard to reach. The UVMS would be very beneficial for stream reaches that have only one entry and exit point with miles of stream in between. Fiscor (2005) was able to map over 27 km of stream in less than 11 hours, on three different trips. The time to reach a backcountry site like this one, to perform a pebble count survey, would take hours of valuable time and possibly days if camping were involved. Yet, this still does not include the time it would take to actually perform the pebble count on a 27 km section of stream.

Chapter 4: DISCUSSION

Particle Size

Statistically significant differences were found for particle sizes at $\alpha=0.15$ when comparing the video time and distance data to the frame control data. Measured video particles had means which were consistently smaller than the frame and pebble counts. The differences in video data from the frame ranged from 37 to 59 mm, as indicated from Table 4. Depending on what the data are being used for, some may say that for viewing moving substrate, a mean difference of only 37 mm is excellent.

The smaller sizes generated from the video methods could be due to inaccurately determining the intermediate axis of a particle on video, the loss of video visibility at greater depths, and/or the inability to measure larger particles in shallow water. The intermediate axis of a particle can sometimes be difficult to determine, even when holding the particle in hand, but trying to find it on a computer monitor can be even more complicated. When measuring particles on the computer monitor, the smallest observed side was measured. This was chosen because particles are usually not balanced on their shortest side. Therefore, the longest and intermediate axes are likely to be the visible sides. Loss of visibility occurred through pool habitat because the light penetration through the water was not strong enough to allow the streambed to be accurately observed. Large particles may have been missed through this habitat. The use of a light attached to the boat or a drop down camera and light combination, as used by Fiscor (2005), could be effective in these circumstances. The error from depth perception would need to be tested if one used the camera-light combination of Fiscor (2005), since the camera faces downstream and not straight down.

The shallow depth of the riffles prevented video measurement of large particles because as the water became shallower, the size of the particle that the observer could see within a single frame decreased. The viewing monitor was 19 inches (≈ 480 mm) at the diagonal and because the lasers faded out at greater depths, the largest conversion factor possible was 2.0. Therefore, the largest particle that could possibly be measured was 960 mm. Although this is considered a large boulder on the visual estimation scale (Table 1), the majority of particles in this class (>600 mm) were located in pools and riffles. The largest particle measured on the videos, for any one reach, was 660 mm. This was located in a pool that was in a transition phase of regaining visibility after being too deep to see. Overall, the largest particles actually present in the stream could not be measured from the video because their suspected intermediate axis could not be seen in its entirety. The use of the side camera may have helped through these shallow riffles. Another possible solution would be to try and measure the larger particles over a series of frames. The measurement may be less accurate, but placement into a classification system such as the Wentworth scale (Table 2) would be possible, allowing for the analysis of percent distribution measurements. The error associated with this would be that only one axis would be visible. The observer may be measuring the longest axis and not the intermediate axis, which could skew the results.

These findings were different than those found by Frezza et al. (2003) who did not find a significant difference in their video mapping measurements and field

measurements of streambed particle size, except on one occasion. Their method in which particles were measured in the field was not recorded, so it is difficult to make direct comparisons with this study. Conversely, the video method used was noted in detail. Their method could capture larger areas of the streambed in a single frame, since the camera was angled upstream and not straight down. This is also similar to the camera angle used by Fiscor (2005). Although, the upstream (or downstream) camera angle could allow the full image of larger particles to be captured, it would also make determination of particle size more difficult because of depth perception. For Frezza et al. (2003), the camera was controlled by hand and not attached to a boat, so it could be moved slower and be more easily manipulated. These methods may generate larger particles from the video which may be closer in size range to the field measurements. However, their method of video data collection would be slower than the UVMS used in this study and would not produce geo-referenced data.

Diameter Size Class

Significant differences were observed for the D_5 , D_{35} , D_{50} , D_{65} , D_{84} , and D_{95} size classes. No significant differences were found for the D_{16} size class variable. The D_5 values were between 1.0 and 2.0 mm for all methods. This was because the lower truncation of particles had the same value for all methods; the smallest value assigned to particles in stream was 1.0 mm and the smallest on video was approximately 1.0 mm (2.0 mm with a 0.59 conversion factor). When significant differences were present for the D_5 value, it was because the data grouping (i.e., PCZ, VDT, VDP, VDZ, and VTP) produced larger values than the frame (see Table 7). For the rest of the diameter size class variables, the video time and video distance runs had values much lower than the frame and pebble count runs.

The video time step data were the principal source of significance for the D_{35} value and larger, as seen by the fact that all video time runs were significantly different than the frame control for these tested variables. The one exception was the video time proportional (VTP) run for the D_{95} variable which was not significantly different than the frame ($p=0.1642$). The D_{50} variable, which is most often viewed as the “typical” substrate, had the most significant differences of any of the variables. The pebble count proportional (PCP) data showed higher values than the frame, but the video time and distance data showed lower values than the frame. Only the pebble count thalweg (PCT) and pebble count zig-zag (PCZ) were not significantly different from the frame. Interestingly, Table 7 shows the average D_{50} value for PCZ (70 mm) being greater than the PCP D_{50} (68 mm), but the PCZ was still not significantly different. This is because the standard deviation was 2.0 for PCP, but 23.18 for PCZ, which kept the PCZ from being significantly different from the frame.

Diameter size classes for video time step runs were smaller in size than video distance runs, but not significantly. However, the difference between the two video methods could possibly be due to the spacing between sampling intervals. With time steps, a time interval was chosen (e.g., 10 seconds) that would be the amount of time to pass between particle measurements. When recording the video, the kayak would sometimes become lodged in shallow riffles. Nevertheless, the video time continued to run. Sampling points would at times, consequently, be right next to one another when

sampling the video on a time step interval. Ultimately, more particles were measured in riffle habitat than should have been, when considering proportions of each habitat unit. This is a problem because samples taken in shallow water tend to be smaller because of the limited view of the screen. Thus, more time in riffle habitat equals smaller particles being measured. The video time zig-zag (VTZ) runs added to this problem because not only did they pass through riffles, but more time was spent near the edges because the kayak had to stop and change directions once it reached a bank. Particles near stream banks are often more fine than the rest of the streambed because the water moves slower near the edges, loses the power needed for sediment transport, and finer particles drop out. Since these are the areas where more time was spent during the VTZ run, data would be expected to show a smaller mean size for VTZ.

The spacing issue was reduced when using the video distance step interval. The GPS coordinates that were embedded into the video frames revealed if the kayak was stationary or either how far the kayak had moved between GPS points. By assigning a distance step (e.g., 10 meters), the likelihood of overlapping and correlation of particles was tremendously reduced. Particles were more evenly sampled between each habitat unit and therefore the mean sample size for video distance data more closely resembled the frame and pebble count data than did the video time data.

Percent Distribution

Visual Estimation Scale

Table 8 shows the significant differences for percent distribution variables in the visual estimation scale. When significant differences were found for the variable fines, the percentage of fines for that grouping (e.g. PCZ) was less than what the frame produced. For small gravel, the percentage was much higher for the video time and distance methods than the frame method. The visual estimation thalweg (VET) run, however, was significantly different than the frame because it produced no small gravel. For video time and distance methods, the observer measured more small gravel than any other distribution. This could be due to the inability to measure larger particles that have intermediate axes extending off of the screen. For this type of particle, the observer had to take a replacement. The first identifiable particle encountered by the sample cross-hair point (after a three step forward count) was measured. Due to the recirculation of water on the downstream side of large particles, smaller particles tend to drop out directly behind larger rocks. Therefore, smaller particles in the fines and small gravel range would be expected to be encountered behind particles of the small boulder size and larger. A possible improvement for this problem would be to try and measure particles over a series of frames as mentioned in the Particle Size section of this chapter, but the particle orientation error would have to be studied. An easier modification would be to take replacement points on a three step reverse count. This way the error associated with measuring smaller particles behind larger particles, may be reduced.

Large gravel was the only variable that did not have significant differences between any of the groupings and the frame, for the visual estimation scale. The variable cobble showed significant differences for all the visual estimation methods as well as the video time thalweg (VTT) and the video time zig-zag (VTZ) methods. The VTT and

VTZ methods had slightly lower percentages of cobble than the frame. Visual estimation of the videos produced percentages of cobble nearly double what the frame produced. This over estimation may be due to observer bias, but this remains to be tested. Only one observer performed this method, so it may be beneficial to have others also visually estimate size distributions. When performing pebble counts, observers tend to select larger particles, when viewing the substrate in order to select a particle to measure. There is no reason to assume that this could not also be true when viewing data on a video screen.

For the remaining variables, the video data (i.e., visual estimation, video time, and video distance) generated very little and sometimes no small boulder, large boulder, or bedrock percentages. In contrast, the pebble count proportional (PCP) data was significantly larger than the frame data for the variable large boulder. PCP data had means that were consistently greater than what the frame data produced. The percent of particles greater than 1000 mm was 3% for PCP and only 0.5% for the frame, though the percent of small particles (1.0 mm) was practically equivalent (13% for PCP and 12% for frame). A possible reason for these results could be that the frame method was not sampled by habitat units, but on equally spaced transects. Thus, the equally spaced transects of the frame method may have sampled less than the proportional method in riffles where larger particles are typically found. If the observer was bias toward larger particles, then that could have played a role against the proportional method.

Wentworth Scale

When excluding the visual estimation data from the analysis, the data could be compared in the more common Wentworth scale (Table 2). Using the Wentworth scale and including the bedrock counts did not change many of the results from those found for the visual estimation scale data. The video distance methods (VDT, VDP, and VDZ), the video time proportional (VTP) method, and the pebble count zig-zag (PCZ) method all still produced significantly smaller percentages of fines than the frame method. The variable gravel still showed significant differences for the video time and distance methods. Changes in the results from the two percent distribution scales begin to be seen with the variable cobble. When before, the VTT and VTZ were significantly different than the frame, now, there were no comparisons that showed significant differences for cobble. The variables boulder and bedrock were significantly less for the video time and distance methods when compared to the frame. This is similar to the visual estimation scale comparisons in which very little and sometimes no boulder or bedrock percentages were seen.

Percent distribution was analyzed again using the Wentworth scale, but this time with the bedrock replacements. Theoretically, since the video measurement data never recorded bedrock, it should more closely resemble the frame data if bedrock replacements were taken. The video distance methods (VDT, VDP, and VDZ), the video time proportional (VTP) method, and the pebble count zig-zag (PCZ) method all still produced significantly smaller amounts of fines than the frame method. Once again, the variable gravel still showed significant differences for all of the video time and distance methods. However, the PCZ method was shown to now produce significantly larger percentages of gravel than the frame. The variable cobble shows significant differences

for the VDT, VTT, and VTZ methods when compared to the frame. These methods produced a smaller percentage of cobble than the frame. For the variable boulder, the video time and distance methods all generated significantly smaller percentages than the frame control method. Changing the percent distribution scale and/or taking bedrock replacements did not give more accurate percentages for the video data.

Sources of Video Error

The following dilemmas may account for the deviations between video data and the frame control measurements:

- Suspended sediment can block the view of the channel floor
- Decreased light transmission in deep water will obscure the stream bottom if it is below the photic zone
- Kayak moving too fast can cause a “blurred” screen
- Kayak takes the path around large and protruding rocks
- Observer bias for visual estimation method where the viewer is disposed toward larger particles
- Small particles can become indistinguishable at greater depths and therefore must be estimated or replaced with a recognizable particle
- Particle sizes too large to capture on a single video frame at shallow depths and therefore must be estimated or replaced with a recognizable particle
- Mistaking conglomerate rock or bedrock for small gravel/fines when the camera is directly on top of the substrate
- Not having the full range of conversion factors for all depths
- Particles may be embedded or incorrectly oriented to display the intermediate axis

Correction can be made for some of these issues. Depending on the average depth of the stream being studied, a light may be mounted on the kayak to illuminate the streambed substrate in deeper waters. Fiscor (2005) attached a waterproof camera with lights to a telescopic pole and used it to capture substrate data from a canoe. This method is beneficial, but cannot be performed alone since someone else is needed to control the canoe or kayak.

To help control the blur created by substrate quickly passing the camera lens, the individual controlling the kayak can try slowing the kayak speed in shallow or particularly fast waters. Although this would lessen a primary benefit of the UVMS – speed – to what extent would have to be determined.

More observers should be used when performing visual estimation if bias is expected, so an average could be assigned for the substrate distribution. This could also show if an observer is truly biased or if allocating larger percentages of cobble in the overall distribution is just the nature of collecting substrate data with the Underwater Video Mapping System (UVMS). Percent distributions should also be calculated by habitat unit. This would identify if there were sections of a stream where the observer could have more confidence in their assessment of substrate. When watching the videos, riffle and pool habitats were sometimes difficult to measure because the precision of the

observer to differentiate smaller particles on the screen was challenged by blurred views and dark depths. Runs seemed to be easier to take measurements in because the water was not too shallow or too deep to interfere with visibility. In comparison to riffles, the kayak speed was slowed through the runs because of the lower velocities of water helping to prevent blurring of the images.

A brief training lesson would also help to eliminate some of the observer bias if it is present. Often in shallow water, a screen shot might appear to be blurred and look like a group of fines, but a trained eye may better distinguish particle edges. This is especially important when viewing conglomerate rock on the videos. Figures 12 and 13 illustrate this thought. Stepping from frame to frame and playing the video slowly forward and backward helps the observer to better recognize the shapes and shadows of particles. Also, the use of the diagonal camera in very shallow water would be beneficial. Although this camera does not have laser pointers to provide a reference size, it can offer an indication of what is present when nothing can be distinguished from the vertical camera.



Figure 12. Picture of blurred substrate #1. Arrows indicate just a few of the possible particles that may appear to be in a group of fines.



Figure 13. Picture of blurred substrate #2. Actual particle is outlined in red.

Chapter 5: CONCLUSIONS

Three methods of obtaining substrate data were performed on a section of Abrams Creek in the Great Smoky Mountains National Park in Tennessee, USA. The methods consisted of performing pebble counts and digitally capturing substrate with the use of an underwater video mapping system as well as using a frame measurement as a control. Stream sampling of surface bed material can be extremely demanding of time and resources. Using the Underwater Video Mapping System (UVMS) provides benefits not attainable through traditional surface substrate sampling techniques. Advantages of this method include less field time, minimal streambed disturbance, convenience of post-field processing, and digitally stored data that can be geo-referenced for use in GIS. Primary objectives for this research focused on determining the reliability of a video mapping system to accurately assess stream channel substrate. Hypotheses stated that measurements of particle size, diameter size class, and percent distribution would not differ in their means at $\alpha=0.15$ among video, pebble count, and frame methods. Differences were expected to be present, but to what degree and to where they would show themselves were unknown.

All three pebble count runs (i.e., thalweg, proportional, and zig-zag) compared well to the frame method with the variables particle size, percent distribution, and diameter size class. This is not surprising since these methods of collecting substrate data have been extensively studied and proven accurate. No significant differences were identified between the pebble count methods and the frame control for the variable particle size. For diameter size class variables, pebble count proportional (PCP) data produced a larger D_{50} than the frame, and pebble count zig-zag (PCZ) data produced a larger D_5 than the frame. For percent distribution in the visual estimation scale, PCP had higher percentages of large boulder than the frame, and PCZ had lower percentages of fines than the frame. For percent distribution in the Wentworth scale (with bedrock replacements), PCZ had higher percentages of gravel than the frame. The thalweg method was not significantly different than the frame control for any of the variables, but its p-values were often lower than those of PCP and PCZ when all the methods were statistically similar to the frame. When examining the methods by time expenditure, the thalweg and zig-zag data took approximately half as long to gather than the proportional method. The zig-zag method was method hypothesized to give a more accurate measurement since all areas of the stream were being sampled, but the thalweg showed less significant differences. More research needs to be performed in order to determine why the thalweg method appeared to be slightly better.

When measuring particles on a computer monitor from the video methods, data analyzed based on a time interval proved to be the most significantly different for all variables being compared. More small gravel was measured than what was actually present according to the frame control, so a fining of the streambed would be incorrectly interpreted if using this video measurement data for substrate determination. Video reviewed using the distance interval had the same number of significant differences as the video reviewed using the time interval. However, the p-values were generally larger for

video distance data, which may allow them to not be significantly different if a lower alpha value were used.

When visually estimating percent distribution of particles from the videos, there was a considerable increase in the amount of cobble that was recorded. This could be attributed to visibility issues and possibly observer bias. The best method of retrieving data from the video is difficult to determine because the visual estimation method and time/distance step methods can only be compared with the percent distribution variable. All three of these methods had significantly different percentages than the frame method, but the visual estimation method had half as many significant differences as the video time and distance methods. One must also factor in the other aspect of measurement, which is time. Video time and distance analysis took approximately eight times longer to review than did the visual estimation method. Although visual estimation loses the ability to determine particle sizes and diameter size classes, it proves to be the best of the three retrieval methods used for this study and its objectives. Multiple reviewers/reviews of data should be conducted when using visual estimation methods, and stream reaches with different substrate distributions should be studied to increase the confidence of this video method.

When trying to gauge the best kayak float pattern (i.e., thalweg, proportional, and zig-zag) used to collect video data, the visual estimation method was used. For the variable percent distribution, all three float patterns had significant differences, but the VET run showed significant differences more often. The proportional and zig-zag float patterns had significant differences for both fines and cobble. However, it must be noted that the proportional video pattern was a combination of the along-the-bank run and the thalweg run. The travel time from the end of a study reach back to the stream entry point would severely increase the overall proportional time. The zig-zag float pattern takes longer to perform than the thalweg pattern, but it provides better representations of the entire streambed.

In comparison to pebble counts and frame measurements, underwater video mapping proved to be a much quicker method for obtaining substrate data for long stream reaches when performing visual estimation for post processing. The UVMS may function as a suitable reconnaissance for determining possible aquatic habitat, thus providing location data for more accurate measurements to be made. In this way, a starting point can be acquired for more biologically centered research such as the reintroduction or study of threatened and endangered aquatic species. The UVMS could also serve as a monitoring protocol if one wishes to document the substantial changes that can be associated with land management activities or high flow events within a watershed. Even if incorrect substrate distributions are originally assigned to a stream section, changes in dominant substrate and their locations should theoretically be detected after such a substantial change occurs.

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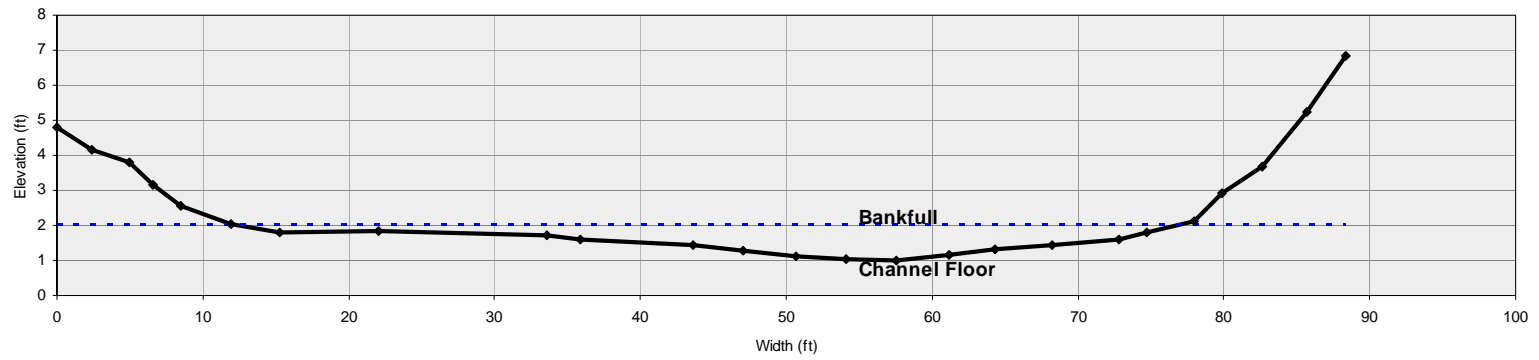
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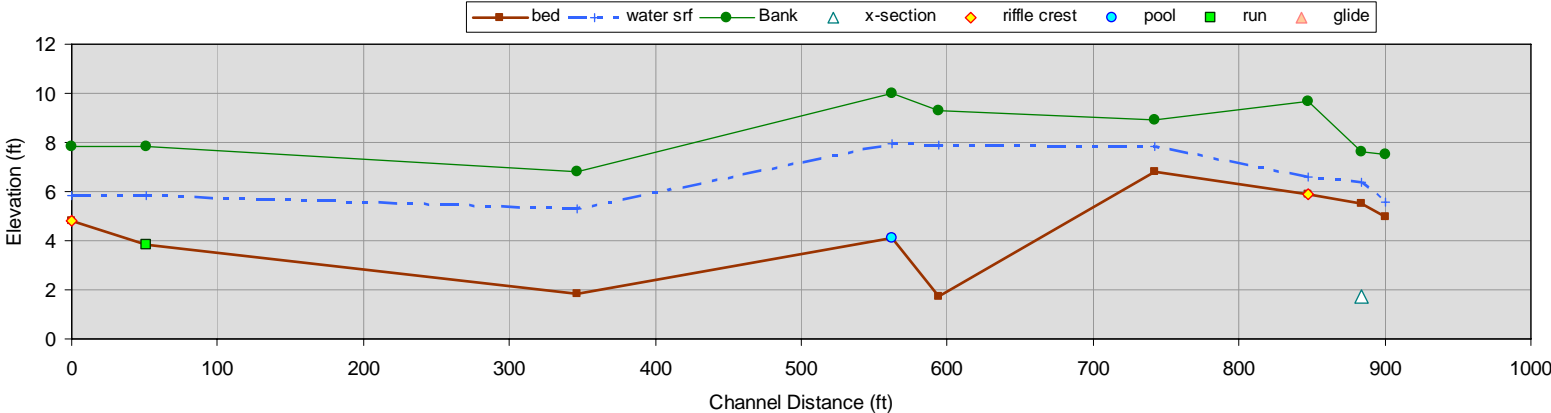
Appendices

Appendix A

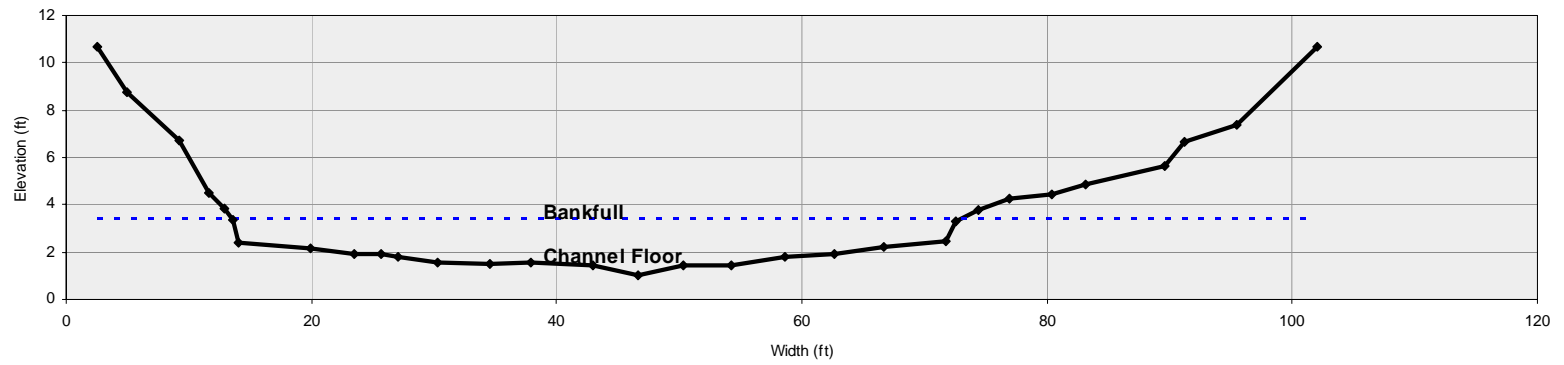
Camp Reach Riffle Cross-Section - Abrams Creek GSMNP, TN 2007



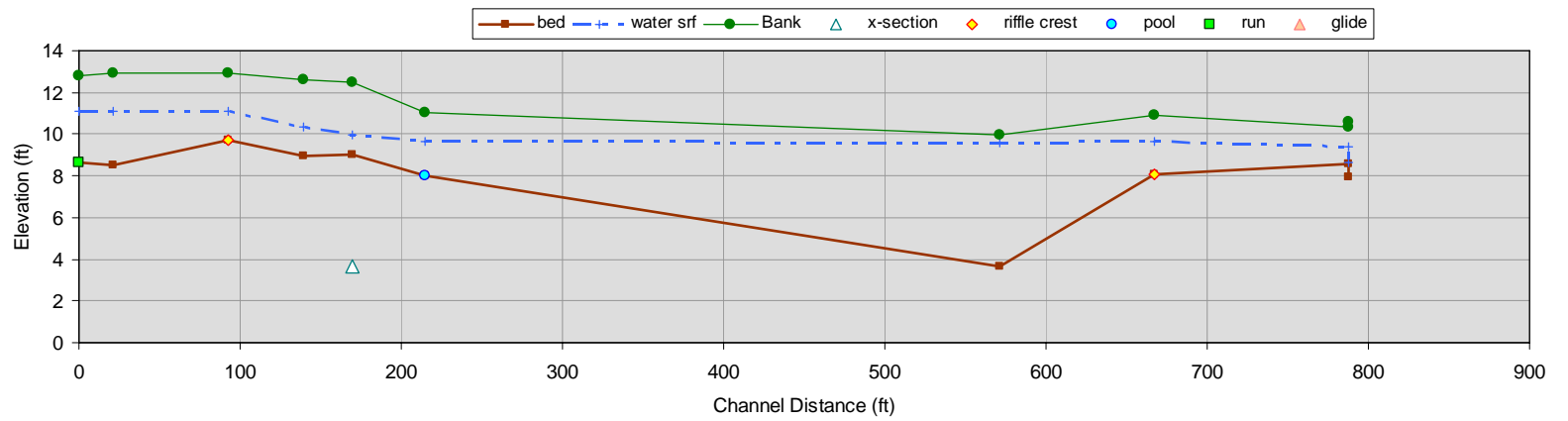
Camp Reach Longitudinal Profile - Abrams Creek GSMNP, TN 2007



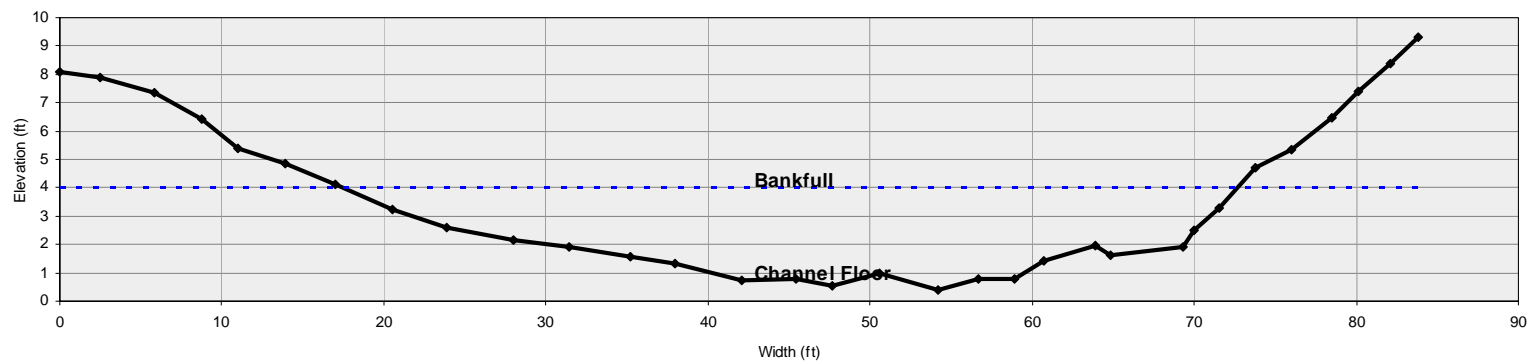
Station Reach Riffle Cross-Section - Abrams Creek GSMNP, TN 2007



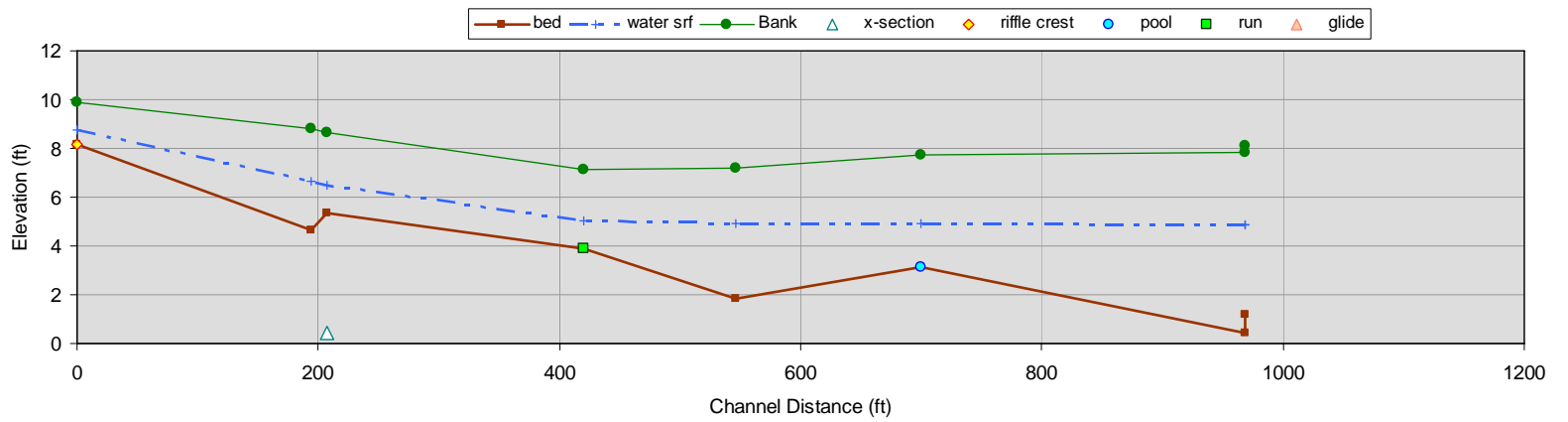
Station Reach Longitudinal Profile - Abrams Creek GSMNP, TN 2007



Bridge Reach Riffle Cross-Section - Abrams Creek GSMNP, TN 2007



Bridge Reach Longitudinal Profile - Abrams Creek GSMNP, TN 2007



Appendix B

Video Mapping Data for the Time Step Series

Descriptive Statistics	Proportional Method	Zig-Zag Method	Thalweg Method	Frames Method
Camp Reach				
Count (n)	100	100	100	NA
Minimum (mm)	1	1	1	NA
Maximum (mm)	660	214	660	NA
Range	559	213	559	NA
Mean	65.43	47.23	63.63	NA
Median	35.50	24.00	40.00	NA
Standard Deviation (SD)	87.83	54.48	90.15	NA
Variance	7714.89	2967.88	8127.08	NA
Skewness	3.54	1.37	3.67	NA
Log Base 2 Mean (L2M)	4.59	4.26	4.60	NA
Back-transformed L2M	24.16	19.20	24.24	NA
Log Base 2 SD	2.38	2.24	5.27	NA
Station Reach				
Count (n)	100	100	100	NA
Minimum (mm)	1	2	2	NA
Maximum (mm)	350	298	380	NA
Range	349	296	378	NA
Mean	68.56	49.21	54.77	NA
Median	46.00	31.50	25.50	NA
Standard Deviation	71.73	53.70	68.11	NA
Variance	5145.28	2883.16	4639.45	NA
Skewness	1.25	1.67	1.78	NA
Log Base 2 Mean (L2M)	4.79	4.49	4.29	NA
Back-transformed L2M	27.73	22.50	19.50	NA
Log Base 2 SD	2.34	2.07	2.33	NA
Bridge Reach				
Count (n)	100	100	100	NA
Minimum (mm)	1	1	1	NA
Maximum (mm)	233	179	203	NA
Range	232	178	202	NA
Mean	47.50	46.80	41.10	NA
Median	17.00	25.50	7.00	NA
Standard Deviation	57.97	51.65	53.22	NA
Variance	3361.08	2667.43	2832.37	NA
Skewness	1.35	1.06	1.39	NA
Log Base 2 Mean (L2M)	4.12	4.28	3.79	NA
Back-transformed L2M	17.44	19.47	13.83	NA
Log Base 2 SD	2.27	2.19	2.31	NA

Number of Counts And Time	Proportional Method	Zig-Zag Method	Thalweg Method	Frames Method
Camp Reach				
Possible Bedrock	2	1	1	NA
Visibility Replacements	25	36	29	NA
Muck	0	4	0	NA
# of Embedded Particles	NA	NA	NA	NA
Sample Time (Minutes)	203	215	394	NA
Kayak Float Time	14.28	16.55	6.65	NA
Station Reach				
Possible Bedrock	3	1	1	NA
Visibility Replacements	39	38	23	NA
Muck	0	0	0	NA
# of Embedded Particles	NA	NA	NA	NA
Sample Time (Minutes)	250	235	256	NA
Kayak Float Time	14.93	20.87	6.18	NA
Bridge Reach				
Possible Bedrock	8	3	17	NA
Visibility Replacements	43	50	39	NA
Muck	0	3	0	NA
# of Embedded Particles	NA	NA	NA	NA
Sample Time (Minutes)	147	187	266	NA
Kayak Float Time	17.33	19.87	7.58	NA

Diameter Class (mm)	Proportional Method	Zig-Zag Method	Thalweg Method	Frames Method
Camp Reach				
Size at D ₅	1.5	1.3	1.8	NA
Size at D ₁₆	2.5	2.4	2.6	NA
Size at D ₃₅	9.4	8	12	NA
Size at D ₅₀	34	23	35	NA
Size at D ₆₅	73	49	64	NA
Size at D ₈₄	130	100	120	NA
Size at D ₉₅	210	170	210	NA
Station Reach				
Size at D ₅	1.6	1.6	1.5	NA
Size at D ₁₆	2.7	3	2.5	NA
Size at D ₃₅	10	11	4.8	NA
Size at D ₅₀	45	32	22	NA
Size at D ₆₅	93	54	54	NA
Size at D ₈₄	130	100	120	NA
Size at D ₉₅	210	160	170	NA
Bridge Reach				
Size at D ₅	1.5	1.5	1.3	NA
Size at D ₁₆	2.5	2.7	2.1	NA
Size at D ₃₅	4.5	6.6	3.4	NA
Size at D ₅₀	16	25	6.4	NA
Size at D ₆₅	51	45	45	NA
Size at D ₈₄	110	110	90	NA
Size at D ₉₅	170	160	160	NA

Substrate Percent Distribution	Proportional Method	Zig-Zag Method	Thalweg Method	Frames Method
Camp Reach				
Percent Sand /Fines	8	12	6	NA
Percent Small Gravel	27	24	27	NA
Percent Large Gravel	45	49	48	NA
Percent Cobble	19	15	17	NA
Percent Small Boulder	0	0	1	NA
Percent Large Boulder	1	0	1	NA
Percent Bedrock	0	0	0	NA
Station Reach				
Percent Sand /Fines	7	7	9	NA
Percent Small Gravel	28	27	37	NA
Percent Large Gravel	30	49	30	NA
Percent Cobble	34	17	23	NA
Percent Small Boulder	1	0	1	NA
Percent Large Boulder	0	0	0	NA
Percent Bedrock	0	0	0	NA
Bridge Reach				
Percent Sand /Fines	8	9	14	NA
Percent Small Gravel	38	30	40	NA
Percent Large Gravel	35	42	30	NA
Percent Cobble	19	19	16	NA
Percent Small Boulder	0	0	0	NA
Percent Large Boulder	0	0	0	NA
Percent Bedrock	0	0	0	NA

Video Mapping Data for the Distance Step Series

Descriptive Statistics	Proportional Method	Zig-Zag Method	Thalweg Method	Frames Method
Camp Reach				
Count (n)	100	100	100	NA
Minimum (mm)	1	1	1	NA
Maximum (mm)	340	211	340	NA
Range	339	210	339	NA
Mean	63.67	59.30	58.58	NA
Median	41.50	38.00	42.50	NA
Standard Deviation (SD)	69.66	60.87	61.88	NA
Variance	4852.71	3704.92	3829.40	NA
Skewness	1.34	1.11	1.62	NA
Log Base 2 Mean (L2M)	4.58	4.83	4.69	NA
Back-transformed L2M	23.98	28.37	25.89	NA
Log Base 2 SD	2.43	2.05	2.22	NA
Station Reach				
Count (n)	100	100	100	NA
Minimum (mm)	2	1	2	NA
Maximum (mm)	444	416	369	NA
Range	442	415	367	NA
Mean	82.38	61.14	64.60	NA
Median	63.50	42.50	43.50	NA
Standard Deviation	84.20	65.32	64.06	NA
Variance	7090.40	4267.33	4104.12	NA
Skewness	1.89	2.08	1.60	NA
Log Base 2 Mean (L2M)	5.32	4.82	5.04	NA
Back-transformed L2M	39.97	28.18	32.86	NA
Log Base 2 SD	2.12	2.18	1.98	NA
Bridge Reach				
Count (n)	100	100	100	NA
Minimum (mm)	2	2	2	NA
Maximum (mm)	271	233	308	NA
Range	269	231	306	NA
Mean	63.74	63.26	53.81	NA
Median	46.00	51.50	30.50	NA
Standard Deviation	64.60	58.23	61.52	NA
Variance	4172.68	3390.15	3785.06	NA
Skewness	1.25	0.70	1.80	NA
Log Base 2 Mean (L2M)	4.95	4.91	4.63	NA
Back-transformed L2M	30.86	30.00	24.78	NA
Log Base 2 SD	2.03	2.14	2.04	NA

Number of Counts And Time	Proportional Method	Zig-Zag Method	Thalweg Method	Frames Method
Camp Reach				
Possible Bedrock	2	0	2	NA
Visibility Replacements	38	32	31	NA
Muck	0	3	0	NA
# of Embedded Particles	NA	NA	NA	NA
Sample Time (Minutes)	135	190	132	NA
Kayak Float Time	14.28	16.55	6.65	NA
Station Reach				
Possible Bedrock	2	5	1	NA
Visibility Replacements	40	50	30	NA
Muck	0	1	0	NA
# of Embedded Particles	NA	NA	NA	NA
Sample Time (Minutes)	165	190	180	NA
Kayak Float Time	14.93	20.87	6.18	NA
Bridge Reach				
Possible Bedrock	4	1	4	NA
Visibility Replacements	48	49	45	NA
Muck	0	5	0	NA
# of Embedded Particles	NA	NA	NA	NA
Sample Time (Minutes)	180	165	210	NA
Kayak Float Time	17.33	19.87	7.58	NA

Diameter Class (mm)	Proportional Method	Zig-Zag Method	Thalweg Method	Frames Method
Camp Reach				
Size at D ₅	1.4	1.6	1.6	NA
Size at D ₁₆	2.4	4	2.9	NA
Size at D ₃₅	8	18	19	NA
Size at D ₅₀	40	36	42	NA
Size at D ₆₅	76	62	67	NA
Size at D ₈₄	130	130	110	NA
Size at D ₉₅	210	210	180	NA
Station Reach				
Size at D ₅	2	1.5	2.3	NA
Size at D ₁₆	4.7	3.5	3.8	NA
Size at D ₃₅	34	19	27	NA
Size at D ₅₀	60	43	44	NA
Size at D ₆₅	99	64	67	NA
Size at D ₈₄	150	120	130	NA
Size at D ₉₅	220	170	170	NA
Bridge Reach				
Size at D ₅	2.2	1.6	1.6	NA
Size at D ₁₆	4.2	3.5	3.4	NA
Size at D ₃₅	22	17	14	NA
Size at D ₅₀	45	51	31	NA
Size at D ₆₅	71	85	56	NA
Size at D ₈₄	130	120	100	NA
Size at D ₉₅	210	170	200	NA

Substrate Percent Distribution	Proportional Method	Zig-Zag Method	Thalweg Method	Frames Method
Camp Reach				
Percent Sand /Fines	10	7	7	NA
Percent Small Gravel	25	18	24	NA
Percent Large Gravel	38	55	50	NA
Percent Cobble	26	20	18	NA
Percent Small Boulder	1	0	1	NA
Percent Large Boulder	0	0	0	NA
Percent Bedrock	0	0	0	NA
Station Reach				
Percent Sand /Fines	5	8	2	NA
Percent Small Gravel	19	20	25	NA
Percent Large Gravel	43	53	46	NA
Percent Cobble	30	18	26	NA
Percent Small Boulder	3	1	1	NA
Percent Large Boulder	0	0	0	NA
Percent Bedrock	0	0	0	NA
Bridge Reach				
Percent Sand /Fines	3	7	7	NA
Percent Small Gravel	25	20	25	NA
Percent Large Gravel	50	47	52	NA
Percent Cobble	22	26	15	NA
Percent Small Boulder	0	0	1	NA
Percent Large Boulder	0	0	0	NA
Percent Bedrock	0	0	0	NA

Pebble Count Data

Descriptive Statistics (w/o bedrock replacements)	Proportional Method	Zig-Zag Method	Thalweg Method	Frames Method
Camp Reach				
Count (n)	96	98	100	417
Minimum (mm)	1	1	1	1
Maximum (mm)	2105	267	555	633
Range	2104	266	554	632
Mean	111.22	74.85	84.71	77.74
Median	68	60.5	61.5	59
Standard Deviation (SD)	232.12	61.5	93.15	84.36
Variance	53880.47	3782.21	8676.59	7116.81
Skewness	7.16	0.85	2.80	2.94
Log Base 2 Mean (L2M)	5.61	5.37	5.35	5.20
Back-transformed L2M	48.93	41.26	40.82	36.66
Log Base 2 SD	2.08	2.04	2.25	2.27
Station Reach				
Count (n)	95	91	96	498
Minimum (mm)	1	1	1	1
Maximum (mm)	1780	1830	2550	1185
Range	1779	1829	2549	1184
Mean	167.67	116.46	143.69	116.89
Median	66	56	61	58
Standard Deviation	294.63	223.92	302.08	162.68
Variance	86806.80	50140.01	91250.05	26463.31
Skewness	3.37	5.54	5.94	2.95
Log Base 2 Mean (L2M)	5.58	5.28	5.38	5.31
Back-transformed L2M	47.84	38.98	41.72	39.57
Log Base 2 SD	2.64	2.44	2.64	2.57
Bridge Reach				
Count (n)	74	70	62	464
Minimum (mm)	1	1	1	1
Maximum (mm)	1615	1060	2310	1745
Range	1614	1059	2309	1744
Mean	139.24	156.84	141.16	126.39
Median	70.50	101.00	70.50	65.00
Standard Deviation	294.15	225.84	302.35	200.85
Variance	86522.93	51003.18	91416.73	40339.17
Skewness	3.78	2.80	6.31	3.60
Log Base 2 Mean (L2M)	4.42	5.49	5.57	5.04
Back-transformed L2M	21.39	44.86	47.37	32.99
Log Base 2 SD	3.23	2.42	2.61	2.90

Number of Counts And Time	Proportional Method	Zig-Zag Method	Thalweg Method	Frames Method
Camp Reach				
With Bedrock	100	100	100	420
Bedrock Replacements	4	2	0	3
Muck	12	6	7	32
# of Embedded Particles	0	0	0	2
Sample Time (Minutes)	148	70	70	405
Station Reach				
With Bedrock	100	100	100	540
Bedrock Replacements	5	9	4	42
Muck	1	0	0	0
# of Embedded Particles	0	1	4	10
Sample Time (Minutes)	140	94	68	592
Bridge Reach				
With Bedrock	100	100	100	644
Bedrock Replacements	26	30	0	180
Muck	0	2	0	22
# of Embedded Particles	2	0	0	14
Sample Time (Minutes)	186	103	83	670

Diameter Class	Proportional Method	Zig-Zag Method	Thalweg Method	Frames Method
Camp Reach				
Size at D ₅	1.7	1.8	1.4	1.4
Size at D ₁₆	14	11	12	6.8
Size at D ₃₅	46	38	39	34
Size at D ₅₀	70	59	61	58
Size at D ₆₅	96	89	90	86
Size at D ₈₄	140	140	140	140
Size at D ₉₅	290	180	240	210
Station Reach				
Size at D ₅	1.4	1.4	1.4	1.4
Size at D ₁₆	5.6	5.8	5.5	6.4
Size at D ₃₅	32	24	28	28
Size at D ₅₀	66	55	61	59
Size at D ₆₅	120	90	110	100
Size at D ₈₄	270	190	220	220
Size at D ₉₅	800	430	540	430
Bridge Reach				
Size at D ₅	1.1	1.8	1.4	1.2
Size at D ₁₆	1.5	8.2	6.9	1.9
Size at D ₃₅	16	50	47	20
Size at D ₅₀	68	97	77	65
Size at D ₆₅	96	140	120	120
Size at D ₈₄	160	240	180	210
Size at D ₉₅	800	720	420	530

Substrate Percent Distribution	Proportional Method	Zig-Zag Method	Thalweg Method	Frames Method
Camp Reach				
Percent Sand /Fines	6	6	11	10
Percent Small Gravel	6	8	4	7
Percent Large Gravel	52	54	53	52
Percent Cobble	28	30	29	28
Percent Small Boulder	2	0	3	1
Percent Large Boulder	2	0	0	1
Percent Bedrock	4	2	0	1
Station Reach				
Percent Sand /Fines	9	9	11	10
Percent Small Gravel	9	10	12	8
Percent Large Gravel	37	45	35	40
Percent Cobble	27	19	29	25
Percent Small Boulder	5	6	5	8
Percent Large Boulder	8	2	4	1
Percent Bedrock	5	9	4	8
Bridge Reach				
Percent Sand /Fines	21	4	7	12
Percent Small Gravel	2	10	6	9
Percent Large Gravel	26	21	24	22
Percent Cobble	20	26	19	22
Percent Small Boulder	0	5	5	4
Percent Large Boulder	5	4	1	3
Percent Bedrock	26	30	38	28

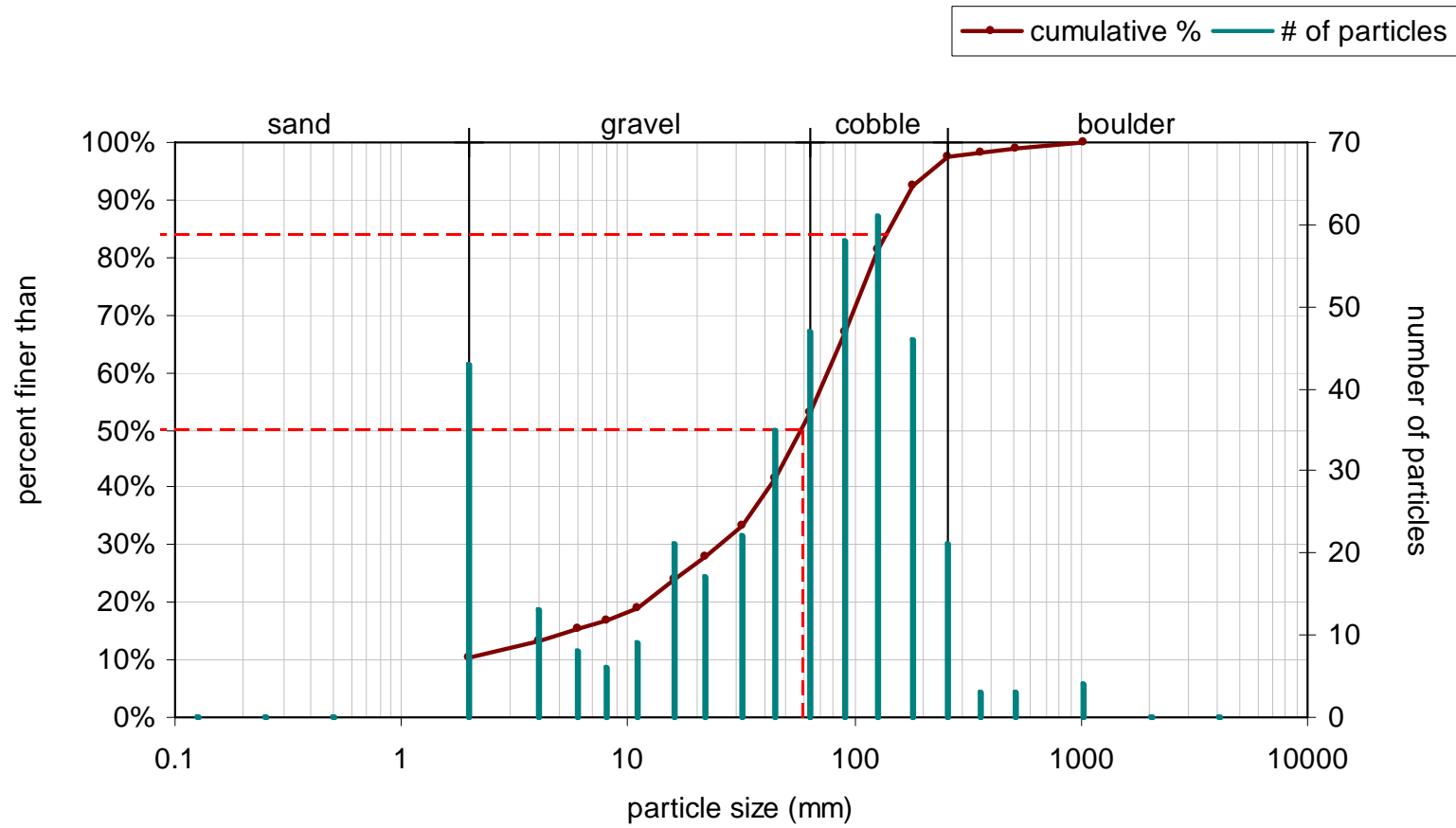
Visual Estimation Data

Substrate Percent Distribution	Proportional Method	Zig-Zag Method	Thalweg Method	Frames Method
Camp Reach				
Percent Sand /Fines	9	7	9	NA
Percent Small Gravel	15	1	0	NA
Percent Large Gravel	31	43	48	NA
Percent Cobble	45	50	43	NA
Percent Small Boulder	0	0	0	NA
Percent Large Boulder	0	0	0	NA
Percent Bedrock	0	0	0	NA
Station Reach				
Percent Sand /Fines	7	3	3	NA
Percent Small Gravel	9	8	0	NA
Percent Large Gravel	39	37	52	NA
Percent Cobble	38	39	45	NA
Percent Small Boulder	3	4	0	NA
Percent Large Boulder	3	4	0	NA
Percent Bedrock	1	5	0	NA
Bridge Reach				
Percent Sand /Fines	7	2	13	NA
Percent Small Gravel	0	4	0	NA
Percent Large Gravel	37	32	37	NA
Percent Cobble	43	37	42	NA
Percent Small Boulder	0	2	0	NA
Percent Large Boulder	7	10	2	NA
Percent Bedrock	6	12	6	NA

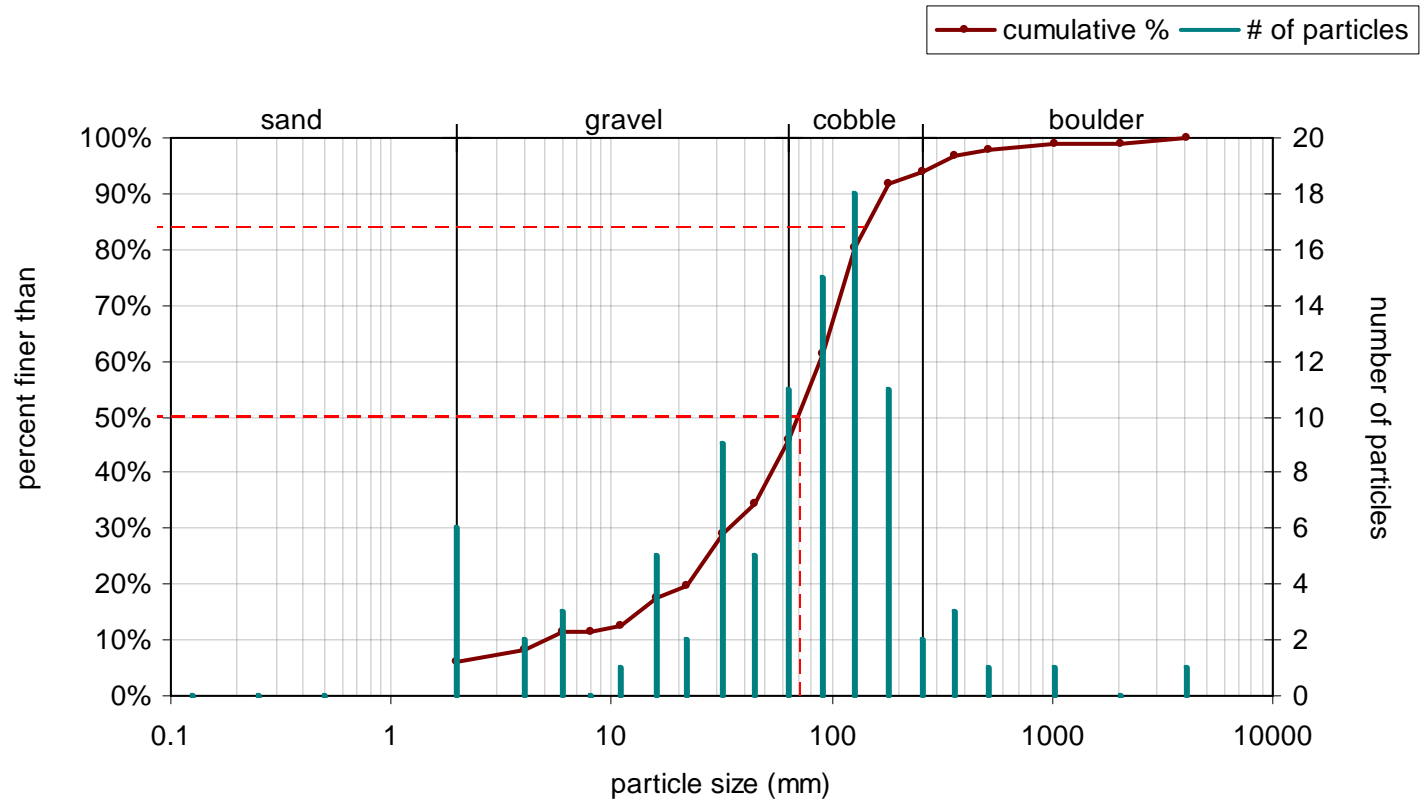
Total Time Used to Perform the Analysis (minutes)	Proportional Method	Zig-Zag Method	Thalweg Method	Frames Method
Camp Reach				
Kayak Float Time	14.28	16.55	6.65	NA
Analysis Time	28.3	33	13.3	NA
Station Reach				
Kayak Float Time	14.93	20.87	6.18	NA
Analysis Time	29.9	42	12.4	NA
Bridge Reach				
Kayak Float Time	17.33	19.87	7.58	NA
Analysis Time	34.7	40	15.2	NA

Appendix C

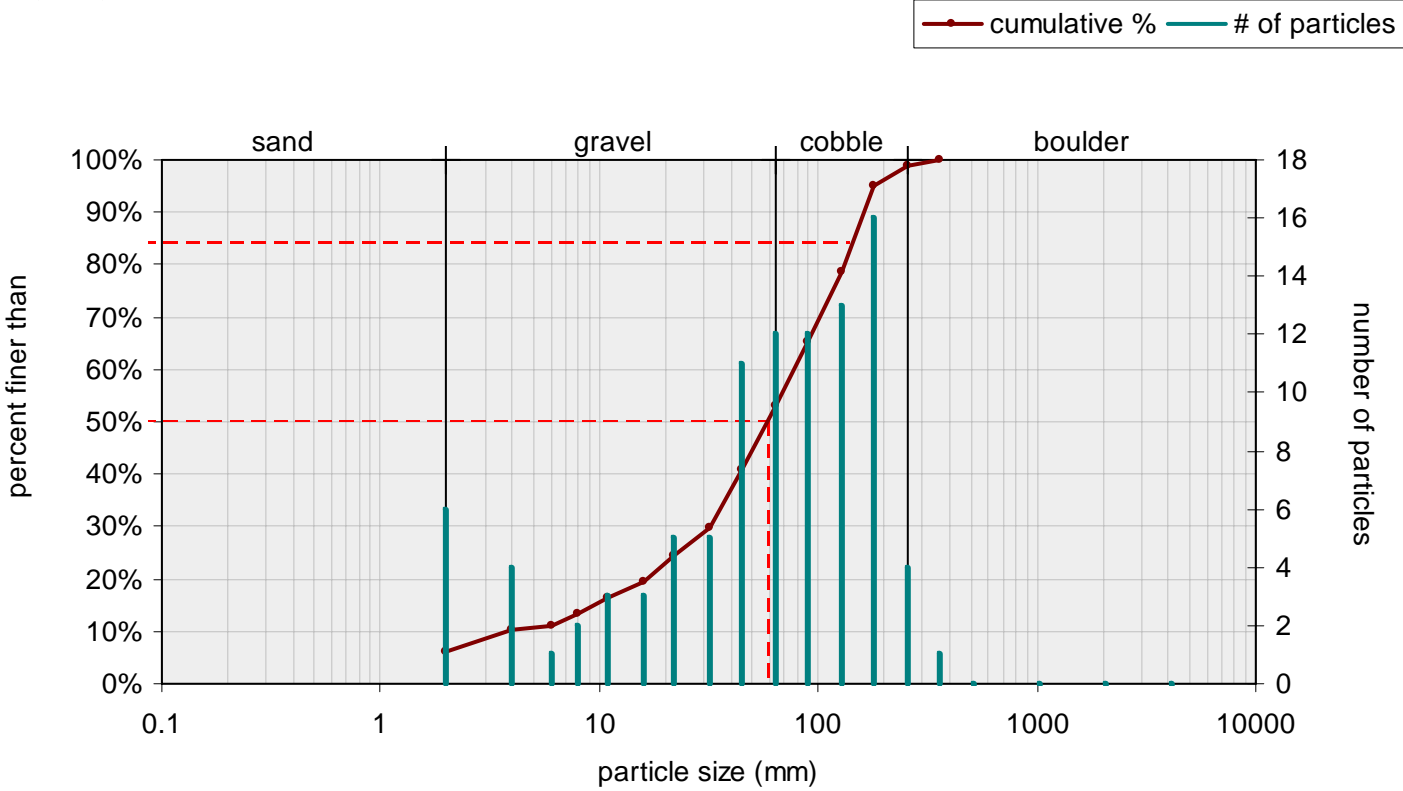
Frames Pebble Count, Camp (Frame) Reach Data



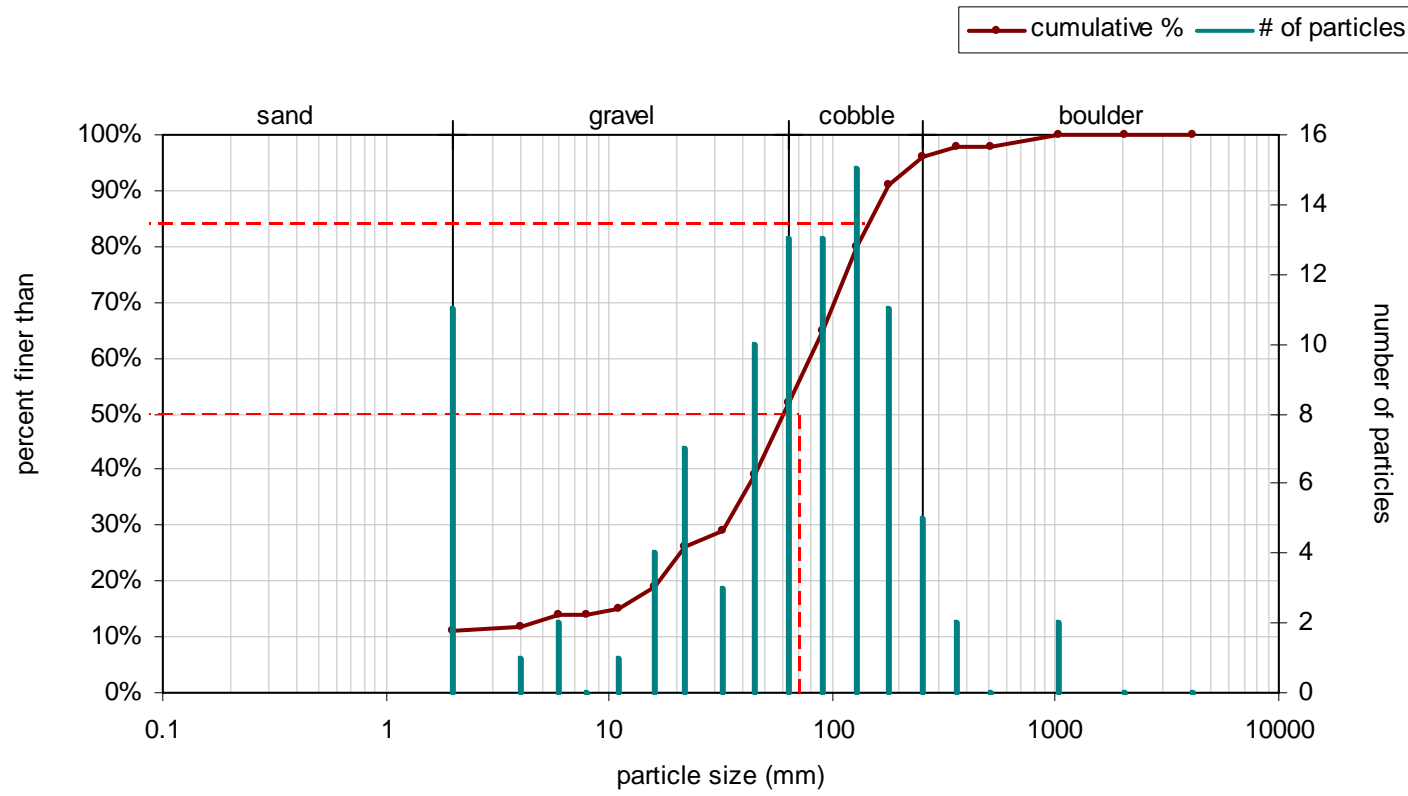
Proportional Pebble Count, Camp Reach Data



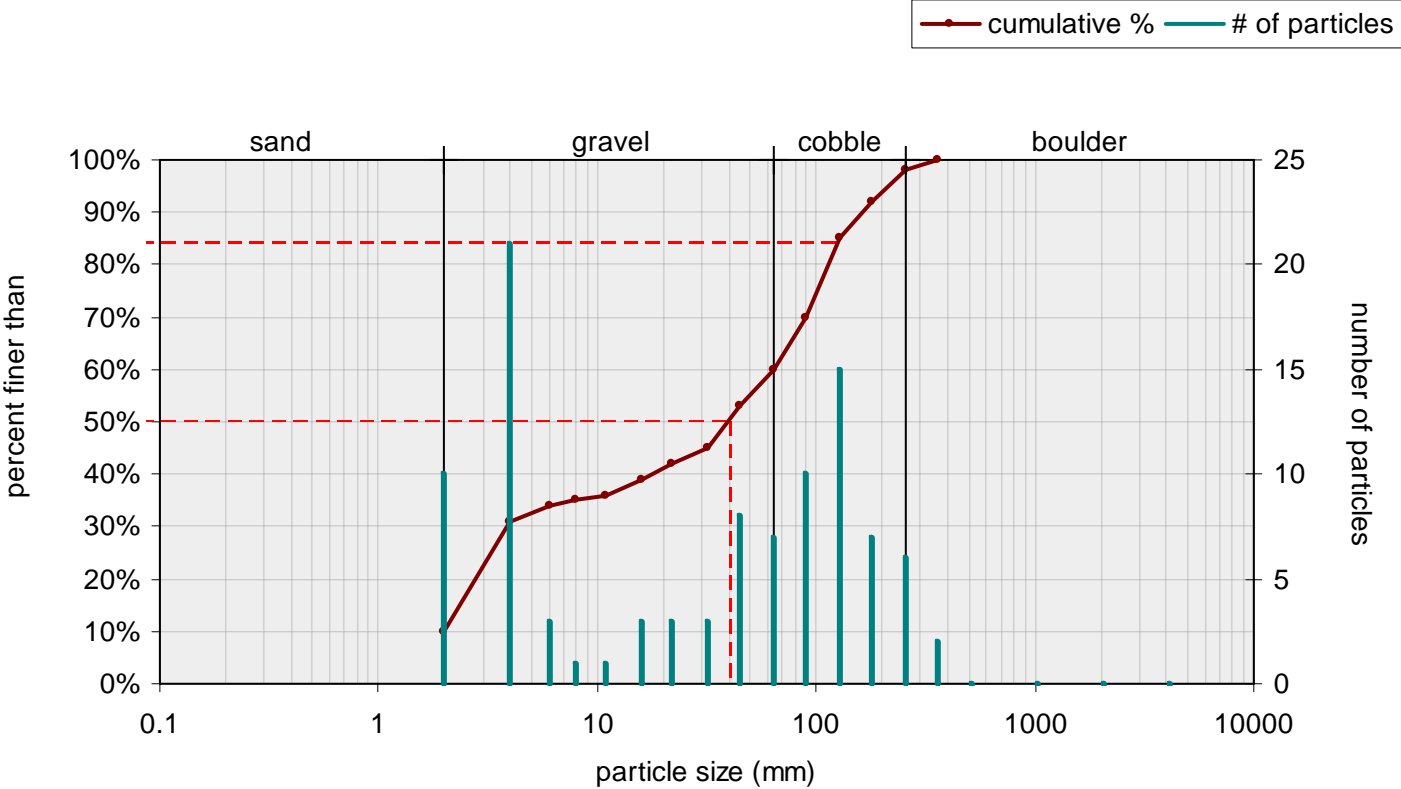
Zig-Zag Pebble Count, Camp Reach Data



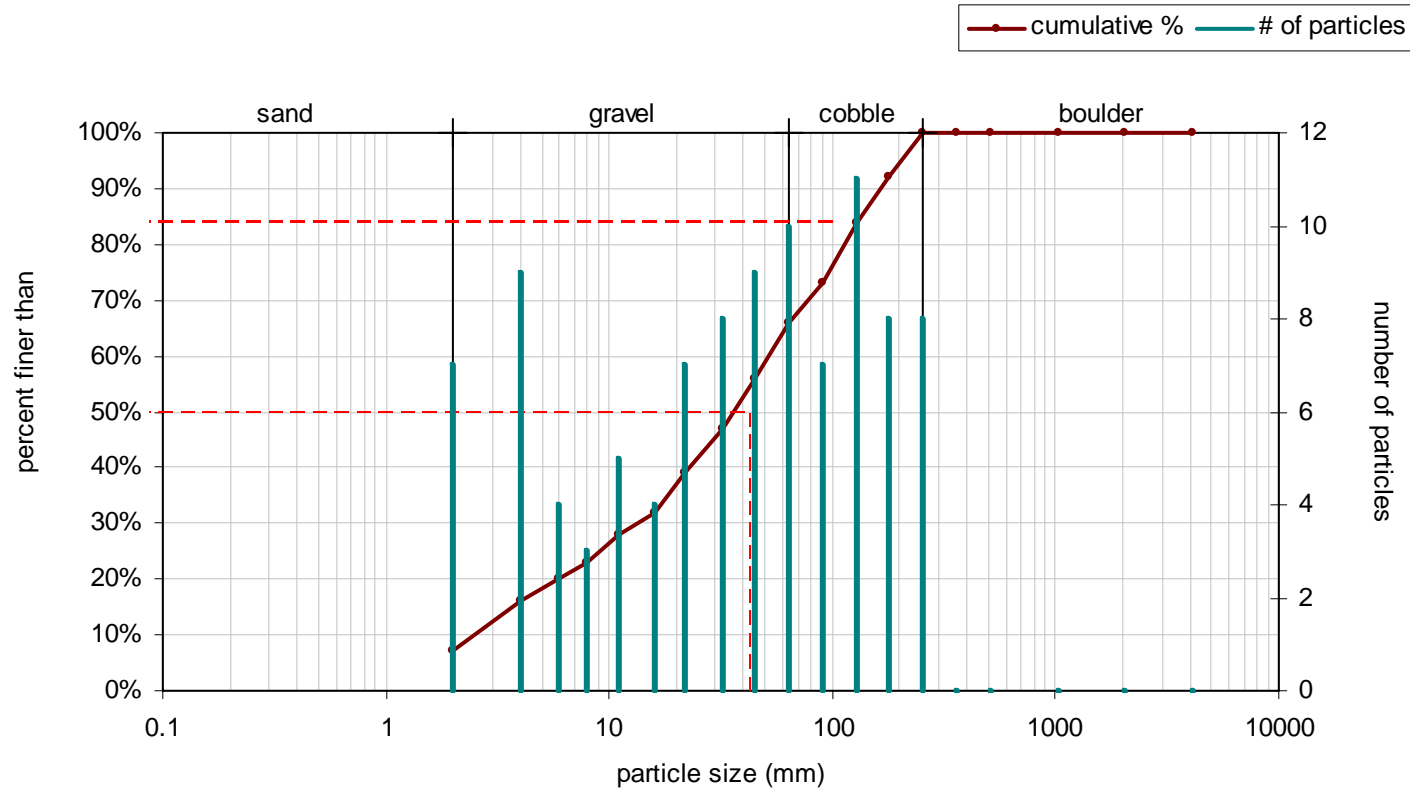
Thalweg Pebble Count, Camp Reach Data



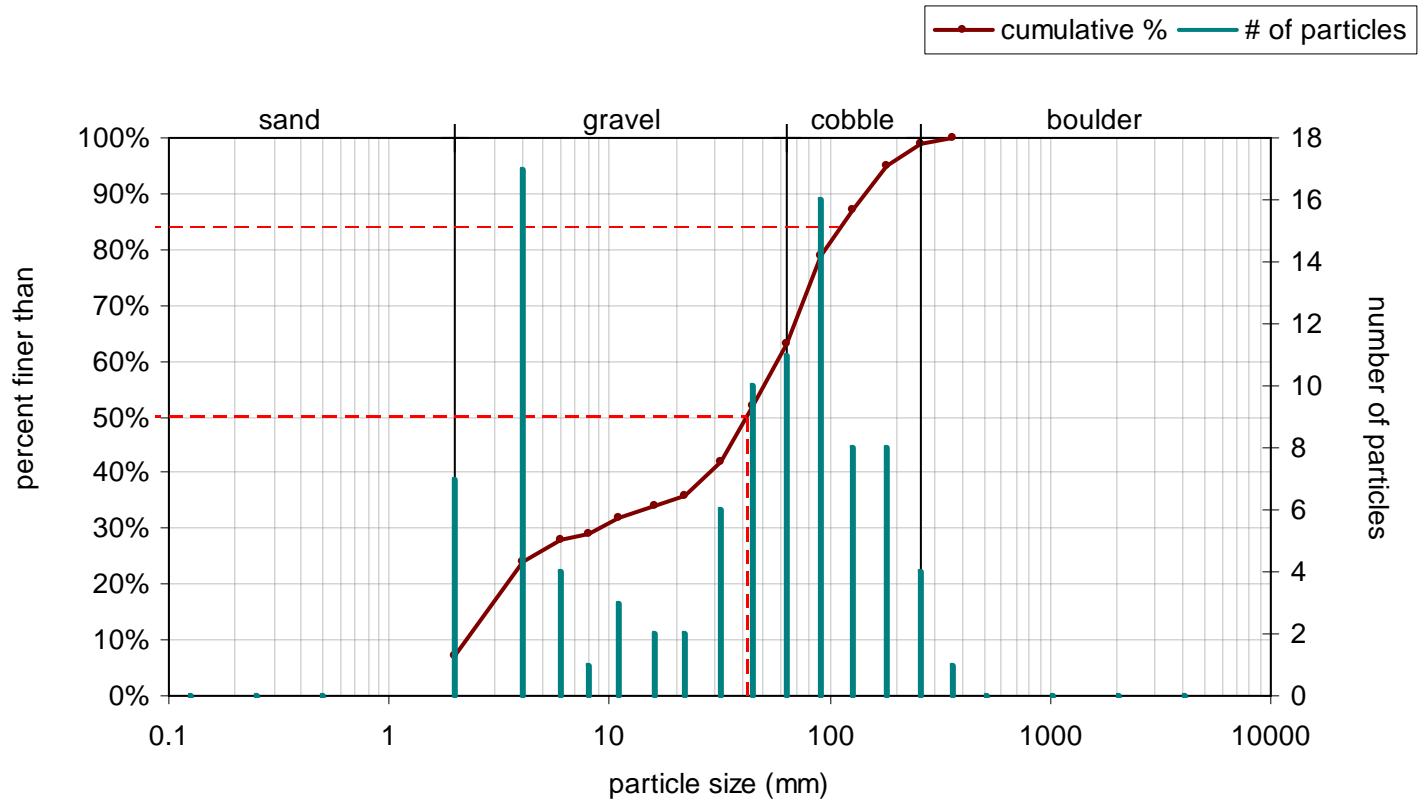
Proportional Video Distance Pebble Count, Camp Reach Data



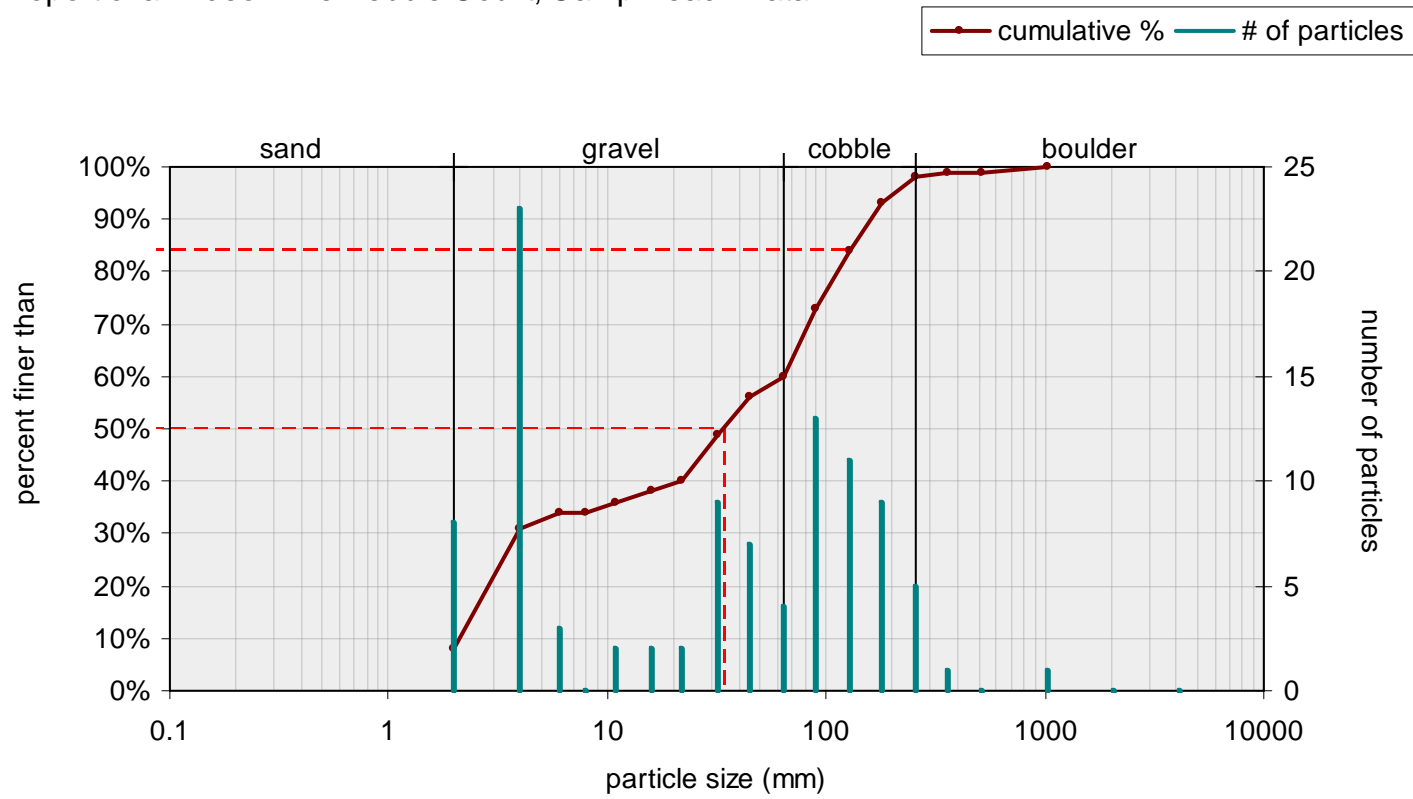
Zig-Zag Video Distance Pebble Count, Camp Reach Data



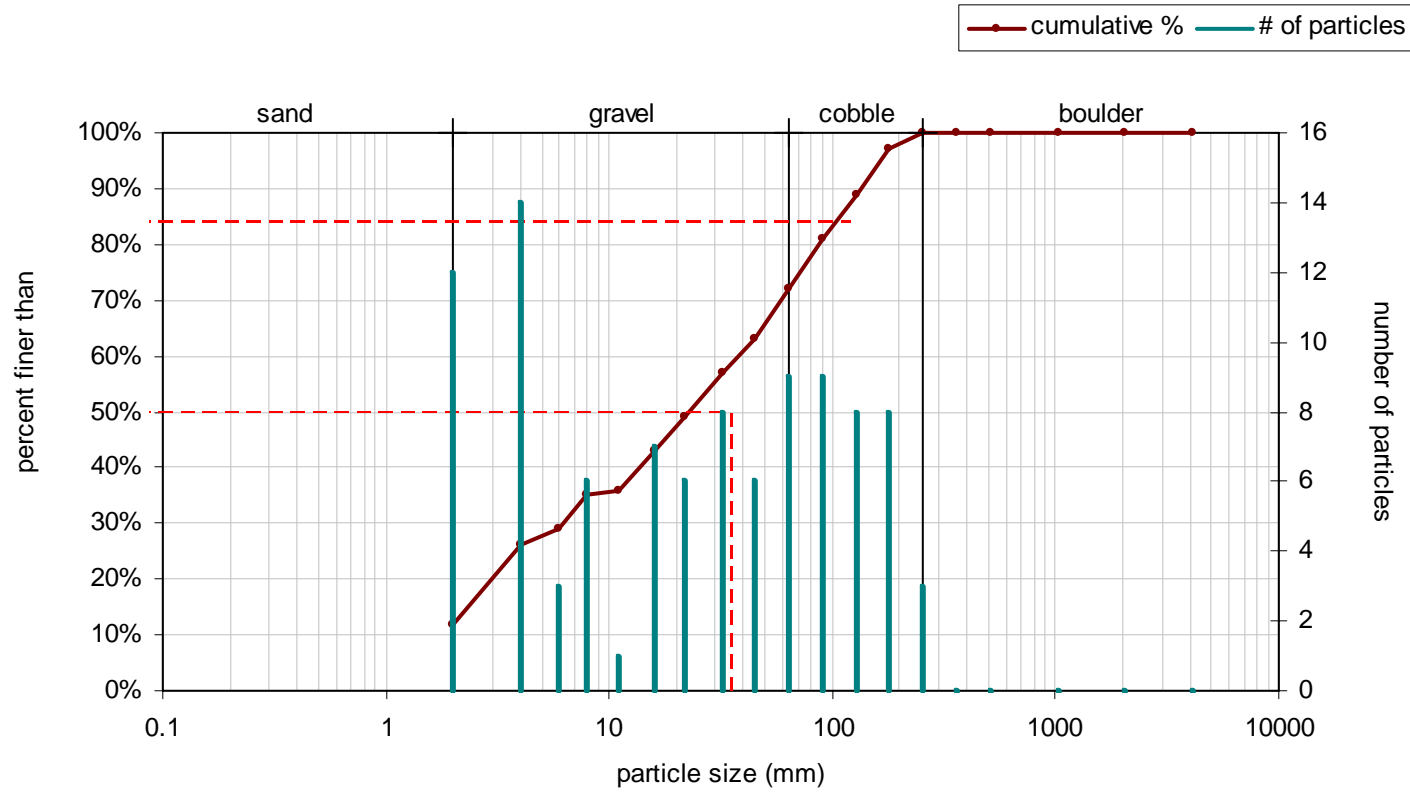
Thalweg Video Distance Pebble Count, Camp Reach Data



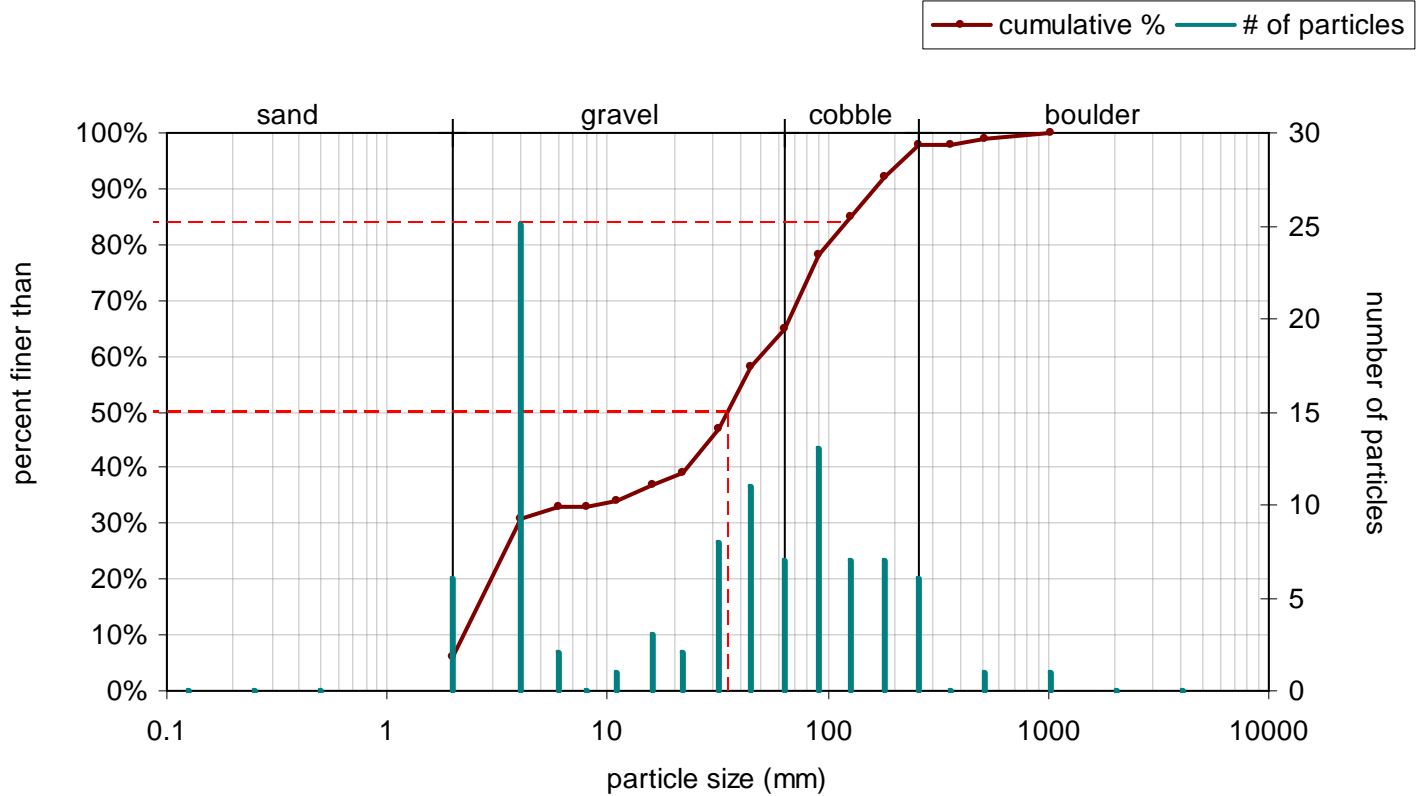
Proportional Video Time Pebble Count, Camp Reach Data



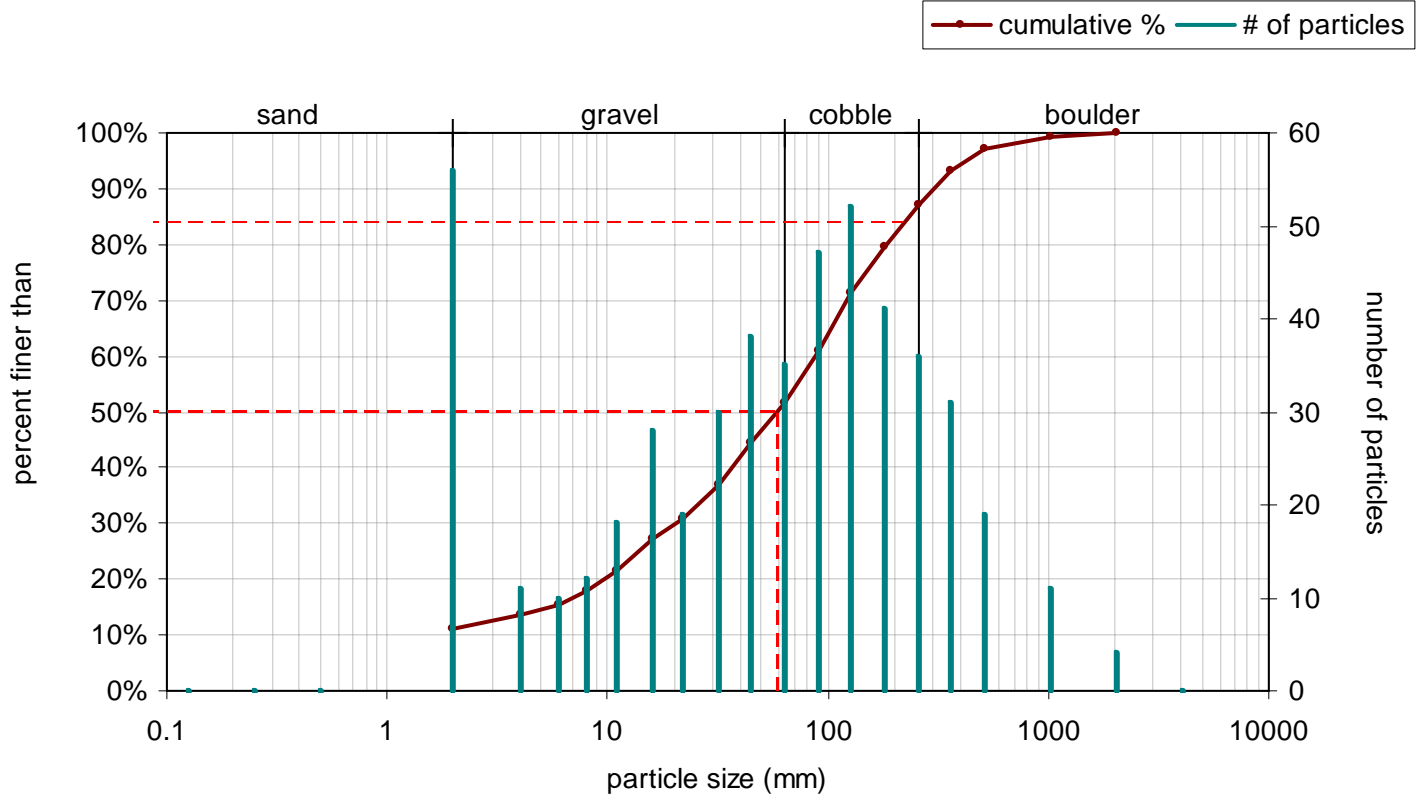
Zig-Zag Video Time Pebble Count, Camp Reach Data



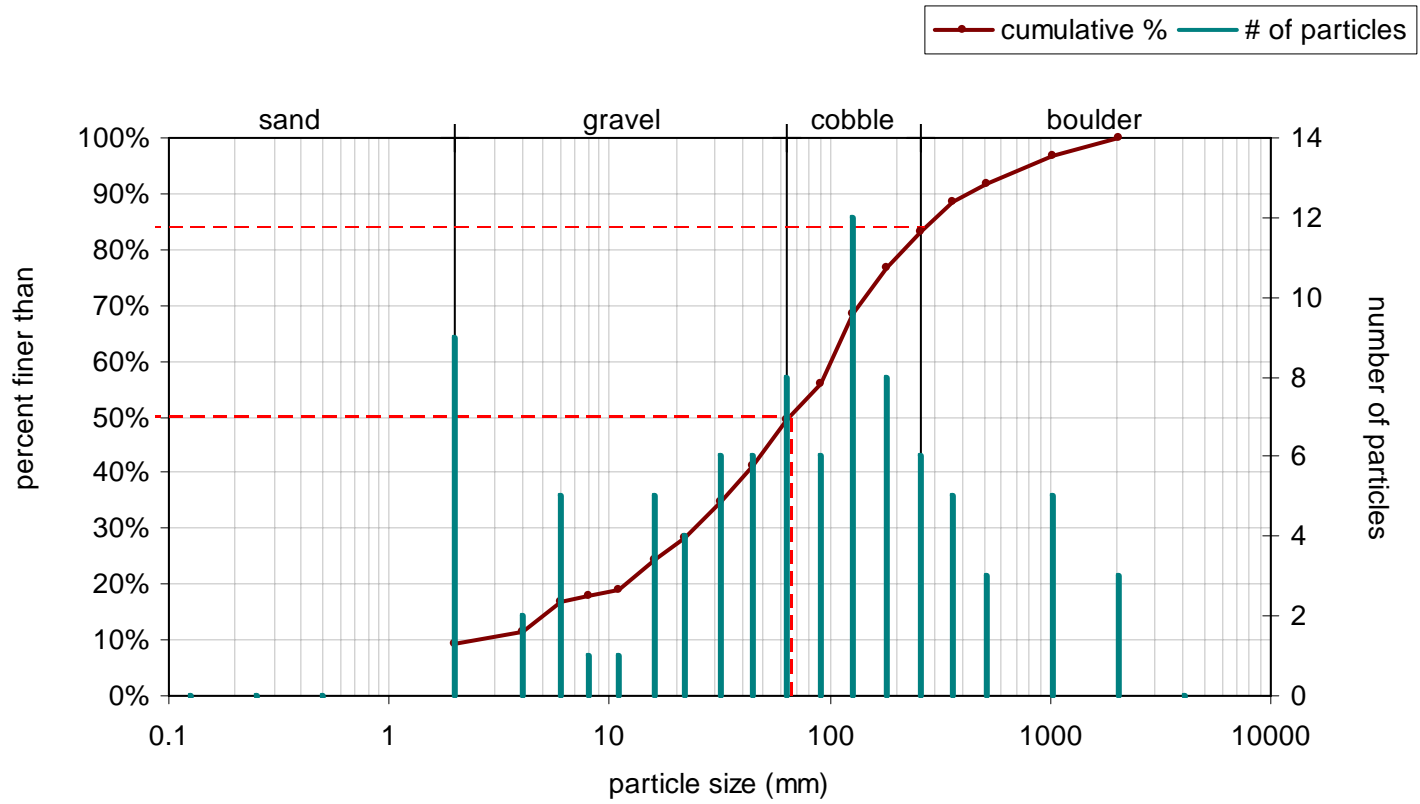
Thalweg Video Time Pebble Count, Camp Reach Data



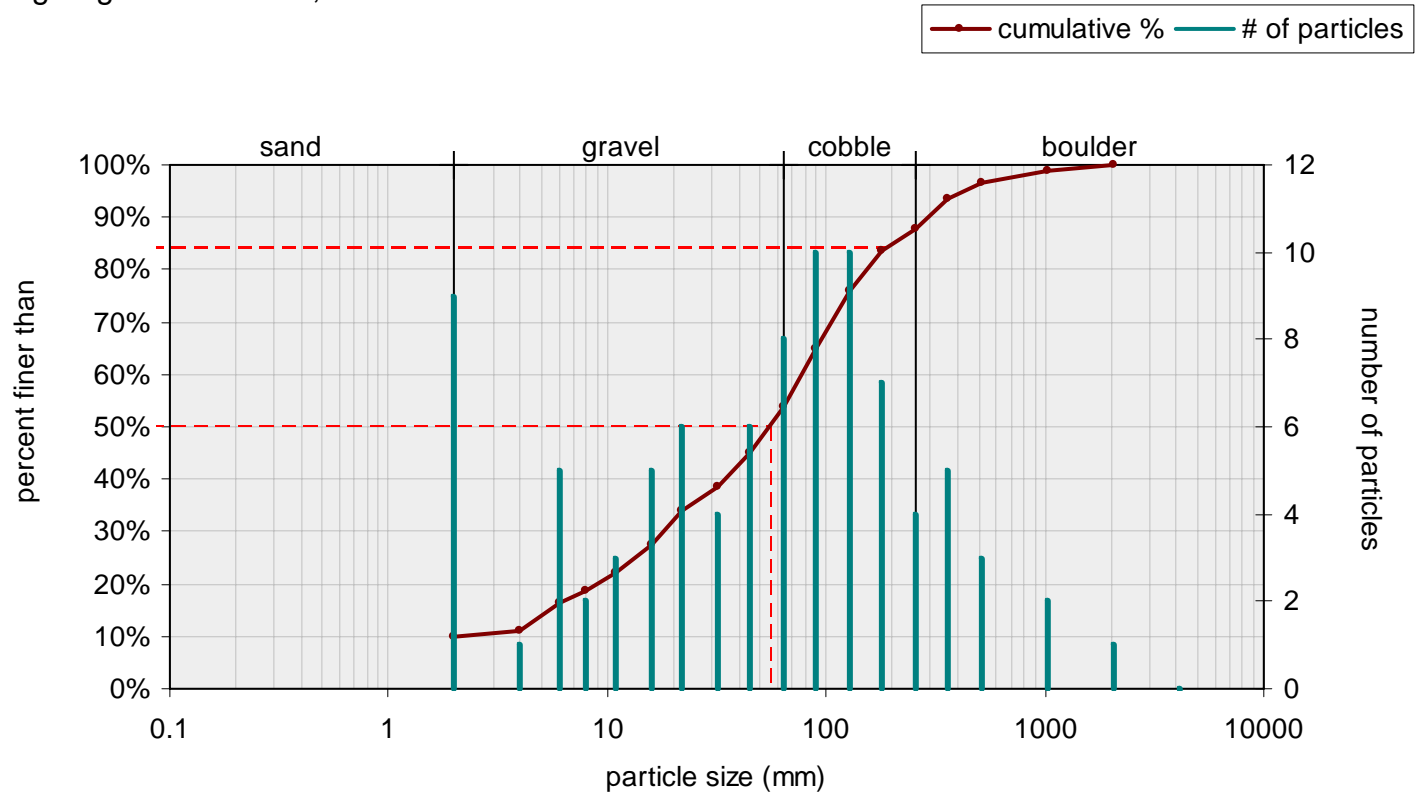
Frames Pebble Count, Station (Frame) Reach Data



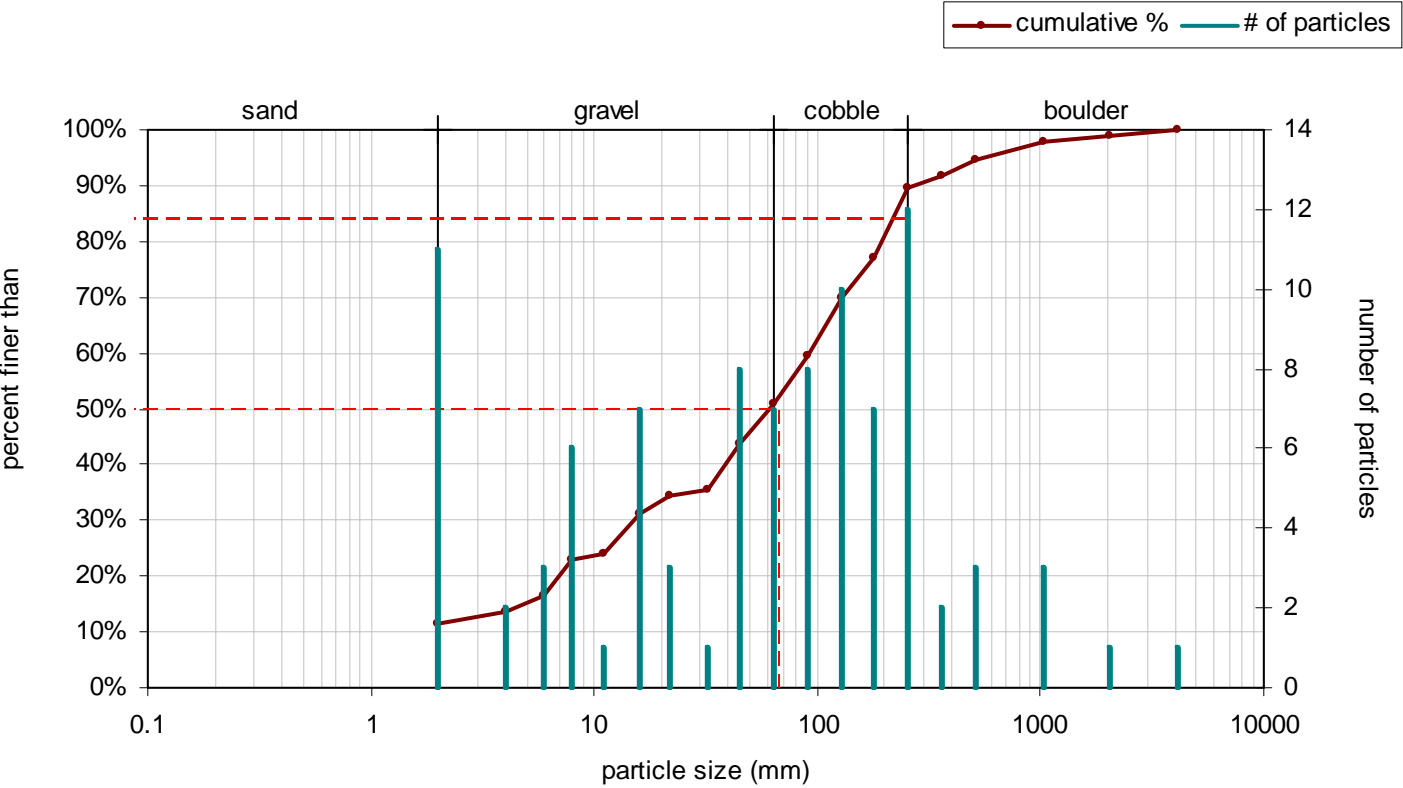
Proportional Pebble Count, Station Reach Data



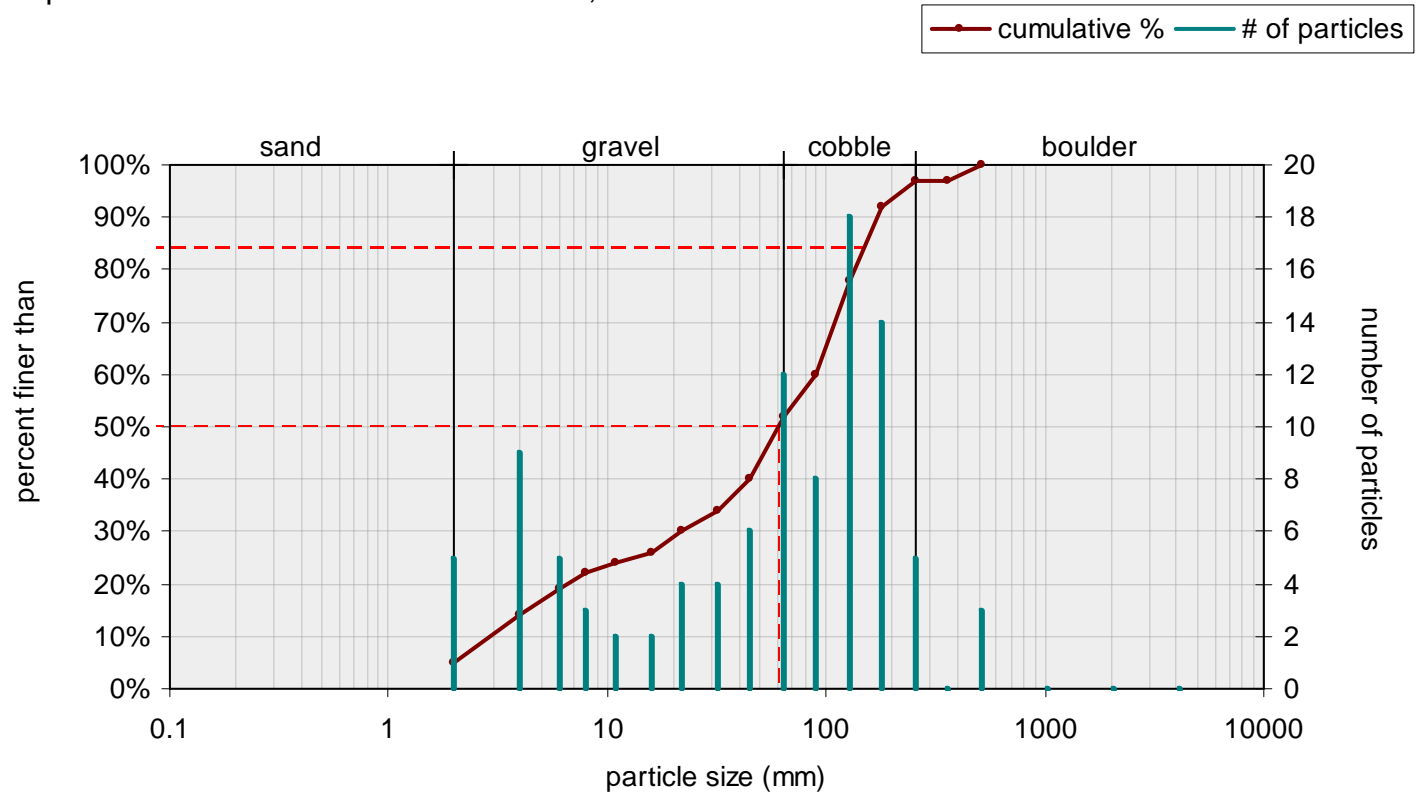
Zig-Zag Pebble Count, Station Reach Data



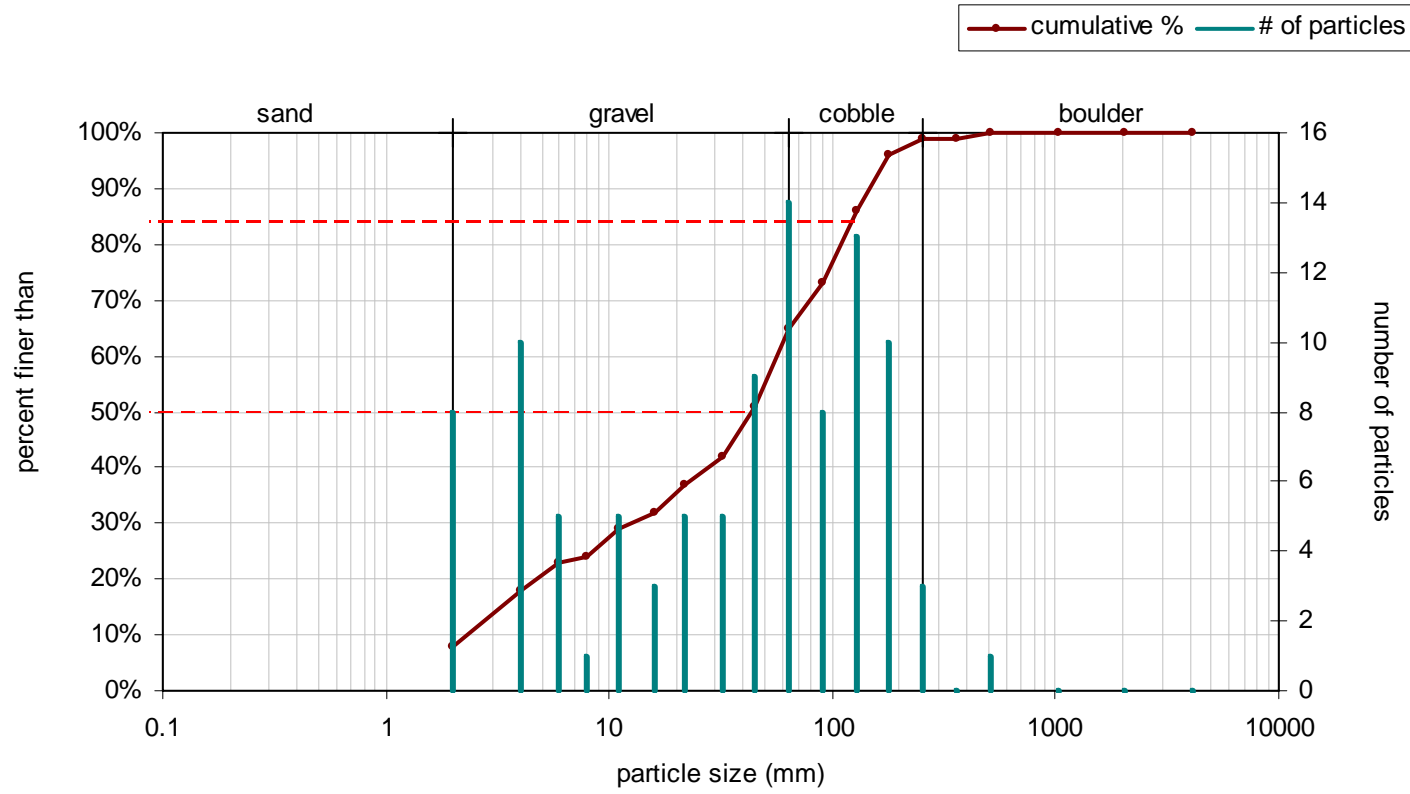
Thalweg Pebble Count, Station Reach Data



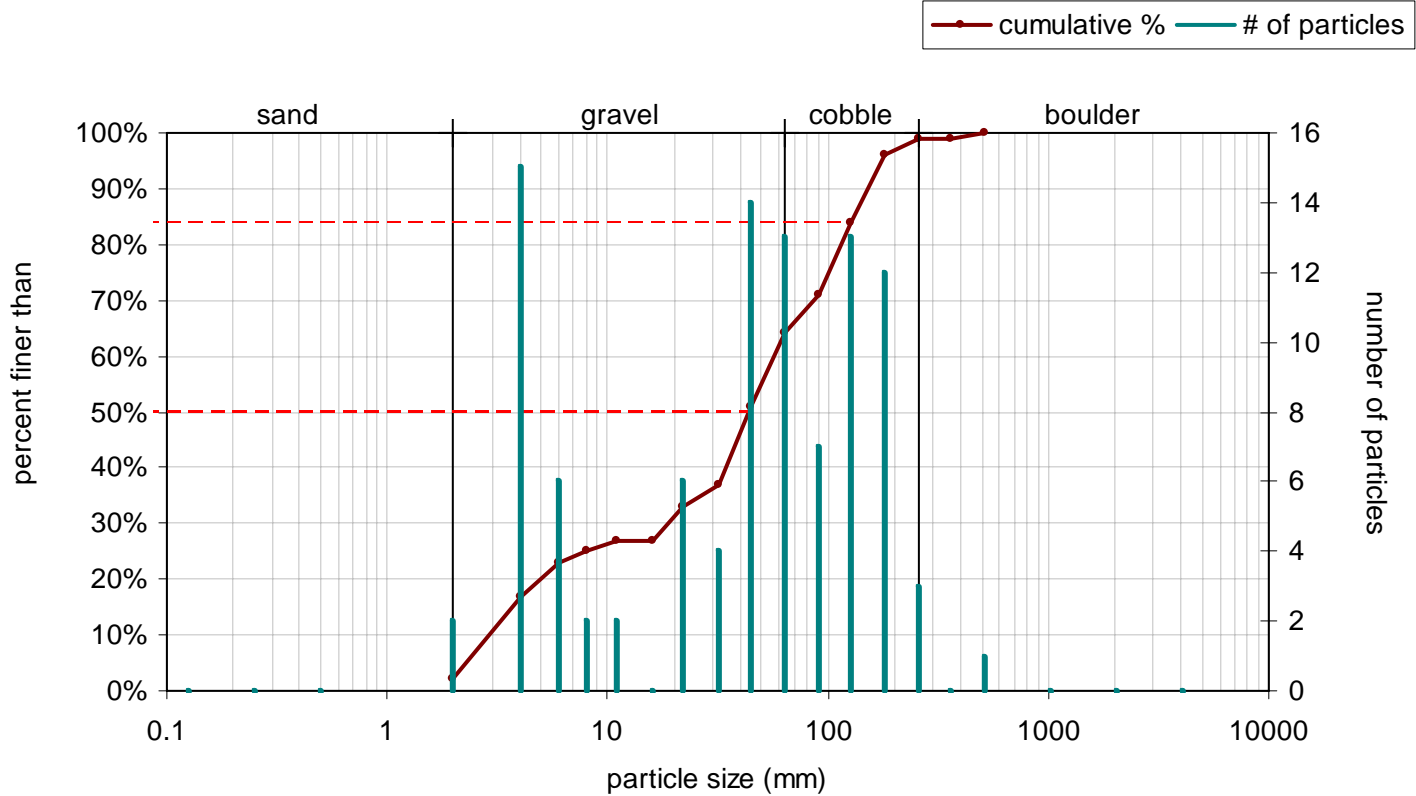
Proportional Video Distance Pebble Count, Station Reach Data



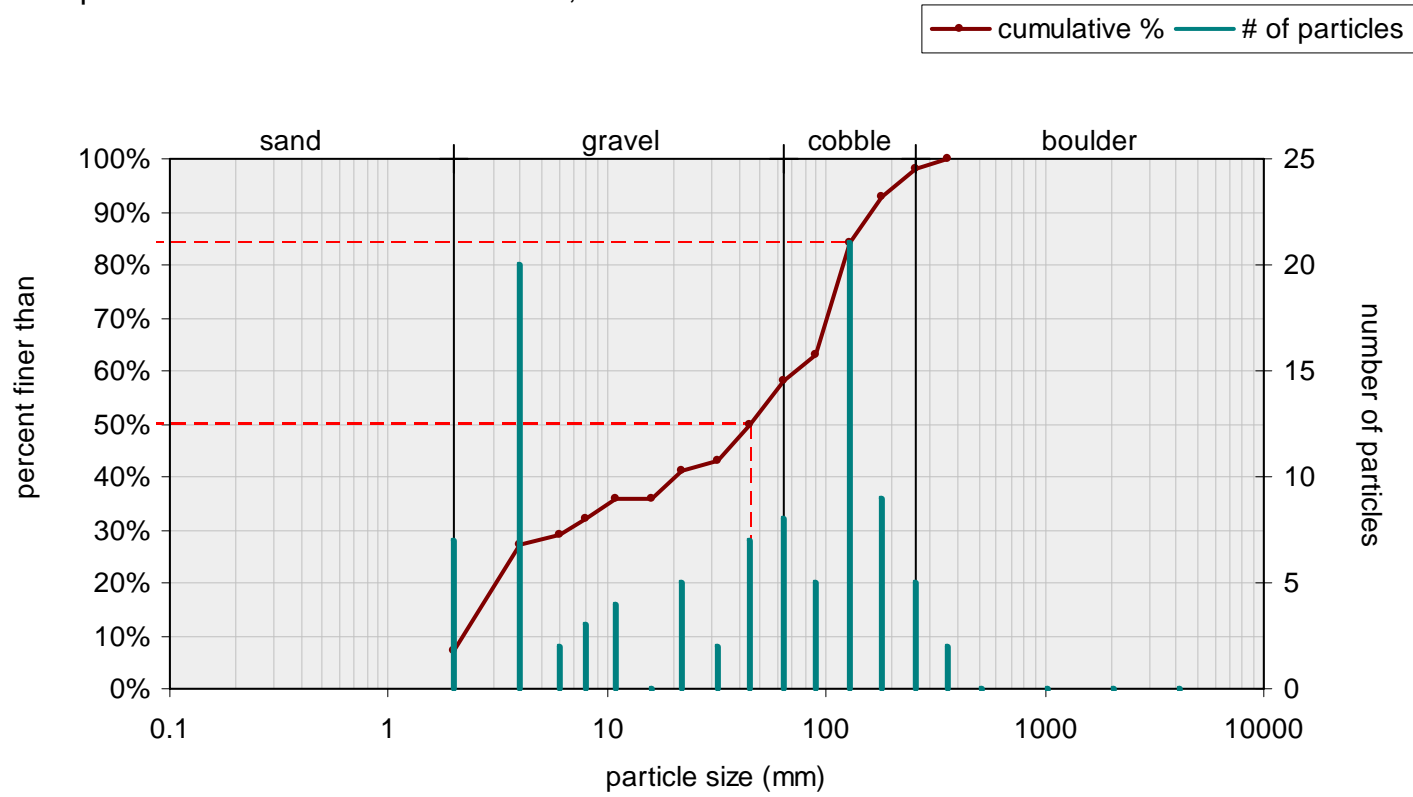
Zig-Zag Video Distance Pebble Count, Station Reach Data



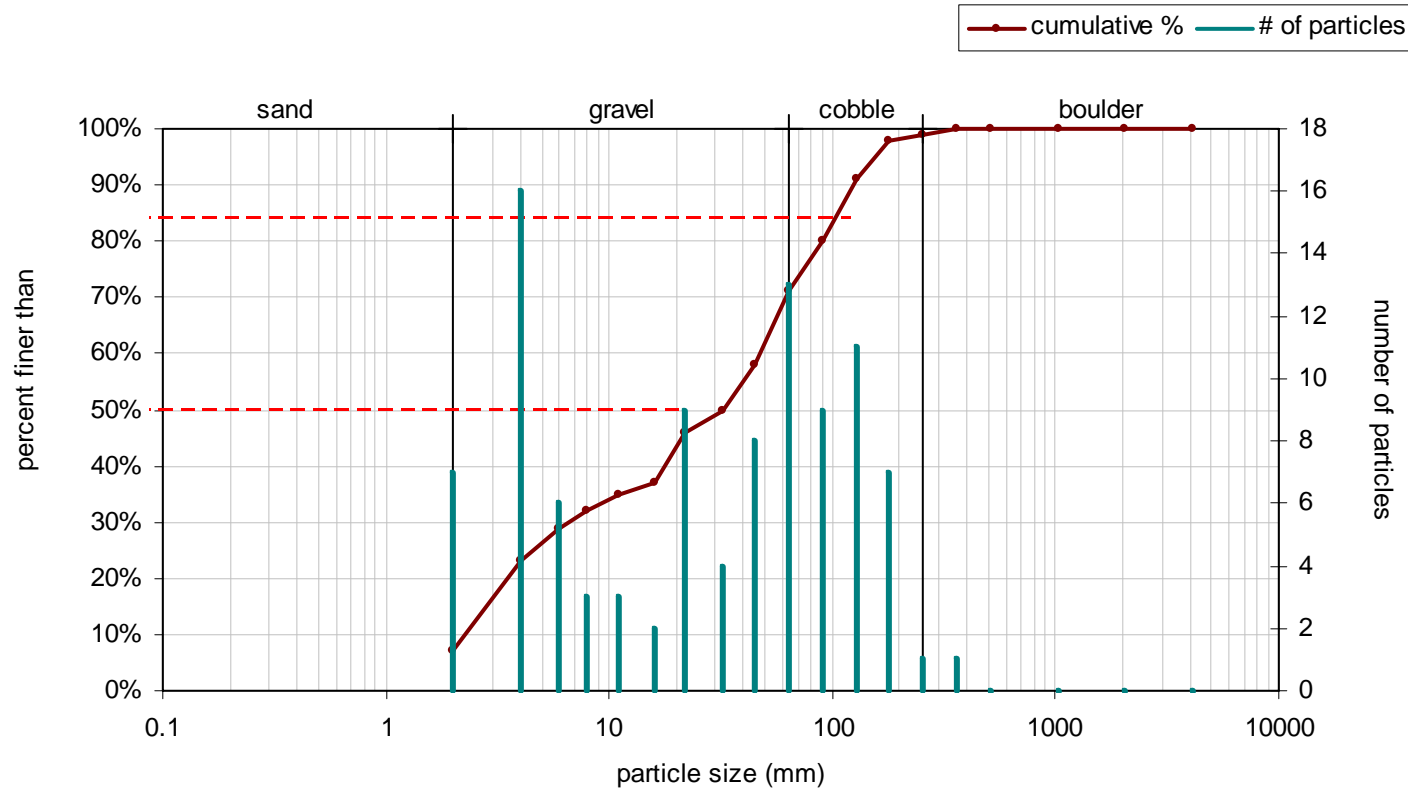
Thalweg Video Distance Pebble Count, Station Reach Data



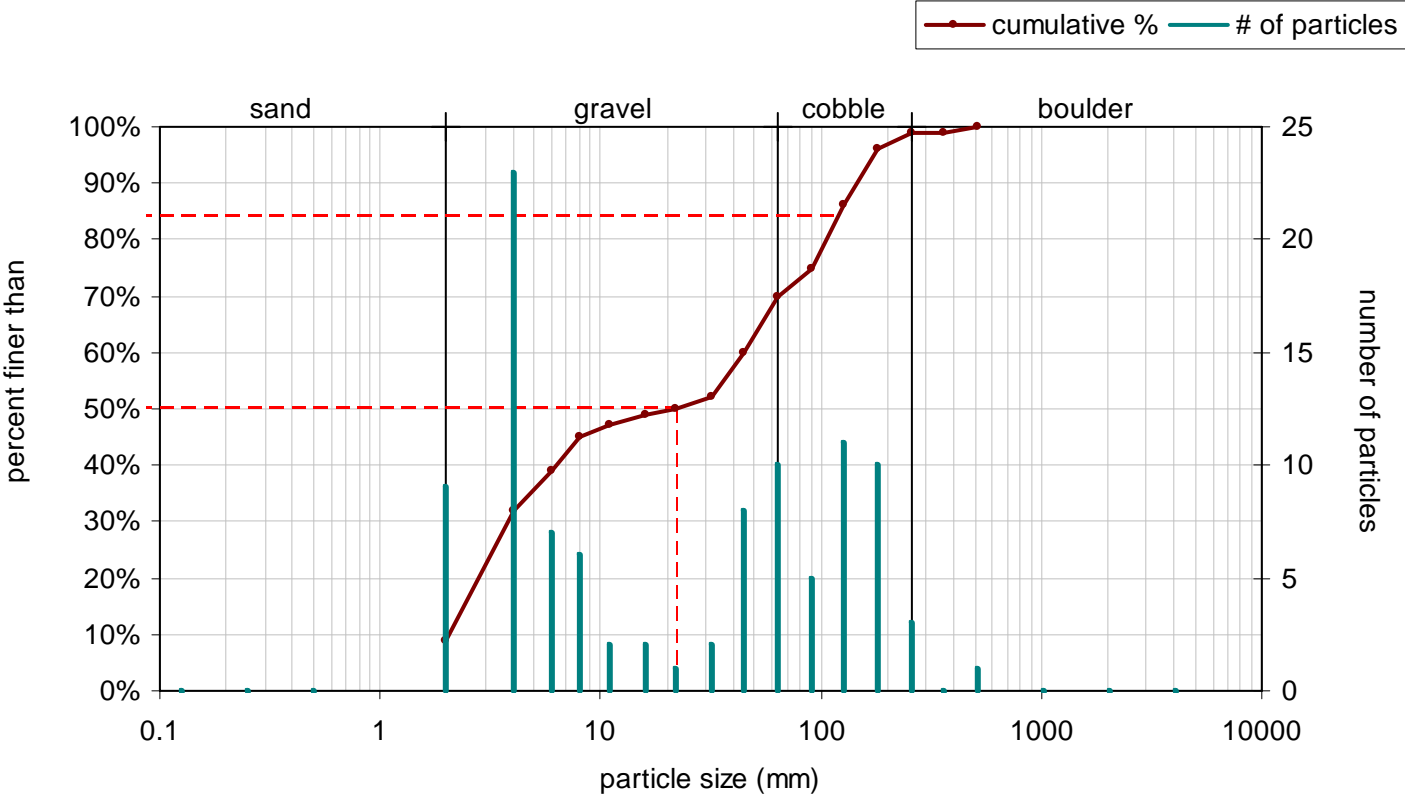
Proportional Video Time Pebble Count, Station Reach Data



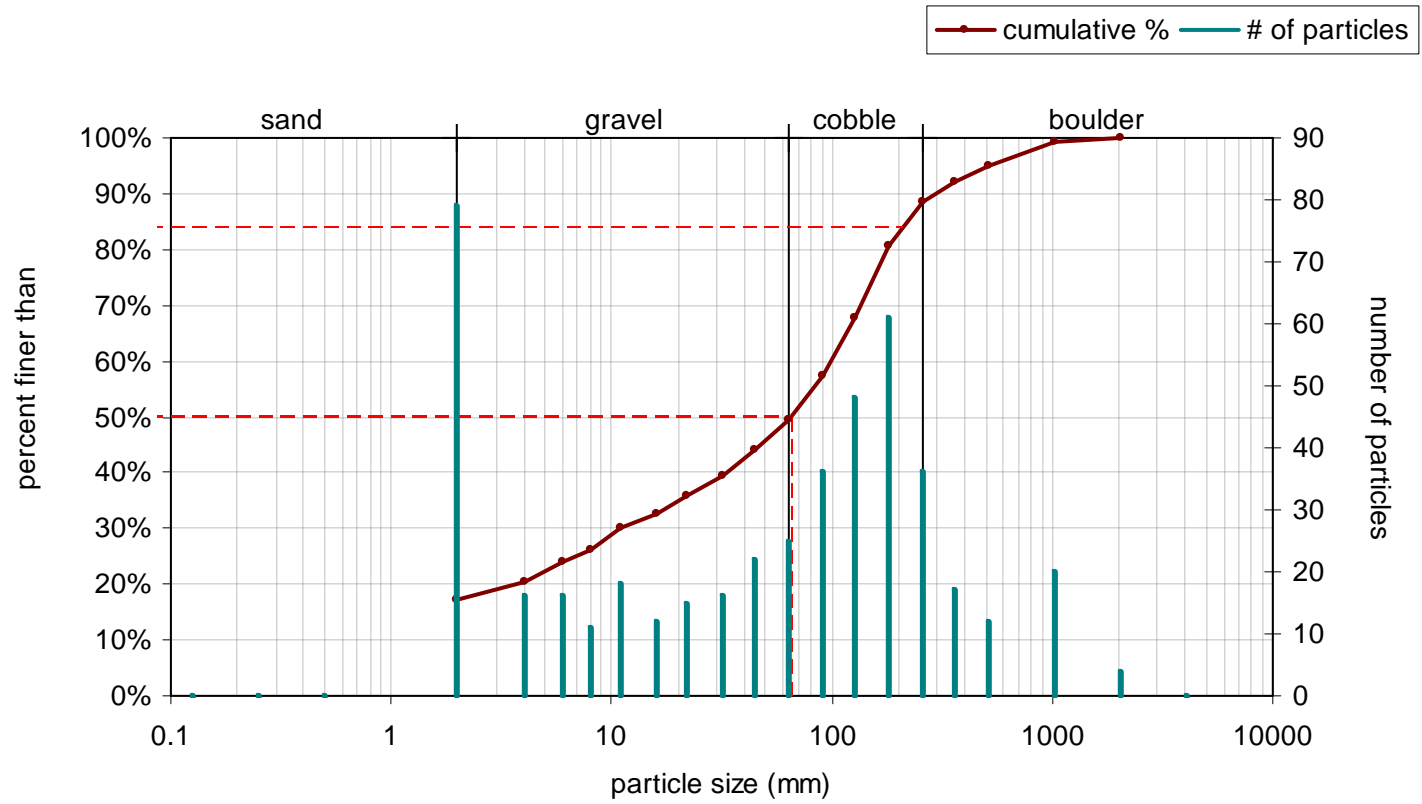
Zig-Zag Video Time Pebble Count, Station Reach Data



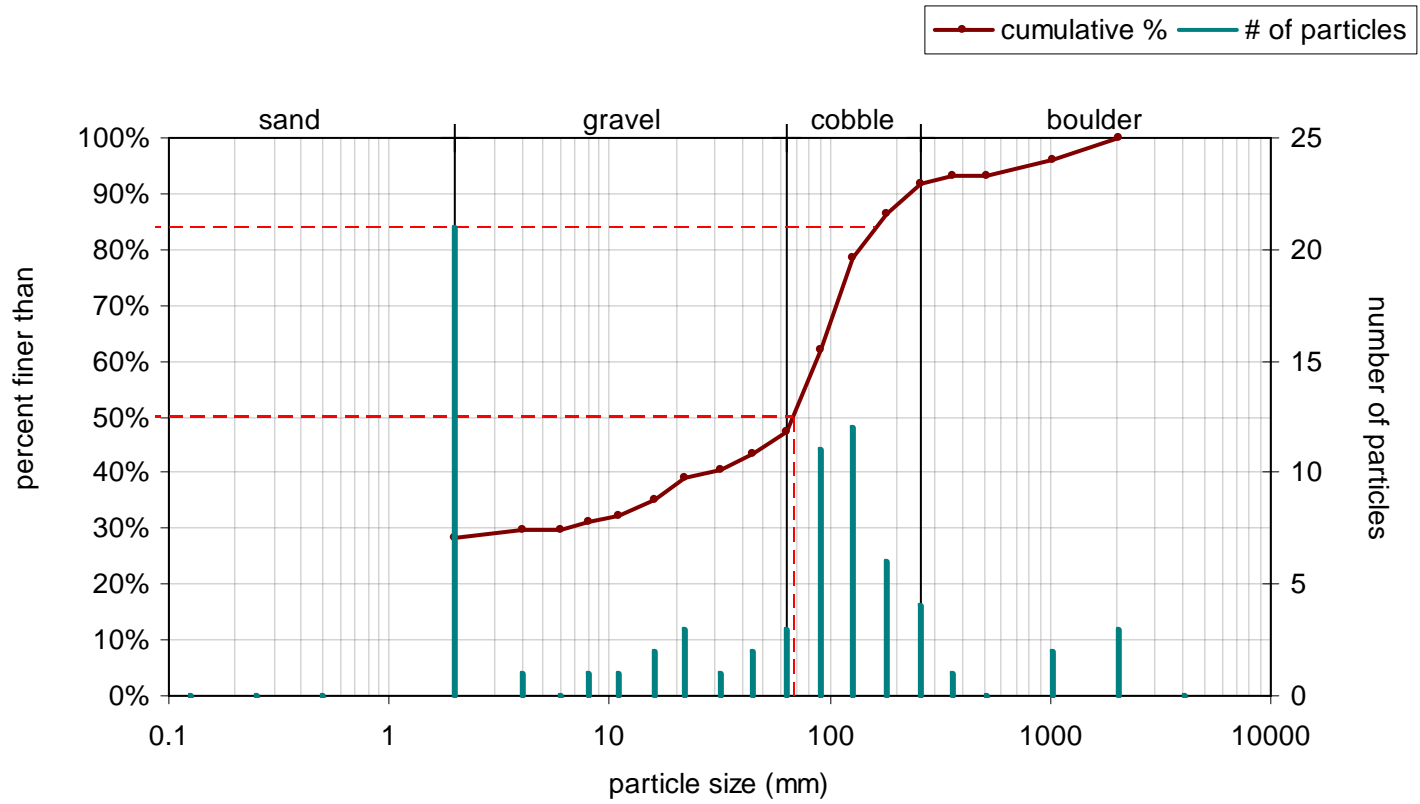
Thalweg Video Time Pebble Count, Station Reach Data



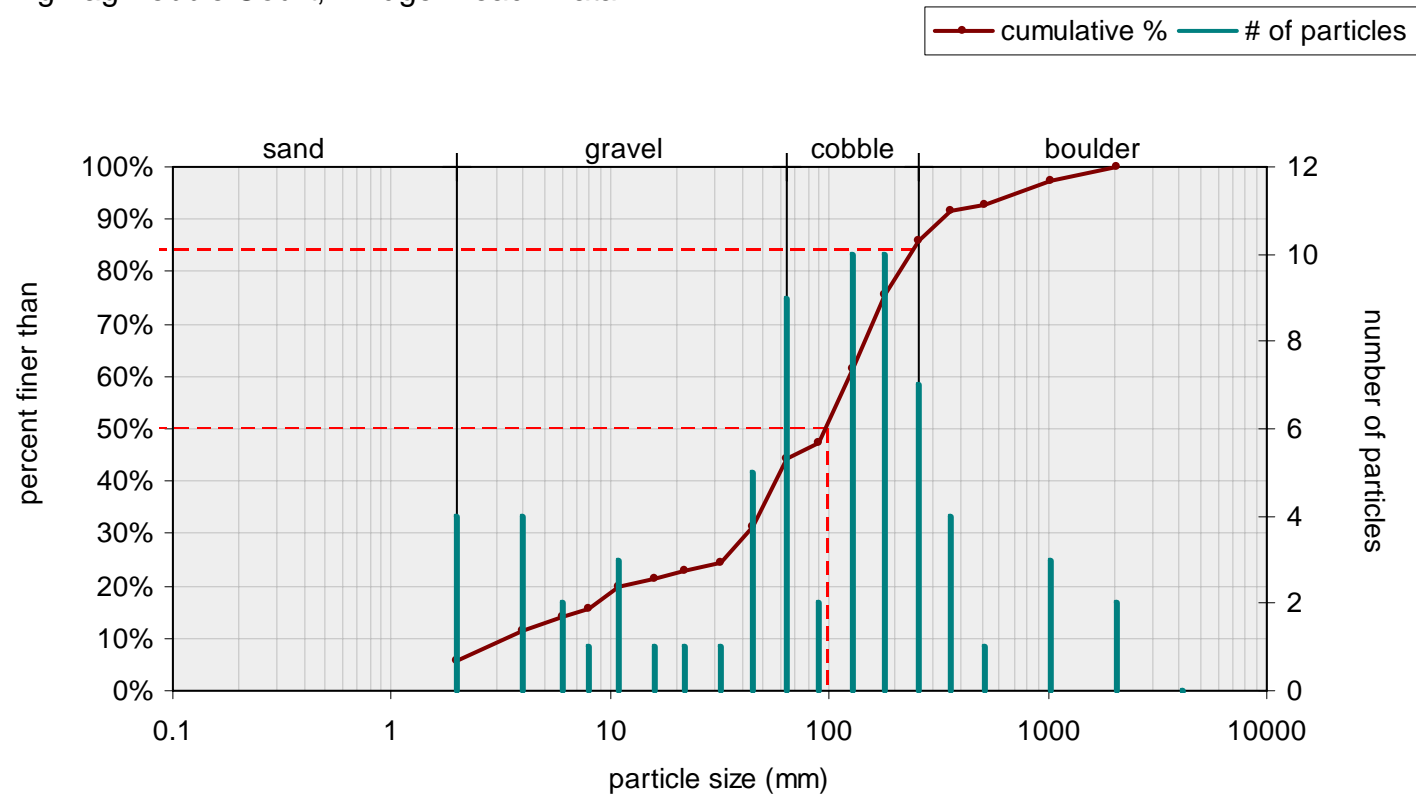
Frames Pebble Count, Bridge (Frame) Reach Data



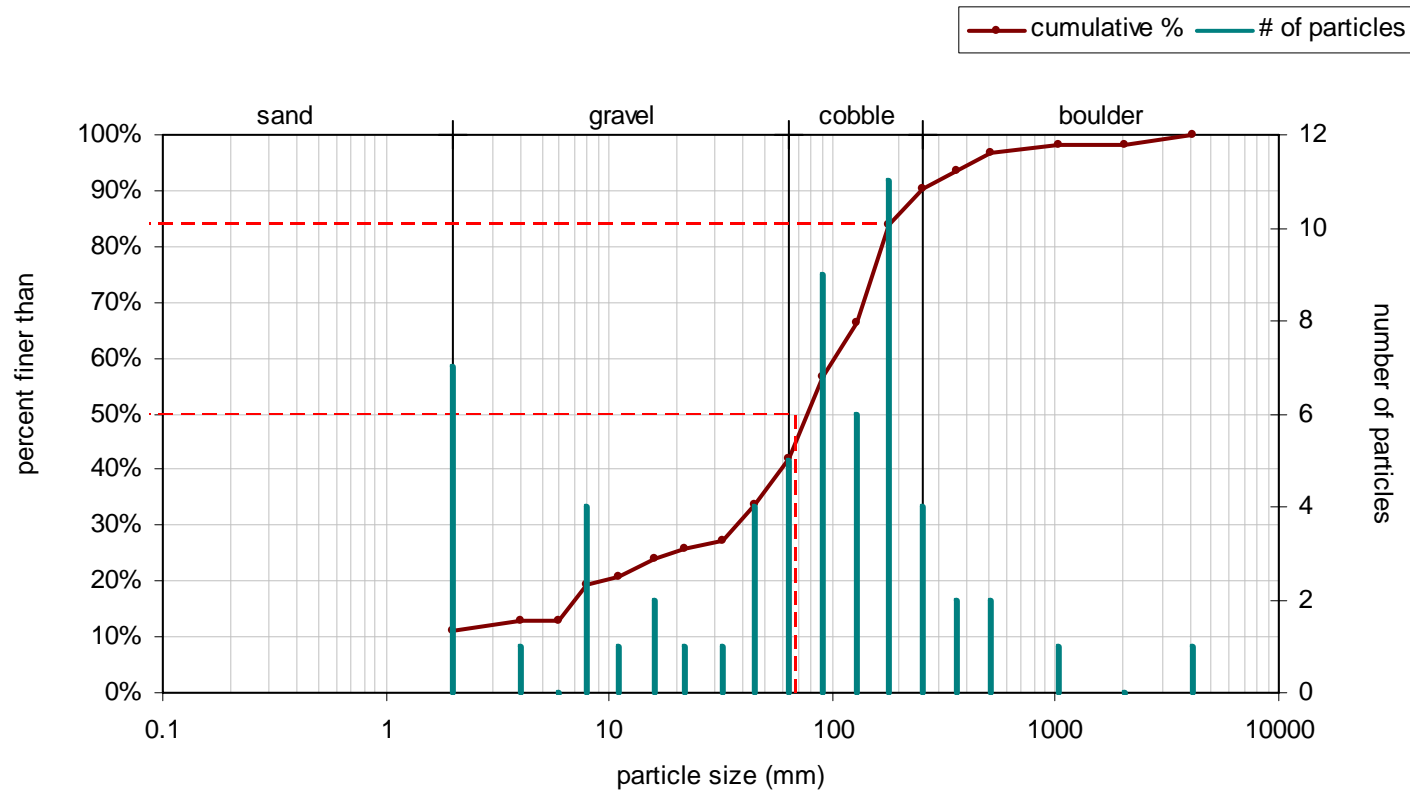
Proportional Pebble Count, Bridge Reach Data



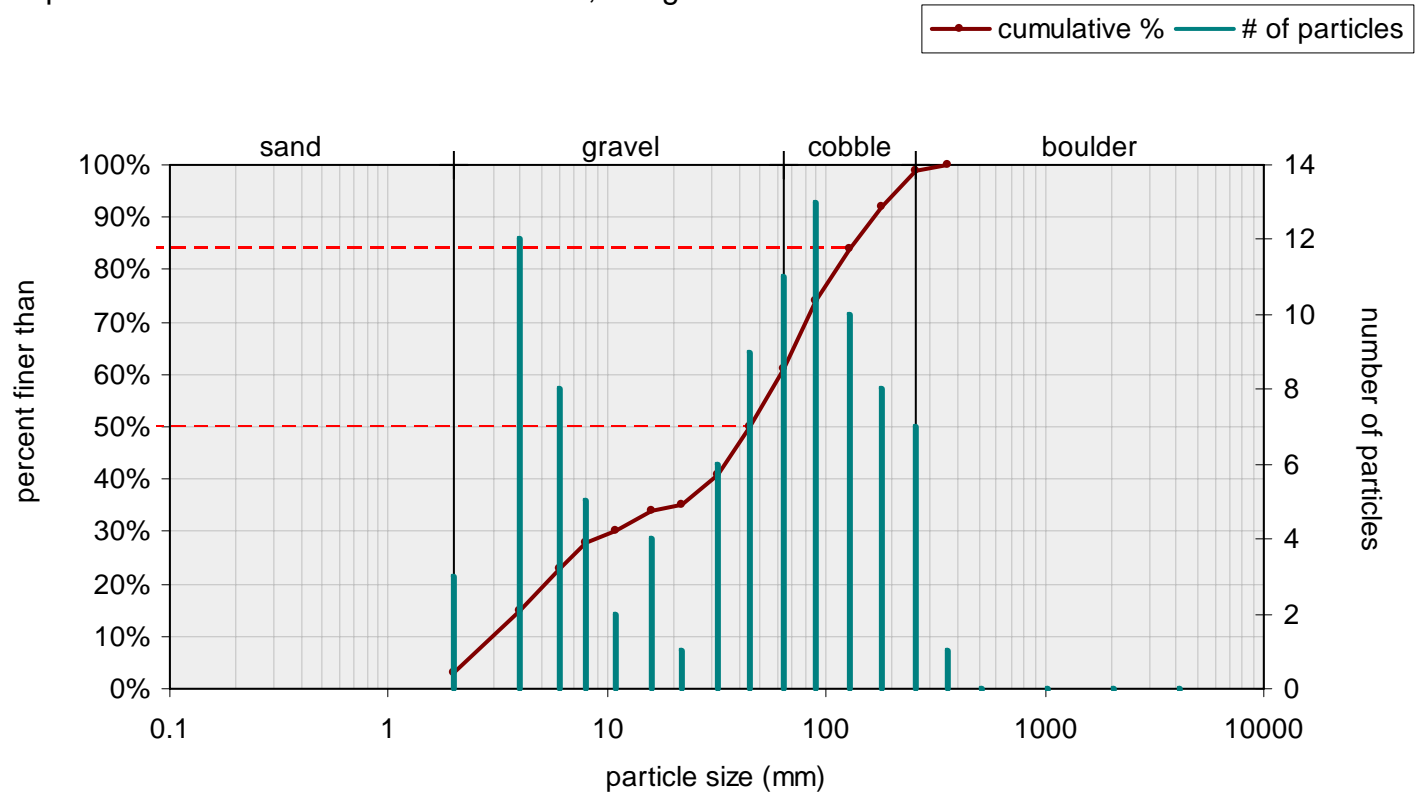
Zig-Zag Pebble Count, Bridge Reach Data



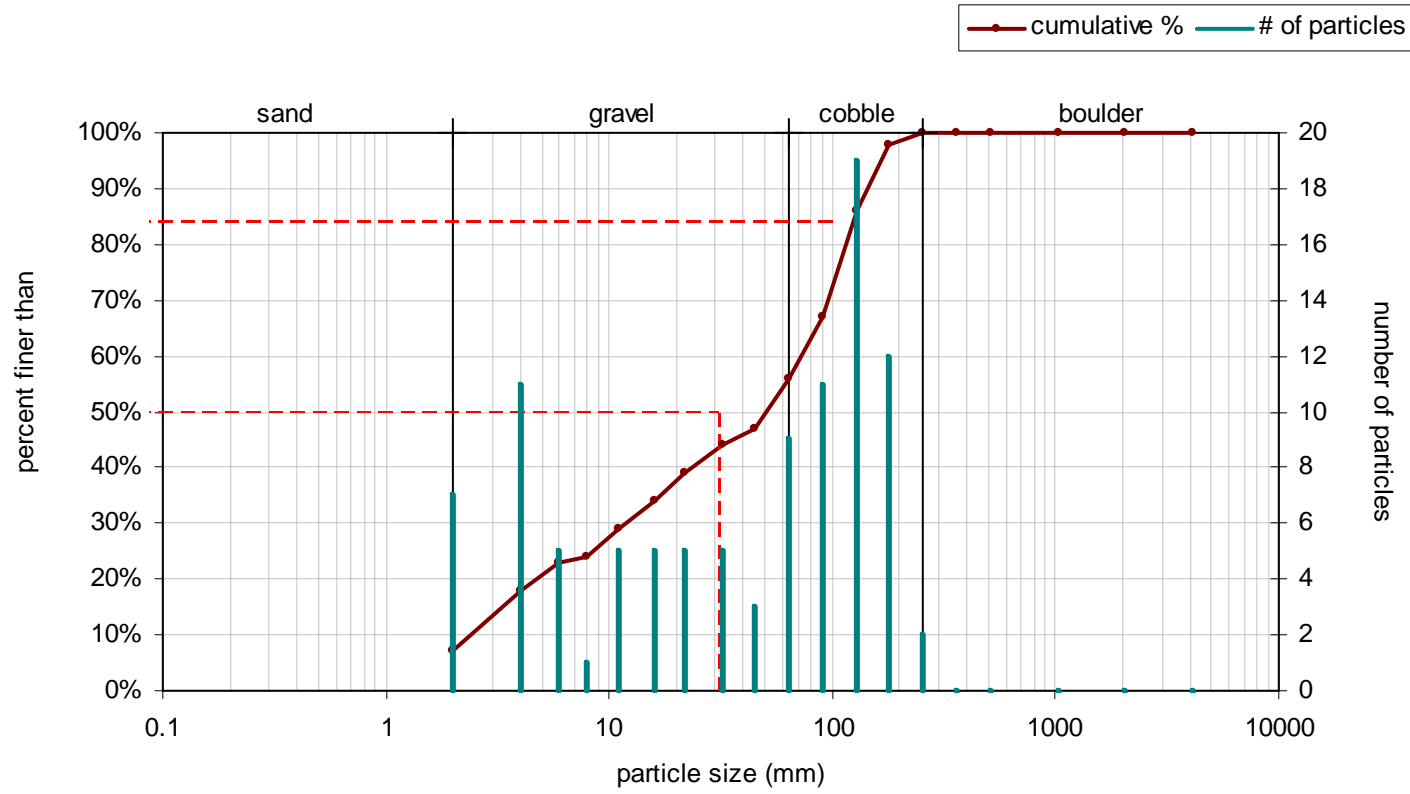
Thalweg Pebble Count, Bridge Reach Data



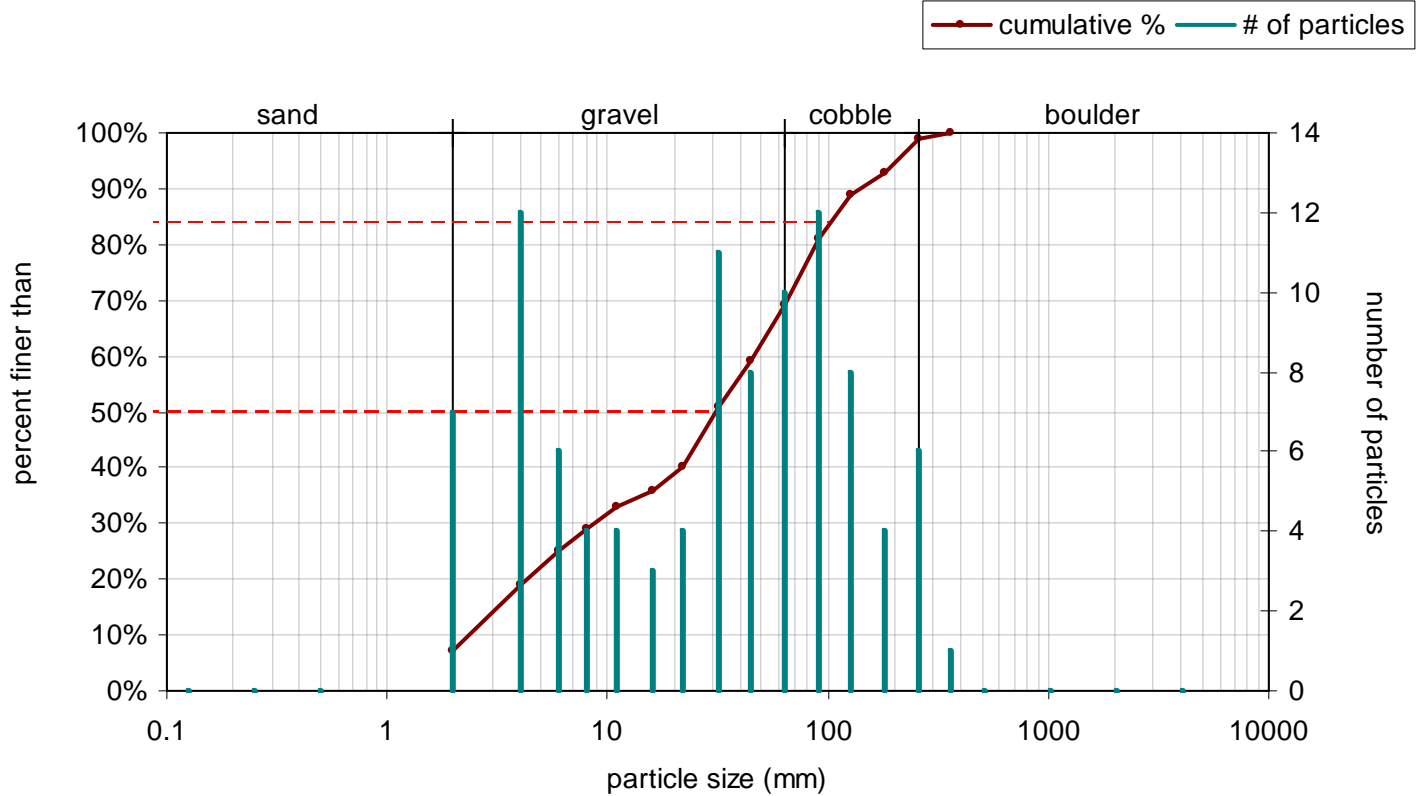
Proportional Video Distance Pebble Count, Bridge Reach Data



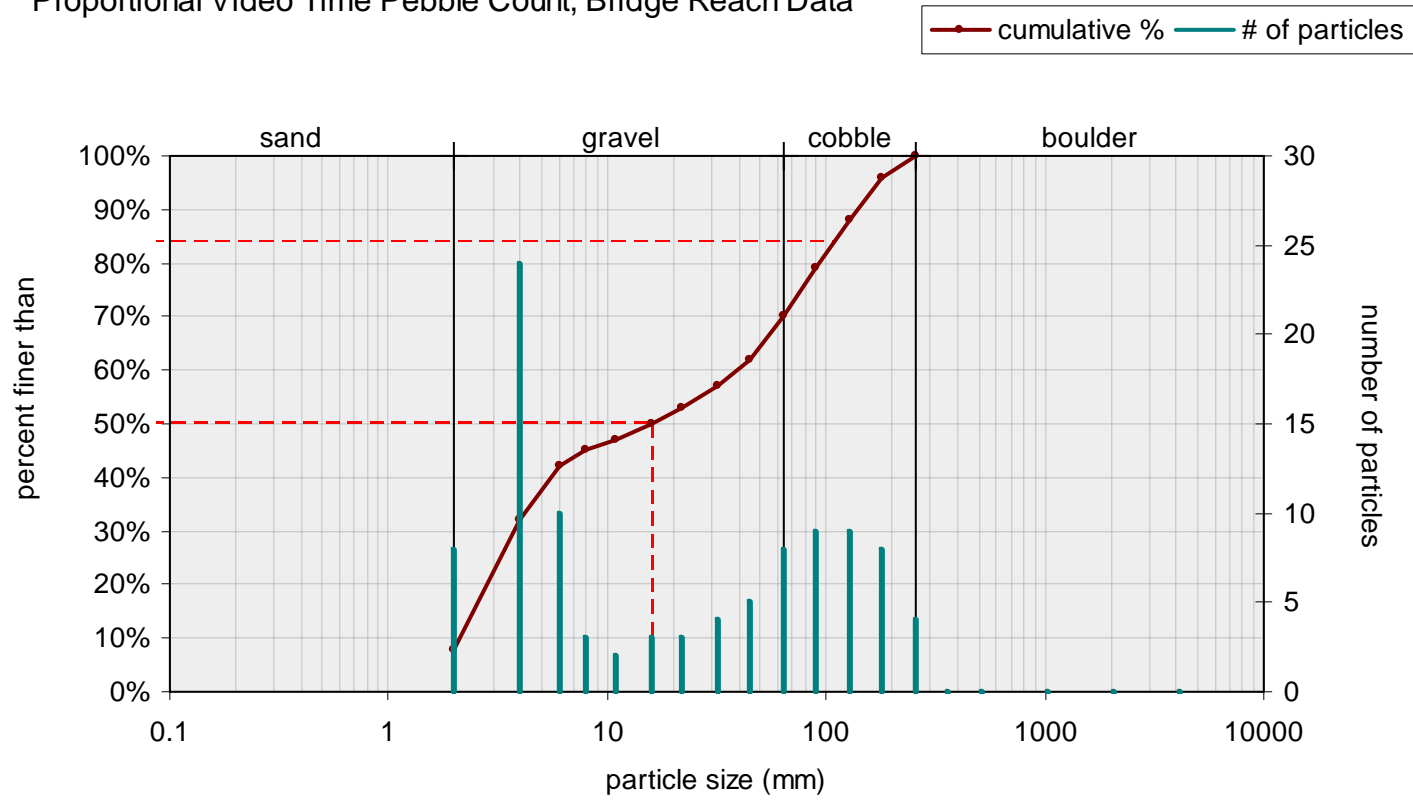
Zig-Zag Video Distance Pebble Count, Bridge Reach Data



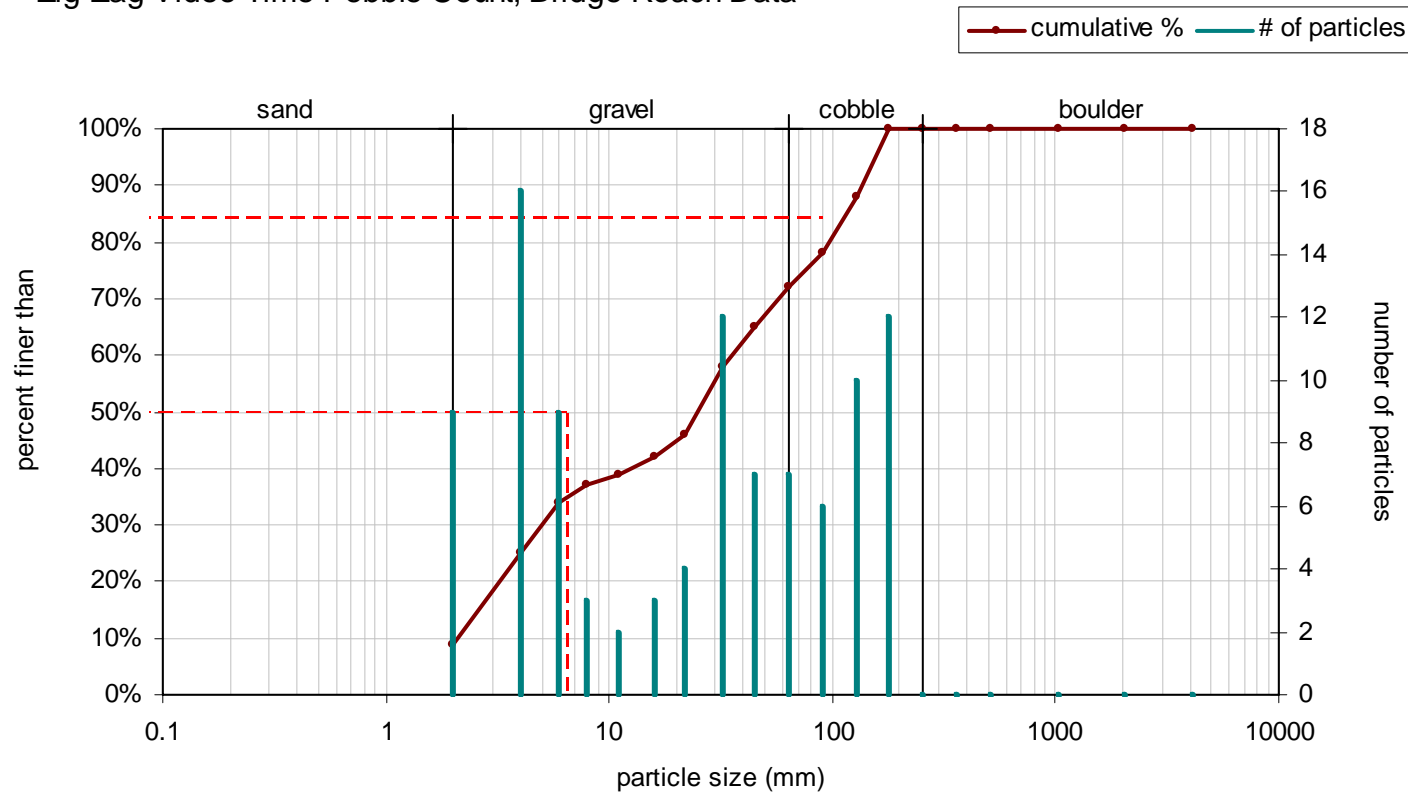
Thalweg Video Distance Pebble Count, Bridge Reach Data



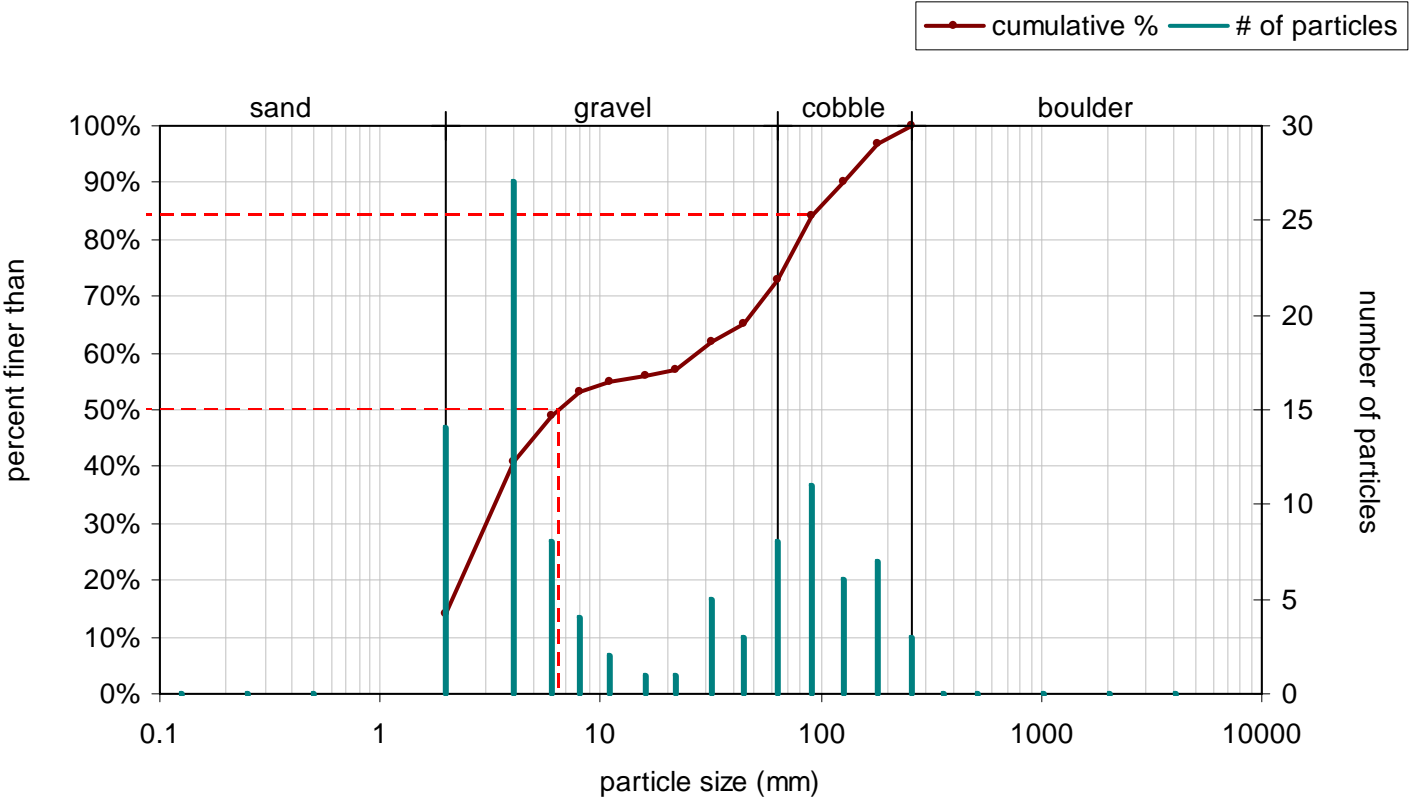
Proportional Video Time Pebble Count, Bridge Reach Data



Zig-Zag Video Time Pebble Count, Bridge Reach Data



Thalweg Video Time Pebble Count, Bridge Reach Data



Vita

Joshua Rogers was born 27 April 1980 in Cumberland County, North Carolina. He was born again through the grace of God on 2 March 1995. After graduation from Dacula High School Mr. Rogers attended Piedmont College and earned a Bachelors of Science degree in Biology in May of 2002. In May of 2003 he was married to Honna K. Rogers wherein they moved to Knox County, Tennessee. He began his graduate work at the University of Tennessee, Knoxville in the fall of 2006. Mr. Rogers earned his Masters of Science degree in Wildlife and Fisheries Science in the summer of 2008 and currently resides in Signal Mountain, Tennessee.