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Classification system of the physical streambed habitat.

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CLASSIFICATION SYSTEM OF THE PHYSICAL STREAMBED HABITAT

By

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A Dissertation Approved on

March 28, 2014

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DEDICATION

This dissertation is dedicated to my parents

who have given me invaluable educational opportunities.

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I would like to gratefully and sincerely thank Dr. Arthur C. Parola for his guidance, understanding, patience, and most importantly, his friendship during my graduate studies at University of Louisville. His mentorship was paramount in providing a well-rounded experience consistent my long-term career goals. He encouraged me to not only grow as an engineer but also as an instructor and an independent thinker. I am not sure many graduate students are given the opportunity to develop their own individuality and self-sufficiency by being allowed to work with such independence. For everything you've done for me, Dr. Parola, I thank you. I would also like to thank all of the members of the Dr. Parola research group, especially Dr. Croasdaile for giving me his advice when there was no light at the end of anything.

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ABSTRACT

CLASSIFICATION SYSTEM OF THE PHYSICAL STREAMBED HABITAT

Abolfazl Shafaie

March 28, 2014

A streambed is the channel bottom of a stream, river, or creek; the physical confine of the normal water flow. It provides necessities for fish and microinvertebrate including shelter, food, and breeding spots. Therefore, it is an essential part of aquatic animal habitats and often seen as an index of stream health.

There is no generally accepted method to quantify streambed physical components and depending upon state and organization a variety of methods are used. The procedure provided in the rapid bioassessment protocol (RBP) (Kaufmann et al., 1999; Sylte and Fischenich, 2002) is probably the most widely used method to assess the effect of various land use activates on stream habitat for management purposes in the United States.

The RBP method was not intended as a procedure to assess streambed habitat; although it is often used for this purpose. This approach reduces the streambed physical components into the two variables: embeddedness and epifaunal substrate. Definitions and sampling procedure of these variables are vague and subjective. Streambed components with varying characteristics are grouped under the same category and some streambed components as important as gravel are not included in the categorizing of the streambed habitat.

A measurement method that combines a photographic technique and grid sampling was developed to assess streambed components in a direct and simple way at the required level of accuracy. The portable photographic box (PPB) device utilizes a photographic technique to record images of physical streambed components under typical base flow of wadeable gravel-bed streams.

Recorded images were digitized manually and the area of each streambed component in each grid cell was estimated to evaluate projected area of streambed component.

The PPB facilitates sampling of streambed components of unit population with adequate picture quality rapidly. Five scenarios for sampling methods with varying accuracy and field and laboratory time requirements for quick and simple inventory of impaired stream habitat were recommended. Based on statistical analysis, residual was reduced from 33% in the rapid bioassessment to 28%, 14%, 7%, 5% and 0% in the first, second, third, fourth, and fifth scenario, respectively.

In addition, measurement of the dissolved oxygen and temperature in ten riffles indicated that temperature in the first layer of subsurface was similar to those measured in the water column. No evidence was found to support substrate measurement of temperature. However, the dissolved oxygen concentration varied significantly for embedded and free patches. In contrast to the free gravel and epifaunal substrate, the DO content in fine material, embedded gravel, and embedded epifaunal substrate components was in anoxia and hypoxia. Hypoxia and anoxia lasted for several days after flood events.

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CHAPTER I

INTRODUCTION

1.1 Streambed Physical Habitat

A streambed is the channel bottom of a stream, river, or creek - the physical confines of the normal water flow. It provides necessities for fish and microinvertebrates, including shelter (Matthaei et al., 2000; Franken et al., 2006); food (Lisle, 1986; Robison & Beschta, 1990; Cordova et al., 2007); and breeding spots (Wood & Armitage, 1997). Therefore, the streambed is a critical component of aquatic animal habitats and often seen as an index of stream health (Sylte & Fischenich, 2002).

The streambed may contain a combination of materials including sediments, woody debris, and algae. These materials range in sizes from fine to large. Another aspect of streambed materials is that they vary longitudinally and transversely to the flow direction. They also vary vertically within streambed strata, including surface layer, subsurface layer, and depth of substrata (Bunte & Abt, 2001). Each material has its own characteristics utilized by aquatic animals. For example, sediment with a size range from 2-8 mm (gravel) is used for spawning by many species of fish. An excess of fine sediment can increase fish egg mortality (Wood & Armitage, 1997). Therefore, the measurement of changes of streambed material is a key objective for management purposes in many stream habitat monitoring programs.

Evaluation of the streambed is accomplished in three spatial scales: patch scale, cross section scale, and reach (or other morphological unit similar to a riffle) scale. The patch scale measurement can quantify the streambed physical components in surface, subsurface, and depth of substrata. Both cross section and reach scale measurements contains varieties of streambed component populations and are implemented mainly to measure physical variations of the surface streambed. Cross section and reach scale measurements of subsurface layers are difficult and expensive and may damage habitat (Bunte & Abt, 2001). The riffle is classified as the best location to obtain reach scale data to detect changes in streambed components (Dietrich et al., 1989).

No generally accepted method is used to quantify streambed physical components. A variety of method are used, dependent upon the purpose and regulatory agency requirements (Sylte & Fischenich, 2002). Procedures for assessing stream habitat that are provided in the rapid bioassessment method appears to be the most widely used method to monitor changes in habitat condition and streambed physical components in the United States (Kaufmann et al., 1999). The main focus of this research is to develop an alternative method for rapid bioassessment of streambed habitat.

1.2 Rapid Bioassessment Method

Streambed components are divided into embeddedness and epifaunal substrate in order to map out the streambed component variability in detail using rapid bioassessment (Kaufmann et al., 1999; Sylte & Fischenich, 2002).

Epifaunal substrate is defined as "cobbles, boulders fallen trees, logs, snags, undercut banks, aquatic vegetation providing refugia, feeding opportunity, and spawning sites for aquatic animals" (Kaufmann et al., 1999). Embeddedness is defined as "the degree to which materials (materials larger than 2 mm) on the surface of a streambed are covered or surrounded by fine sediments (materials less than 2 mm)" (Kaufmann et al., 1999) (Figure 1.1).

The measurement procedure utilized in this protocol for patch scale is the estimation of embeddedness and epifaunal substrate inside a 10 cm- diameter hoop visually on the 25% increment (Kaufmann et al., 1999). The percentage of embeddedness and epifaunal substrate is evaluated in four classes of [0-25%= excellent, 25-50%= good, 50-75% =fair, and 75-100% = poor] (Figure 1.2). In order to assess a cross section, the evaluation is conducted at five patches located at the percentage of [0, 25, 50, 75, and 100%] of wetted width of channel and average (Figure 1.3). For riffle evaluation, embeddedness and epifaunal substrate are estimated in each cross section, spaced at intervals of four times the channel width, and then averaged.

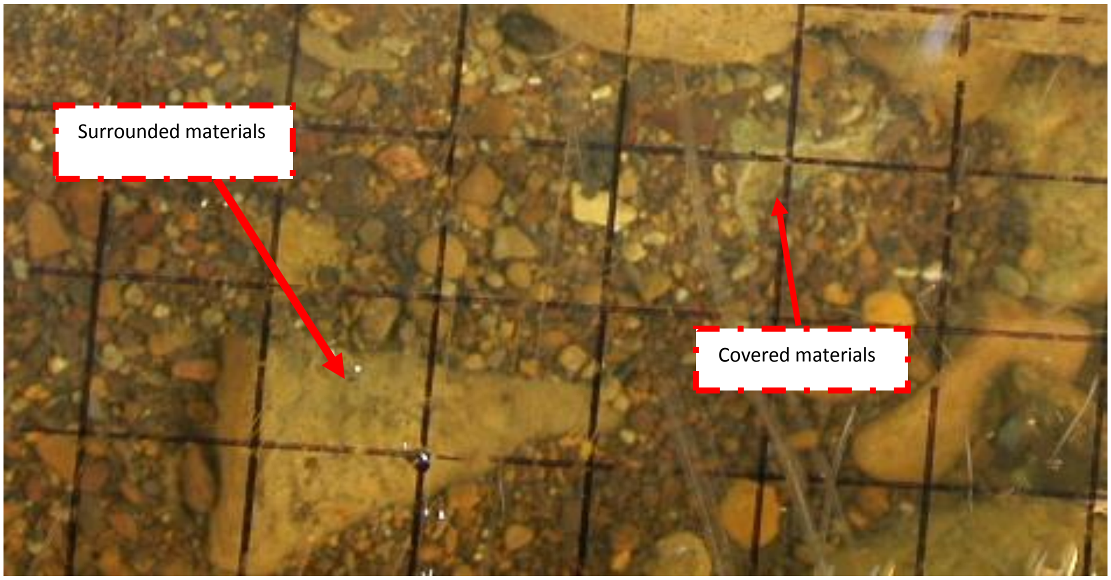


Figure 1.1. Surrounding and covered materials by material less than 2 mm (embeddedness) -- the rapid bioassessment method.

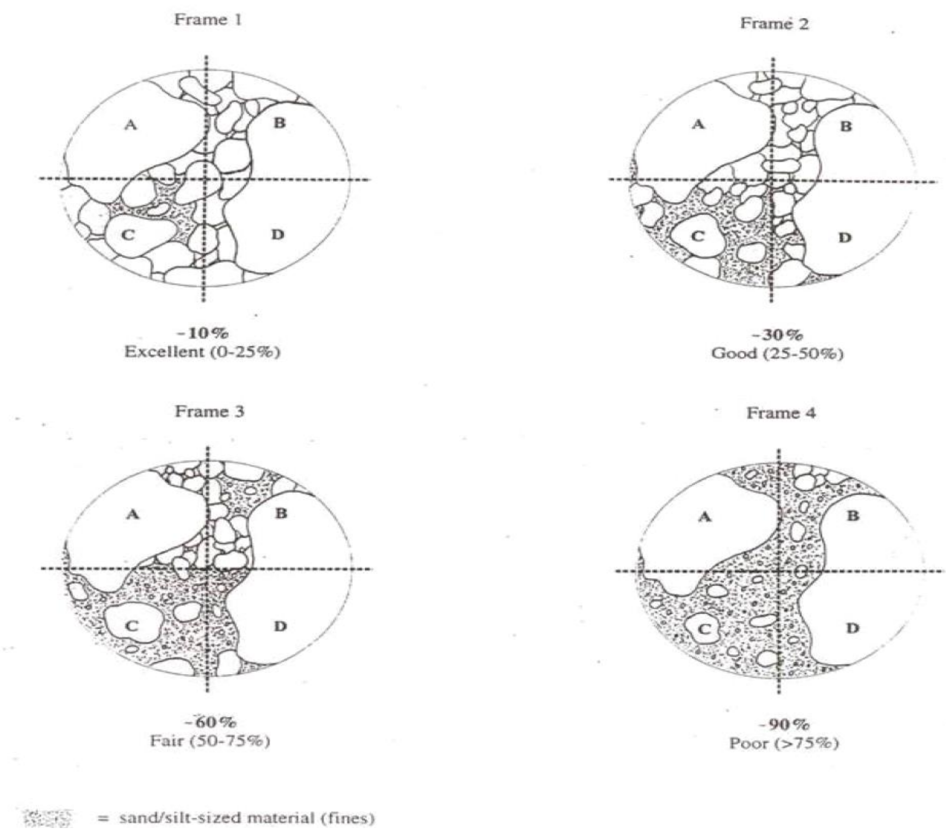


Figure 1.2. Streambed physical component sampling in the rapid bioassessment method (Kaufmann et al., 1999).

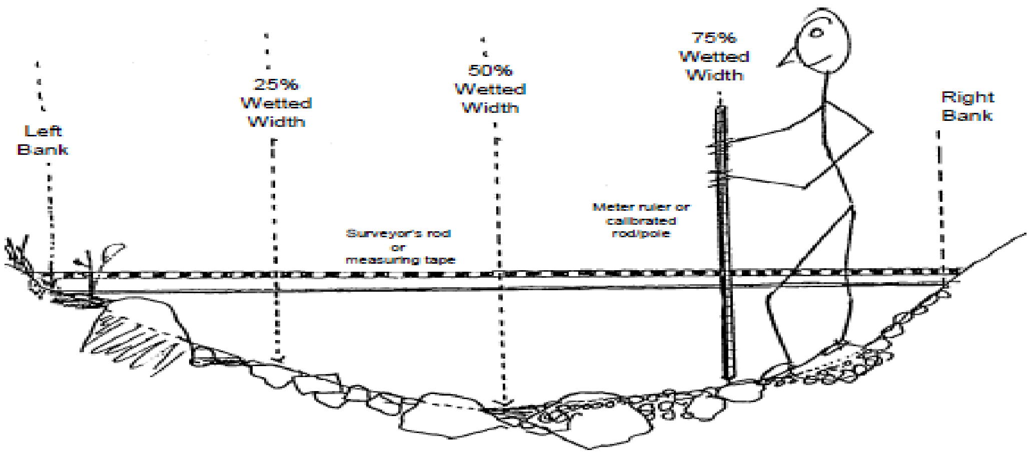


Figure 1.3. Streambed physical component _ cross section scale_ in the rapid bioassessment method (Kaufmann et al., 1999).

1.3 Motivation and Significance

The major drawbacks in the rapid bioassessment method are as follows.

1. Despite the importance, complexity, and diversity of streambed components, evaluations of the streambed habitat are reduced to two simple components: epifaunal substrate and embeddedness.

2. Measurement is subjective and prone to observer error (Kondolf, 1995; Crowder & Diplas, 1997; Rice & Church, 1998).

3. This method quantifies streambed physical components within 25% order; therefore, it is incapable of detecting local variations of a distinct population of streambed physical components at a level less than 25%.

4. Hoop area may be too small to sufficiently sample at the patch scale area (Crowder & Diplas, 1997), and no supportive documents show that the 10 cm diameter hoop accurately samples the patch area of the streambed.

5. Measurement methodology is inadequate, as measuring of five spots in the cross section and riffle area may not be sufficient to characterize the area of interest (Rice & Church, 1998).

6. Despite the importance of dissolved oxygen and temperature within the substrate for benthic organisms, it is not assessed as part of the rapid bioassessment procedure. This is likely due to the difficulty of a visual inspection of the effect of DO and temperature in the substrate.

In summary, the rapid bioassessment method is designed to provide a rapid monitoring technique, which contributes to a fast track record of basic streambed components for management purposes. However, drawbacks can be seen in assessing streambed habitat. These flaws justify the study of the rapid bioassessment method in detail and refinement of the original framework of the method for sampling of the physical streambed components.

1.4 Research Purpose

Although rapid bioassessment is an easy-to-use field approach for sampling streambed physical components, the accuracy and resolution are limited. The main goal of this study is to develop an alternative method to increase the number of important components of the habitat and to increase the resolution and accuracy of measurement.

The objectives of this study were to develop a streambed classification system that categorizes physical streambed components in a simple but comprehensive manner and to develop an efficient and simple method to quantify these components. This also involved the development of a sampling methodology to collect field data at the riffle scale in order to quantify dissolved oxygen and temperature in the streambed surface layer.

CHAPTER II

LITERATURE REVIEW

This chapter reviews the key variables of streambed components, as well as compares and contrasts the main methods in measuring streambed physical components. Subsequent to the literature review, the summary of main physical streambed components are outlined.

2.1 Streambed Physical Components

Streambed physical characteristics are important biologically and hydraulically in aquatic animal life. Bjorn and Reiser (1991) found that percent fine is important for salmonid to select spawn sites. However, the key factor is sediment size in which salmonid can excavate and create the spawning area. Miller et al. (2004) reported that microinvertebrates, particularly Ephemeroptera, Plecoptera, and Trichoptera (EPT), are affected by streambed physical components including percent fine material and grain size. The USDA recommend streambed grain size, percent fine material, and large woody debris as main components of physical streambed in the evaluation of fish and microinvertebrate habitat health.

Geis and Dauble (1998) measured temperature, dissolved oxygen, and substrate permeability in the hyporheic zone to assess patterns of spawning. In addition, dissolved oxygen (DO); epifaunal substrate stability; temperature; streambed grain size variability (Walters et al., 2008); woody debris; log jams; coarse particulate organic material (CPOM); boulders (Merz & Chen, 2005); and algal cover (Kaufmann et al., 1999) were major variables found to affect fish and invertebrate aquatic habitats.

In order to condense factors under study, parameters were grouped according to the same functionality to avoid dependent parameters. Fine percent, streambed grain size, temperature, DO, epifaunal substrate stability, grain size variability, Woody debris and log jams, CPOM, boulders, algae, and aquatic macrophytes are proposed as main streambed physical components. Substrate permeability is related to the distribution of substrate sizes and percentage of fine materials (McNeil & Ahnell, 1964;

Chapman, 1988), as is epifaunal substrate stability (Curran & Wilcock, 2005). In addition, boulder and fine grain size are included in streambed grain size distributions. Grain size variability is a function of streambed grain size distribution. Although several other biochemical components are important, this study focused on DO and temperature.

The following section reviews the relevant importance of streambed components that contribute to fish and microinvertebrate habitat requirements.

2.1.1 Streambed Grain Size

As an essential constituent of streambed substrata, substrate grain size is well established as an important factor for aquatic habitat. Biologists utilized streambed grain size to identify the complex effects of streambed substratum on structure and abundance of aquatic animals (Williams, 1978; Gayraud & Philippe, 2001). Streambed substrate consists of all shapes and sizes of sediment including boulder (> 256 mm), cobble (256-64 mm), gravel (64-2 mm), sand (2-1/16 mm), silt (1/16-1/256 mm), and clay (< 1/256 mm). The term fine sediment refers to sediments less than 2 mm in size, thus encompassing sand (2-1/16 mm), silt (1/16-1/256 mm), and clay (< 1/256 mm).

Elevated levels of fine sediment in the streambed can affect aquatic habitat reduction or/and habitat change and can cause increased drift, lowered respiration capacity by physically blocking gill surfaces, lowered dissolved oxygen concentrations, and changed feeding activities (Lemly, 1982; Water, 1995; Wood & Armitage, 1997). Curran and Wilcock (2005) experimentally proved that the sand sediment supply may cause substrate instability.

Another component of streambed grain size is gravel, which is well recognized and established as a prime factor for construction of fish redds (Reiser & Bjornn, 1979; Devries, 1997; Mayer et al., 2005). In addition, microinvertebrates and fish use gravel substrate as a refuge and food source (Wood & Armitage, 1997).

Benthic invertebrates use cobbles and boulders for grazing and habitat activities. Water (1995) pointed out that insects widely graze on the cobble surface and inhabit beneath and the interstitial spaces between cobbles. Biomass, diversity, and the abundance of invertebrates were significantly higher in the cobble interstitial space after flood disturbances than other substrate patches (Quinn & Hickey, 1990;

Lancaster & Hildrew, 1993; Korsu, 2004). As far as sheltering issues, the cobble interstitial space provides the refugia for microinvertebrates during high flooding (Haggents, 1988), where cobbles are stable during floods.

2.1.2 Large Woody Debris (LWD)

Large woody debris (LWD) is defined as a tree branch greater than 10 cm in diameter (Harmon et al., 1986). Large woody debris creates important storage areas for inorganic sediment (Manga & Kirchner, 2000) and organic material (Magoulick, 1998). LWD anchors debris (Merz, 1979) and may create backwater that maintains water depth during low flow in summer (O'Connor & Ziemer, 1989). Moreover, LWD can function as a cover to protect prey from predators (Billy, 1984).

2.1.3 Coarse Particulate Organic Material (CPOM)

Coarse particulate organic material (CPOM) is defined as packed leaves that are not transported and washed away by a marginal spates (Kaufmann et al., 1999). CPOM is an important part of the streambed content (Imbert et al., 2005; Rabeni et al., 2005; Braccia & Voshel, 2006) and contributes to the habitat complexity by providing food sources, refugia, and also may provide streambed stability during floods (Culp et al., 1983; Reice, 1991). CPOM is the main source of food and energy in the stream ecosystem (Azzouz & Sanchez-Ortega, 2000).

2.1.4 Dissolved Oxygen (DO) and Temperature

Similar to other animals, fish and macroinvertebrates require oxygen for daily activities; lack of dissolved oxygen in water directly influences the entire stream biota community. Oxygen deprivation is classified in two categories depending upon the amount of dissolved oxygen shortage: hypoxia is partial oxygen deprivation; anoxia is complete oxygen deficit. Hypoxia reduces the egg survival rates and embryo fitness of amphibians (Mills & Barnhart, 1999). In combination with reduced temperature, it negatively affects the survival rates and body size of mayflies (Winter et al., 1996). Anoxia decreases the burrowing depth of aquatic animals (Burd & Brinkhurst, 1984; Weissberger et al., 2009). Bjornn and Reiser (1991) recommended the hypoxia and anoxia threshold of 5 and 3 mgl^{-1}, respectively.

Temperature is also a major component affecting fish and the microinvertebrate community structure (Boon & Shiers, 1976; Daufresne et al., 2004). Preferred temperature is varied for aquatic animals; however, it is mainly between 8.5° C to 20° C for cold water animals (Allan, 1995; Elliott et al., 2000).

2.1.5 Algae and Aquatic Macrophytes

Effects of algae and aquatic macrophytes on benthic microinvertebrates can be beneficial or detrimental, depending upon the density of algae in the water (Dudley et al., 1986; Persson & Crowder, 1998). Algae and aquatic macrophytes provides nutrients for fry (Power et al., 1983; Power, 1990) and enhances the habitat variability and provides predation refuges (Kornijow & Gulati, 1992).

Conversely, algae blooms influence the stream water quality by affecting the dissolved oxygen and nutrients (Murdock et al., 2004; Zimmer et al., 2006; Vanni et al., 2006). Algae also can disrupt the habitat by smothering the streambed (Dudley et al., 1986).

2.2 Review of Methods for Assessing Embeddedness

This section will summarize common methods of evaluating the stream substrate habitat and will comment on the limitations and requirements. These techniques include several versions; however, the main principals as well as a comparison and contrast of these approaches will be discussed.

2.2.1 Platts/Bain Method

In the Platts/Bain method, embeddedness is estimated subjectively and is defined in the same manner as the rapid bioassessment method (Sylte & Fischenich, 2002). This method visually estimates the embeddedness in the thalweg in five percentage ranges: 0-5, 5-25, 25-50, 50-75, 75-100, which are described as negligible, low, moderate, high, and very high embeddedness, respectively.

2.2.2 Burns Method

The Burns method measures the area embedded within the streambed, inside a 60-cm hoop tossed on the streambed (Sylte & Fischenich, 2002). The embeddedness of at least 100 particles inside the hoop is evaluated visually. Embeddedness is similar to the rapid bioassessment and Platts/Bain methods. However, fine material is smaller than 6.3 mm, and large material is considered to be between 4.5cm to 30cm.

2.2.3 United States Fish and Wildlife Service-Upper Colorado River Measurement Method

In this method, the definition of embedded particles is similar to the rapid bioassessment method; however, the measurement method is dissimilar (Sylte & Fischenich, 2002). The embeddedness is estimated by evaluating the depth of embedded particles. To assess the depth of embedded particle, the index finger is extended down to reach the tip of the embedded layer and is referred to as embeddedness if more than moderate force is required. Twenty measurements per site are collected.

2.2.4 USGS National Water Quality Assessment Program Method

The embeddedness is defined similar to the rapid bioassessment method. The particle embeddedness depth, rather than the aerial percentage, of embedded particles is evaluated (Sylte & Fischenich, 2002). Five particles are randomly selected from the streambed, and the percentage of each particle's height buried in fine sediment is determined using a ruler or graded caliper.

2.3 Summary

Main streambed physical habitat components are fine material, gravel, epifaunal substrate, CPOM, LWD, algae, and aquatic macrophytes. Although several other biochemical components are important, this study focused on DO and temperature.

The assessment of streambed habitat components (Tables 2.1 and 2.2) is essential in evaluating the effect of physical processes on aquatic communities (Kaufmann et al., 1999). The streambed components listed in the Tables influence the aquatic habitat ecologically and hydraulically.

Table 2.1

Physical Habitat Components with Ecological Functionalities

Physical Component	Spawning Suitability	Nutrients and Food Resource	Bed Stability	Refugia and Sheltering
Fine Material				
Gravel	✓			
Epifaunal Substrate			✓	✓
CPOM		✓		✓
LWD		✓	✓	✓
Algae and Aquatic Macrophytes		✓	✓	✓

Table 2.2

Physical Habitat Components with Hydraulic Functionalities

Physical Component	Interstitial availability	Varying velocities	Creating flow depth	Bed Roughness
Fine Material				
Gravel	✓			
Epifaunal Substrate	✓	✓	✓	✓
CPOM		✓	✓	✓
LWD	✓	✓	✓	✓
Algae and Aquatic Macrophytes	✓	✓	✓	✓

CHAPTER III

PROPOSED PHYSICAL STREAMBED HABITAT COMPONENTS

This chapter describes components in a proposed streambed habitat. The definitions of components of the proposed classification system as well as determining stable epifaunal size are discussed in the following section.

3.1 Physical Parameters

Physical parameters are fine material (sand, silt, and clay); gravel; cobble; boulder; LWD; CPOM; algae; and aquatic macrophytes. Physical components in the proposed classification system should be measurable, accurate, and inexpensive under a range of hydraulic and sedimentary conditions in the field.

Preliminary field works show that the sampling of fine material in the wetted area is challenging, subject to error, and requires a large amount of samples. This is consistent with previous works (Graham et al., 2005; Storm et al., 2010). The upper boundary of fine material that is recognizable in this study is 2 mm. Therefore, due to the expense as well as inaccuracy in sampling fine grain materials smaller than 2 mm, these materials are grouped under the category of fine material. If material less than 2 mm covers and surrounds the material larger than 2 mm, it is referred to as embedded material (Kaufmann et al., 1999). Embedded gravel and embedded epifaunal substrate are used to categorize fine materials that cover or surround gravel and epifaunal substrate materials, respectively.

Materials larger than gravel have been referred to as stable epifaunal substrate in the streambed habitat characterizations (Platts et al., 1983; Kaufmann et al., 1999). The stability of epifaunal substrate particles is a function of channel geometry and flow magnitude (Buffington & Montgomery, 1997). Boundary shear stress is used to determine the stability of bed material. In this study, estimated shear stress is used to separate the upper boundary of mobile gravel from the lower boundary of stable epifaunal component. The details of the stable epifaunal substrate determination based on estimated shear stress are described in next section.

In general, based on the limitations and restrictions discussed, physical components are simplified by the following:

Fine Material: Inorganic materials with size smaller than 2 mm

Mobile Gravel: Inorganic materials smaller than stable epifaunal substrate that not contributing to stable habitat for aquatic animals. Determination of the mobile gravel size is based on boundary shear stress

Free Gravel: Gravel without recognizable fine materials in the surface layer that is frequently mobilized

Embedded Gravel: Combination of gravel and fine materials that is frequently mobilized

Stable Epifaunal Substrate: Inorganic materials larger than gravel that provide stable habitat for aquatic animals. Determination of the stable epifaunal substrate size is based on boundary shear stress

Free Epifaunal Substrate: Epifaunal substrate that is not surrounded or covered by fine materials

Embedded Epifaunal Substrate: Epifaunal substrate that is surrounded or covered by fine materials

LWD: Large woody debris (LWD) is defined as a wood piece with a minimum diameter of 10 cm that protrudes from or lays within a streambed (Lisle, 1986; Kaufmann et al., 1999)

CPOM: Coarse particle organic material (CPOM) is packed leaves not transported by a marginal spate (Kaufmann et al., 1999)

Algae and Aquatic Macrophytes Algae are numerous photosynthetic organisms in aquatic habitat ranging from single-celled forms to complex multicellular forms. "Aquatic macrophytes are floating, submerged, or emergent water plants" (Kaufmann et al., 1999).

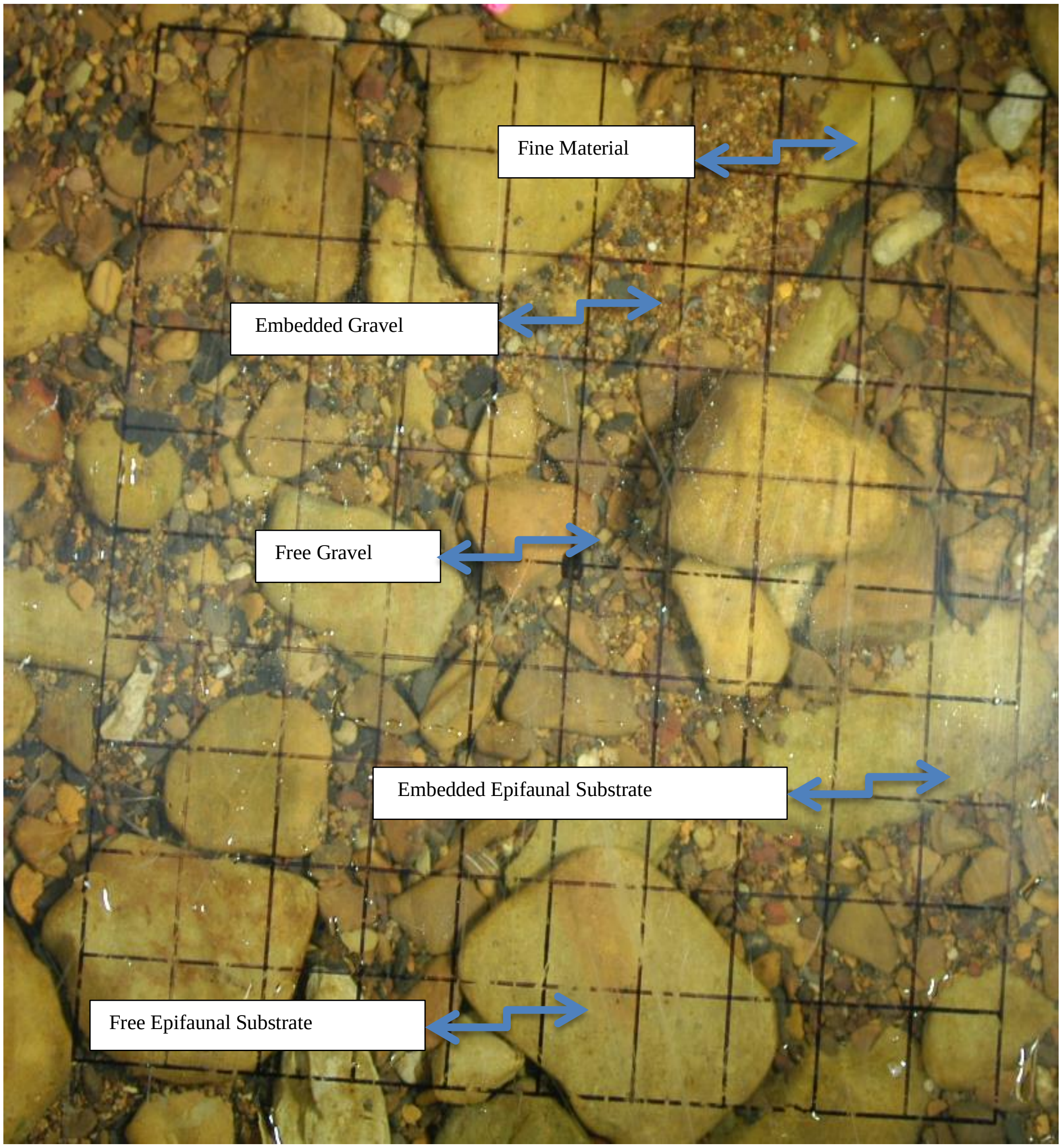


Illustration 3.1. Image recorded underwater using PPB with labeled streambed components.

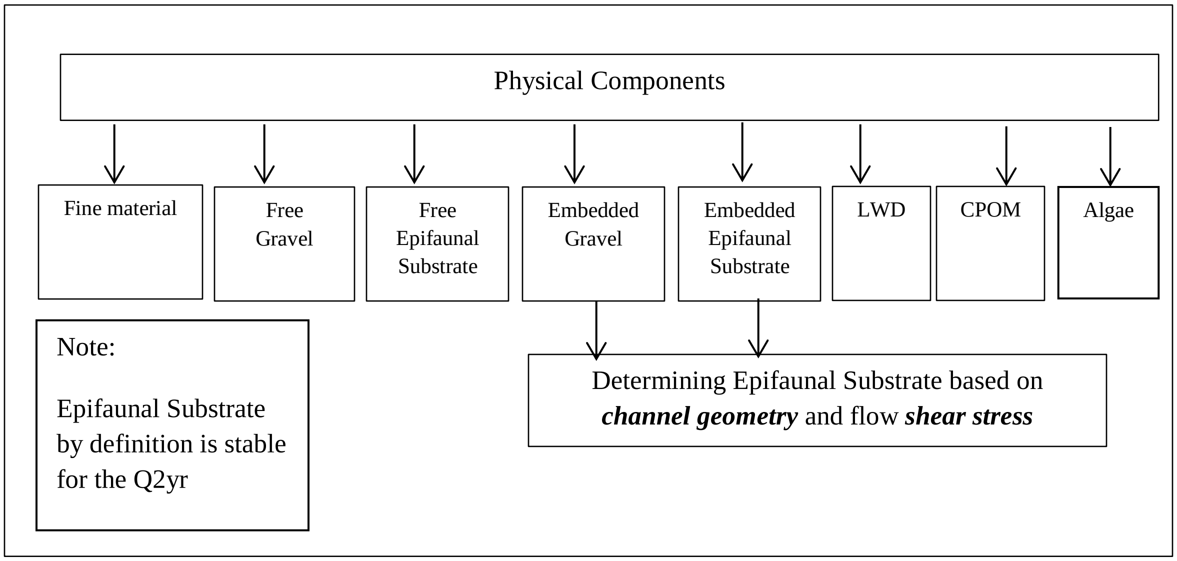


Figure 3.1. Diagram of proposed classification system.

3.2 Determining Stable Epifaunal Substrate

Determination of the stable epifaunal substrate is based upon the channel shear stress, which is a function of channel geometry and flow magnitude and is defined as the force created by the flow acting on the bed. It is a measure of the stream ability to entrain bed material per unit area (Buffington & Montgomery, 1997).

3.2.1 Shear Stress

The magnitude of stress is a function of water surface slope, channel geometry, and flow magnitude. The shear stress at threshold when the material is entrained is known as the critical shear stress (τ^*). The minimum size of stable epifaunal substrate is the size of streambed material mobilized when shear stress is greater than critical shear stress for a specified flow frequently coming from a biologic perspective. Hence, a knowledge of shear stress and critical shear stress is needed in determining the minimum size for stable epifaunal substrate.

The discharge (Q) is selected to maintain the stability of the streambed for sheltering and preventing drifting of fish and microinvertebrates during flood events. Therefore, flood recurrence interval is a function of life span of aquatic animals. The life span of most stream aquatic animals in Kentucky is less than two years (Dr. Bruccia, personal communication, November; 2011). Given these considerations, channel discharge with a 2yr return period (Q_{2yr}) is selected to determine the stable epifaunal substrate.

Average shear stress (Neill, 1968; Andrews, 1984; Detrich et al., 1989; Wilcock & McArdell, 1993; Buffington & Montgomery, 1997) is defined as:

$$\tau_0 = \gamma RS \tag{3.1}$$

Where:

τ_0 is reach average streambed shear stress (lb/ft^2 or N/m^2)

γ is specific weight of water (62.4lb/ft^3 or 9810N/m^3)

R is hydraulic radius (ft or m)

S is energy dissipation rate (ft/ft or m/m)

To compute shear stress with equation (3.1), water surface slope (S) and hydraulic radius (R) need to be determined. In natural rivers and streams, S can be approximated by streambed slope (Chow, 1959).

Streambed Slope: Riffle slope is determined as the difference between elevations over the riffle length along the middle thread of the channel (thalweg) from riffle crest to riffle tail (Kaufmann et al., 1999) (S_{Riffle}).

$$S_{Riffle} = \frac{(\Delta H)_{Riffle}}{(\Delta L)_{Riffle}} \tag{3.2}$$

Channel backwater from bends also can affect shear stress over riffles (Shepherd & Schumm, 1974), reducing channel shear stress by decreasing the water slope and streambed reach slope from that estimated from riffle slope. This is reflected in the streambed reach slope. The term S_{Reach} is the average slope between elevations (ΔH) over the length along the middle thread of channel (thalweg) from riffle crest to next pool tail (ΔL) (equation 3.3).

$$S_{Reach} = \frac{(\Delta H)_{Reach}}{(\Delta L)_{Reach}} \tag{3.3}$$

Hydraulic Radius: Hydraulic radius is expressed as the ratio of channel area to wetted perimeter (Chow, 1959).

$$R = \frac{A}{P} \tag{3.4}$$

Where:

A = Cross-sectional Area of channel (ft^2 or m^2)

P = the perimeter of channel (ft or m)

The hydraulic radius is determined from the Q_{2yr}, the Manning equation, and the Limerinos (1970) equation for roughness.

3.2.2 Critical Shear Stress

Critical shear stress is shear stress that measures the epifaunal substrate. Once τ^* (Shields parameter) has been assigned, the critical shear stress for an epifaunal substrate having a diameter of D is determined from equation (3.5).

$$\tau_c = \tau^*(\gamma_s - \gamma)D \quad (3.5)$$

Where:

τ^* = Shields parameter, dimensionless

R^* = grain Reynolds number = u^*D/ν, dimensionless

τ_c = critical shear stress (lb/ft^2 or N/m^2)

γ_s = specific weight of sediment (lb/ft^3 or N/m^3)

γ = specific weight of water (lb/ft^3 or N/m^3)

D = epifaunal substrate diameter (ft or m)

u^* = shear velocity = $(gRS)^{1/2}$ (ft/s or m/s)

ν = kinematic viscosity of the fluid (ft^2/s or m^2/s)

g = acceleration of gravity (ft/s^2 or m/s^2)

In order to determine substrate size using this equation, the Shields parameter (τ^*) needs to be determined. Four formulas were selected to determine Shields parameter (Buffington & Montgomery, 1997): Shields (1936), Neill (1968), Andrews (1984), and Wilcock and McArdell (1993).

Shields (1936) is restricted to uniform material. Natural streambeds rarely have uniform bed gradations. Neill (1968) determined $\tau^* = 0.030$ for gravel mixtures. Andrews (1984) found the equations (3.6 and 3.7):

$$\tau^* = 0.0384\left(\frac{d_i}{d_{50}}\right)^{-0.887} \text{ (Streambed with non-uniform surface grain size)} \quad (3.6)$$

Where:

d_i = Grain size for size i, ft or mm

d_{50} = median diameter of the subsurface material, ft or mm

$$\tau^* = 0.0384 \text{ (fully turbulent and non-uniform surface grain size streambed)} \quad (3.7)$$

According to Andrews (3.6 and 3.7), the critical shear stress for individual particles is valid when $0.1 < (d_i / d_{50}) < 1.85$.

Wilcock and McArdell (1993) conducted a series of experiments in the straight, rectangular flume to investigate the channel stability. They developed the following equation covering a wider range of grain size distribution with $0.77 < (d_i / d_{50}) < 17.30$.

$$\tau^* = 0.028\left(\frac{d_i}{d_{50}}\right)^{-0.45} \text{ (Streambed with non-uniform surface grain size)} \quad (3.8)$$

In the first step in determining the stable epifaunal substrate size, the Shields dimensional parameter and shear stress are determined using formulas (3.5 to 3.8). The stable epifaunal substrate size is then determined by equating shear stress to critical shear stress ($\tau_c = \tau_0$).

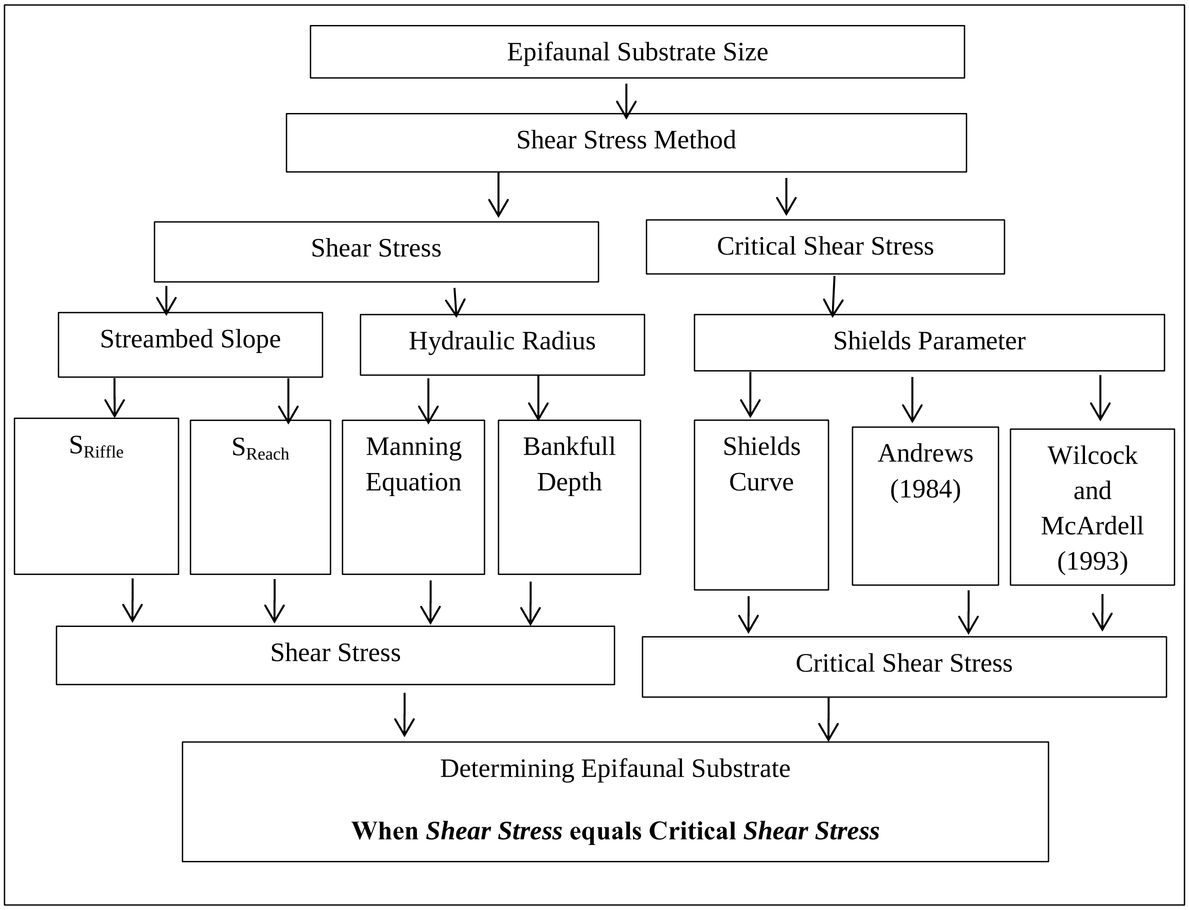


Figure 3.2. Epifaunal substrate size determination using shear stress.

The method for estimating stable epifaunal substrate size is:

1. Determine Q_{2yr}
2. Collect channel morphology slope and pebble count data
3. Produce grain size distribution using pebble count to determine d_{84} and d_{50}
4. Estimate S_{Riffle} and S_{Reach} using equations (3.2 and 3.3)
5. Estimate hydraulic radius
6. Determine τ_0 using equation (3.1) with slopes and hydraulic radius in steps 4 and 5
7. Estimate τ^* using equations (3.6, 7, and 8) and d_{50} of substrate size
8. Estimate stable epifaunal substrate size using equation 3.5 by forcing $\tau_c = \tau_0$
9. Compare estimated epifaunal substrate sizes based on a range of channel slopes and hydraulic radius and to evaluate the variability

3.3 Example Application

The following section presents an example of streambed components for a riffle located in the Wilson Creek. The Q_{2yr} for this riffle is 91.2 cfs. The $d_{84} = 0.328$ ft and $d_{50} = 0.164$ ft were estimated using the pebble count method. Riffle and reach slopes were measured as 0.008 and 0.007. The water depth and wetted cross section area were 1.25 ft and 18.23 ft^2, respectively.

Hydraulic radius (R) and τ_0 are shown in columns 5 and 6 in Table (3.1). The τ^* was estimated using formulas 3.10, 3.11, and 3.12. Estimated stable epifaunal substrate size (d_i) associated with each τ^* are presented in columns 7, 9, and 11.

Table 3.1

Determining Epifaunal Substrate Size (d_i) for Varying Hydraulic Conditions

		S	**R**(ft) **(5)**	τ_0 (lb/ft^2) **(6)**	**d_i(mm)** Equ. (4-10) **(7)**	**d_i /d_{50}** Equ. (4-10) **(8)**	**d_i(mm)** Equ. (4-11) **(9)**	d_i /d_{50} Equ. (4-11) **(10)**	**d_i(mm)** Equ. (4-12) **(11)**
Measured Area (ft^2)	18.23	0.008	1.76	0.87	**719.78**	14.40	**153.61**	3.07	**67.57**
	18.23	0.007	1.87	0.84	**498.86**	9.97	**142.34**	2.85	**64.86**
Measured Depth(ft)	1.25	0.008	1.25	0.62	**35.01**	0.70	**82.49**	1.65	**48.00**
	1.25	0.007	1.25	0.56	**14.04**	0.28	**68.43**	1.37	**43.29**

The term d_i /d_{50} for equations (3.10) and (3.11) are shown in columns 8 and 10, for both Andrews (1984) and Wilcock and McArdell (1993), respectively. According to column 8, the d_i /d_{50} is outside of the Andrews (1984) range. In contrast, the d_i /d_{50} measured using Wilcock and McArdell (1993) are in the range of formula applicability. However, d_i that was determined according to Wilcock and McArdell (1993) in column (11) is larger than cobble, which overestimates the epifaunal substrate size for low channel discharge. Therefore, d_i was determined based on the measured area variable for the Wilcock and McArdell (1993) equation and d_i was determined based on the measured area and measured depth variables from the Andrew equation are outside the application boundary constrains for substrate size and are eliminated from determining the substrate size (red numbers).

Among the d_i determined based on the measured depth parameter, quantities associated with the reach slope variable provide a more conservative value of substrate size than riffle slope quantities (row 4 vs. row 5 in Table 3.1). In addition, quantities of reach slope include the backwater effects, which might reduce the critical shear stress and affect the epifaunal substrate size.

Epifaunal substrate size measurement is selected based on two main parameters including measured depth and S_{Reach} parameters using equations (3.10, 11, and 12). The d_i based on these formulas is 14.04, 68.43, and 43.29 mm. Among them, 14.09 mm is related to medium gravel size material and is small for the selected channel discharge. Between the other two quantities (43.29 and 68.43 mm), 43.29 mm is selected as the substrate size lower boundary, as it gives a more conservative value.

Table 3.2 shows the epifaunal substrate size (d_i) for each riffle studied. The epifaunal substrate size was determined based on equation (3.12) using measured depth and S_{Reach} parameters.

Table 3.2

Determining Epifaunal Substrate Size (d_i) for Each Riffle

Riffle Name	1	2	3	4	5	6	7	8	9	10
d_i(mm) Equ.(3-12)	43.29	47.23	16.55	74.95	34.53	82.82	29.32	55.42	31.09	21.91

CHAPTER IV

STREAMBED PATCH SAMPLING METHOD

This chapter presents the sampling method of streambed components. The first section compares and contrasts current methods of physical streambed component measurement on the surface layer. The objectives are to (1) recognize restrictions and benefits of common techniques in analyzing habitat studies, and (2) choose an inexpensive, accurate, and easy-to-use method to quantify streambed components in the field. The second section presents the proposed sampling method. In this application, limitations and field application of the proposed method were considered in detail. In addition, an example of data analysis of the proposed method is presented.

4.1 Streambed Component Sampling Techniques

In this section, common methods of streambed component measurement are identified, compared, and contrasted to provide a context for the proposed method. The streambed evaluation techniques vary in accuracy and required efforts (Whitman et al., 2003) and include grid, visual, wax and adhesive material, and photographing techniques.

To better understand each technique, the assumptions and limitations are summarized based on research by Bunte and Abt (2001). The common features include fieldwork, laboratory work, type of equipment, necessary training, ease of implementation and accomplishment in the field, repeatability, accuracy, and field efficiency (Table 4.1). The proposed method and the approaches or techniques reviewed as part of the following summary are limited to those that sample the surface grain size distribution of a streambed. All other stream and streambed characterizations and properties, and related techniques involved in collection of subsurface sediments or suspended sediments in the column of water, are beyond the scope of this work.

The following Table summarizes the characterizations of techniques used to assess streambed material. The first column shows the key restriction parameters, and other columns highlight the status of each technique.

Table 4.1

Techniques for assessment of grain size distribution of streambed surface layer

Variable	Grid	Visual	Wax And Adhesive Material	Photographic
Fieldwork duration (High or Low)	High	Low	High	Low
Laboratory work duration (Limited and Long)	Limited	Limited	Long	Long
Equipment	Limited field	Limited field	Laboratory equipment	Field and laboratory
Training	Moderate	Significant	Moderate	Limited
Ease of accomplishment in the field	Restricted to channel and flow conditions	Easy	Restricted to channel and flow conditions	Easy
Repeatability	Repeatable-intrusive	Non-repeatable-non intrusive	Repeatable-intrusive	Repeatable- non intrusive
Accuracy	Unknown	Unknown	Unknown	Unknown
Field efficiency and suitability according to streambed material type	Gravel	Gravel	Fine material	Gravel

The following paragraphs provide definitions and descriptions of terms associated with stream fieldwork and methods for stream characterization.

Fieldwork: Fieldwork implies conducting a test or measurement or obtaining a sample at the stream site location, which provides an opportunity to observe and measure a stream in its natural and undisturbed setting. A great number of surface sampling methods can be used, i.e., the grid method uses a grid to identify and collect the pebbles, and the wax technique utilizes wax or clay to obtain the pebbles from the streambed surface. One constraint on the application of grid and wax methods is the significant amount of field time required to obtain a sample. In contrast, visual and photographic techniques require much less fieldwork time to sample components of a streambed, but require much more data review and processing time (around 1-2 hours for the visual method vs. 8 hours for the grid or wax method per riffle).

Laboratory work: Laboratory work typically deals with evaluation of physical materials collected at a stream site and transported back to the test facility location. Evaluation and processing of digital data collected in the field can be performed in a digital or computer laboratory, and these effects can be attributed to laboratory time. Grid and visual approaches require limited or no laboratory work. However, photographic and wax techniques involve a substantial amount of laboratory work for construction and analysis of grain size distribution.

Equipment: Grid and visual techniques require limited field equipment and require items such as a ruler or a gravelometer, while photographic and wax techniques require either field equipment or laboratory equipment, or both. In phototropic methods, a camera is needed to record an image of the streambed; and commercial software, which may involve significant expense, is required in the laboratory to review, process, and evaluate streambed characteristics of interest. However, in wax and adhesive methods, inexpensive materials, such as clay, are used to segregate the surface components from the subsurface on site and in the laboratory, and mechanical sieving is utilized to obtain and construct a grain size distribution.

Training: Training is minimal for proper use of the photographic technique, while moderate training is required for grid and wax techniques. In the use of the visual evaluation technique, significant training and experience is needed to minimize errors in estimating of grain size distribution.

Ease of accomplishment in the field: Photographic and visual techniques can be easily accomplished in the field. In contrast, grid and wax methods are more limited in swift current or slippery streambed conditions.

Repeatability: The precision of grid, photographic, and wax techniques is quantifiable. However, the visual technique involves an inherent subjective bias associated with the observer, which prevents meaningful comparison between observers. No reliable method exists to quantify precision. Tracking spatial and temporal changes in streambed components through the use of grid and wax techniques is not possible due to the intrusive nature of techniques. Both photographic and visual techniques are non-destructive approaches and leave the streambed intact.

Accuracy: Both grid and visual techniques allow for operator and statistical errors. Grid samples underestimate fine materials and overestimate larger particles such as cobble. Visual methods tend to overemphasize the frequency of fine gravel when the deposit consists mainly of fine gravel and overestimate the frequency of coarse particles in deposits consisting mainly of coarse gravel. The photographic technique underrepresents fine material, whereas the wax technique underrepresents cobble and larger material. Therefore, the true grain size distribution of the population sediment is unknown in any technique.

Field efficiency: Grid, visual, and photographic sampling techniques are suitable for a gravel streambed; however, these approaches neglect sand and finer materials. In contrast, wax and adhesive material techniques focus on sand and fine material but are incapable of sampling gravel size materials.

In summary, limited laboratory time and field equipment indicate that the grid sampling technique is an inexpensive method for sampling streambed components. This technique is easily accomplished in most streambed and channel conditions. However, it is a destructive method, and the precision of the estimate of volume of fine sediment is high uncertainty.

The visual estimation method is inexpensive, rapid, and practical in the field. However, this technique is highly subjective due to observer judgments, is shown to be non-repeatable, and has unknown accuracy.

The wax and adhesive materials technique is mainly used to sample fine surface material in a small sampling area (Fripp & Diplas, 1993). This technique is expensive, difficult to use in the field, and intrusive in nature.

The photographic technique is relatively easy to use in the field. As a non-intrusive method, this technique requires limited field time and training to collect streambed images. As digital camera and image processing software, both required as field and laboratory tools, are readily and economically available, the photographic technique is a relatively inexpensive method and is repeatable and suitable for gravelly streambeds. In general, photographic techniques facilitate non-destructive sampling of gravel and cobble beds with substantially limited field time. Thus, photographic techniques are an economical choice when field time is limited, although significant laboratory time is needed for data processing and image analysis.

The main purpose of this study is to identify a process capable of characterizing the streambed components in the field in an inexpensive and efficient manner. Thus, features associated with the wax and adhesive material technique that have limited feasibility in the field lead to their elimination. Despite economical and ease of accomplishment in the field, the visual technique is subjected to personal bias, with limited efficiency to track changes in the local trend in aquatic habitat communities (Roper & Scarnecchia, 1995). These concerns eliminated the visual and wax techniques as consideration for this project.

In summary, the two techniques, photographic and grid sampling, were the approaches selected for further investigation based on economic efficiency, ease, and precision. The focus was to develop an in-situ technique for evaluating streambed components. The selected sampling technique is a combination of the appealing features of photographic and grid sampling methods. Photographic and grid sampling techniques can be performed at a variety of spatial scales. As an in-situ assessment technique for streambed component evaluation, this approach could provide a method requiring less time and less variance in results than traditional methods.

Both techniques have application limitations and restrictions, particularly in shallow areas. These limitations are discussed in detail in the following sections to explain their application in hydraulic and sedimentary conditions.

4.2 Photographic Technique

This section presents a review of the photographic techniques for identification of substrate components. In photographic aerial sampling, a photograph of the streambed surface is used to estimate the projected aerial surface of visible streambed particles by recording streambed image and manual digitization.

Ibbeken and Schleyer (1986) developed a photographic technique to characterize streambed components in open unconsolidated gravel without fine materials. By manual digitization, they identified the grain size diameter as small as 10 mm and acknowledged that the accuracy of photo sieving is comparable to mechanical sieving.

Whitman et al. (2003) used a photographic technique to characterize coarse (> 2 mm) and fine (< 2 mm) substrate particle sizes and compared results with other sampling techniques, such as

Wolman (1954) pebble count and Platts et al. (1983) embeddedness. Results revealed that the photographic technique oversampled pebbles in comparison to the pebble count technique, which was significantly different than the Platts et al. (1983) method. As opposed to other methods, the photographic technique is considered to be a rapid and accurate measurement without disturbing streambed. The researchers suggested employment of the photographic technique in streams with a minimum of 8 cm effective water depth.

Wang et al. (1996) argued that the photographic technique for analyzing substrates is limited to clear shallow areas and takes considerably longer time than visual techniques. Photographing a sediment surface requires less field time per sample, while the analysis of the images requires a relatively large amount of laboratory time. Graham et al. (2005, 2010) attempted to reduce laboratory time by developing the gravelometer, which is software to automatically digitize the streambed photo and eliminate manual identification of grain size. Extracting grain size information from several streams with a range of lithology and hydraulic conditions highlighted that automatic grain size digitization can substantially reduce laboratory time. They claimed a reduction in laboratory time from 5 to 16 % of traditional methods, such as the grid technique.

Image quality was found to be a prime restriction in using this software. A common issue in wetted areas is poor image quality such as grain, glare, and blur. Grainy problems are due to the low intensity light situation. Glare occurs due to back reflection of ambient light, and blurry images result from camera movement or improper shutter speed. Moreover, an imperfect lens can induce tilt and distortion, as well as an increase in error in measuring grain size.

In addition to camera-related issues, software problems limit the ability to distinguish each grain edge, resulting in undercounting. Large materials are over segmented to smaller materials, and smaller materials are under segmented to larger materials. Therefore, the application is not recommended for materials less than 16 mm. Another disadvantage is software cost, in comparison to the visual method with limited material costs (Table 4.2).

In summary, issues in methods and challenges regarding collection, processing, and analysis of streambed component images are summarized in Table 4.2. The first column shows the issues; the second column is a brief explanation; and the third states the process, stage, and reference citation.

Table 4.2

Limitations of Photographic Technique in Grain Size Distribution of Streambed Surface Layer

Problem	Explanation	Consideration
Grainy	Low intensity light situation	Image collection problem (Graham et al., 2010)
Glare	Low quality picture due to back reflection from ambient light to camera	Image collection problem (Graham et al., 2010)
Blurry	Low quality picture due to movement of the camera and slow shutter speed	Image collection problem (Graham et al., 2010)
Lens distortion	Picture distortion due to wide lens	Image collection problem (Graham et al., 2010)
Tilt	Picture distortion due to tilted camera installation	Image collection problem (Graham et al., 2010)
Minimum depth requirement	8 cm minimum required for lighting	Image collection problem (Whitman et al., 2003)
Under and over grain count	Grain edge problem	Image processing problem (Graham et al., 2010)
laboratory time	Laboratory time involved in analyzing and processing for construction grain size distribution	Image analysis problem (Wang et al., 1996)
Material cost	Camera and software cost	Image collection, processing, and analysis problem (Whitman et al., 2003)

Details of each problem group are reviewed in the following section order to avoid each issue and to develop a modified imaging for streambed component measurement.

4.2.1 Image Collection Problems

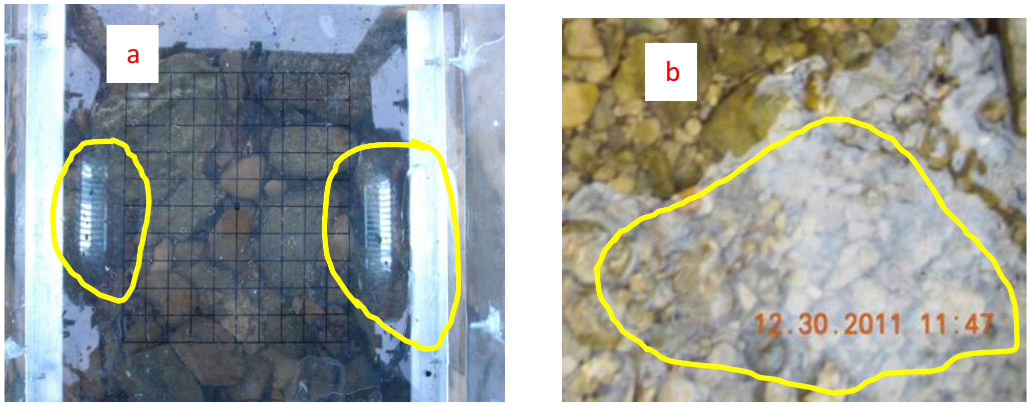
A digital image of a streambed sample area can be utilized to determine or estimate streambed component features. Thus, it is important to acquire a high quality photograph. The challenges in recording a high quality picture in a shallow water area, such as riffle. A *riffle* is a short and coarse-bedded section of stream with relatively shallow and high velocity flow in relation to other reaches of stream (Illustration 4.1), resulting in increased velocity and higher turbulence ripples from the water surface. Consequently, imaging the streambed is challenging, and collection problems often result in grainy, glare, and blurry images (Graham et al., 2005, 2010).

Technically, digital imaging results when a camera releases a burst of light that strikes objects. Some of the light then bounces back to the camera, generating an image. A streambed may include grains with a variety of textures and colors ranging from dark to bright. Dark materials absorb much of the light and reflect small amounts of the light back to the camera. In contrast, light reflected directly back at the camera from bright materials and thus not much is absorbed may overwhelm the sensitive light detectors resulting in less absorption. Therefore, in the streambed with a variety of colors and textures, a camera may produce low-quality images, which may be of limited use in streambed classification. Grainy and glare problems are a result of light reflecting back into the camera from grains of varying colors.

Grainy image is due to low light intensity reflected from dark materials (Illustration 4.2.), whereas glare is high intensity light from bright material (Illustration 4.3.).

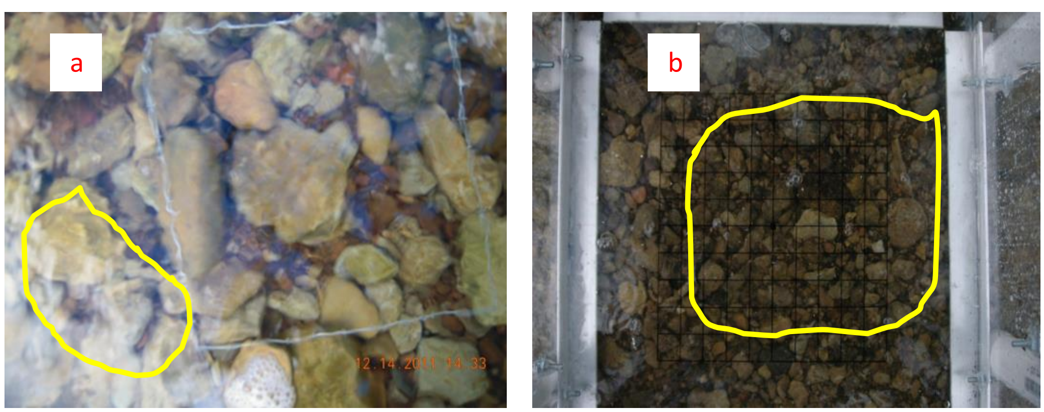
Illustration 4.1. Typical riffle in bluegrass in Kentucky, USA.

Illustration 4.2. Examples of grainy problems in image collection.



<u>Illustration 4.3a and 4.3b.</u> Examples of glare problems in image collection.

<u>Illustration 4.4a and 4.4b.</u> Examples of glare problems in image collection.



<u>Illustration 4.5a and 4.5b.</u> Examples of motion of camera problems in image collection.

To address grainy and glare problems, a device was constructed to control the lighting conditions using artificial lighting to create a consistent ambient light source. The instrument is referred to as a portable photographic box (PPB), with the intent to improve image quality in shallow and swift currents, such as riffle. The PPB was evaluated under a range of hydraulic and sedimentary conditions and found to be more time and cost efficient than the current methods for streambed grain size measurements. Data collection and preliminary evaluation were accomplished in the field for one year in order to identify issues with grainy, glare, blurry, lens distortion, tilt, and minimum depth requirement. The sources of errors are as follows:

Grainy: Insufficient light source (Illustration 4.2)

Glare: Light reflection from particles (Illustration 4.4a), wave (Illustration 4.3b), PPB (Illustration 4.4a), water surface (Illustration 4.4b), flow (Illustration 4.5a), and bubbles in water (Illustration 4.4b)

Blurry: Motion of camera and PPB (Illustration 4.5a)

Lens distortion: Imperfect lens

Tilt: Camera and PPB tilting

Minimum depth requirement: Insufficient light source (Illustration 4.3a), glare from beneath the box (Illustration 4.2a), and turbidity

Construction and Use of the PPB: The Portable Photographic Box (PPB) was constructed to improve the picture quality by providing sufficient and consistent light conditions. The PPB is constructed of a Plexiglass sheet (Illustration 4.6a) and sealed with aquarium glue to prevent intrusion of water inside the box. Each side of the bottom area is 1.5 ft. long, with height of 2 ft. due to the minimum distance of the camera from the substrate in order that materials as small as 2 mm can be recognized. The high of the box was chosen as 2 ft. through trial and error in the field. The area to be photographed, with 2 mm materials still recognizable, was 1 ft. A small area was added to correctly measure the grain at the edge of the predefined area. Therefore, each side of the bottom area was raised to 0.5 ft. to 1.5 ft. by 1.5 ft. The box with a side length of 1.5 ft. by 1.5 ft. at the bottom area and a height of 2 ft. was constructed from a scratch-resistant Plexiglass sheet. Plexiglass is clear in color to identify grains under it, and is firm and scratch-resistant, which is appropriate for rough streambed conditions such as riffle. The photographic box was inserted into the aluminum frame (Illustration 4.6b) to enhance its resistance against external forces. A small box, referred to as a *camera holder*, was installed on top of the main box to prohibit the camera from shaking and falling into the water while recording the image.

Illustration 4.6a and 4.6b. Plexiglass sheet (a) and aluminum frame (b) used in construction of PPB.

Lightning conditions also is an issue with the PPB. Lightning inside the box was insufficient and inconsistent (Illustration 4.7a and 4.7b). Several field tests were conducted during winter 2010 to evaluate natural and artificial lighting sources. As natural light is a less reliable source for photography, especially in the winter, light situations should be controlled through artificial lighting sources such as an external LED.

Two LEDs (Husky 180 LED rechargeable work light) were installed in both sides of the PPB (across from each other) to illuminate the streambed and record images without the requirement of high ISO. Testing LED (Illustration 4.8) in varying places and angles inside and outside of the box illustrated that the outside LED caused less reflection problems on the bottom of the box. Therefore, the upper end of the LED was installed at the height of 1.5ft. from the bottom. The bottom end of the LED was attached by chains to the box sides to affix them at a 45-60 degree angle (Illustrations 4.9a and 4.9b). Installing two powerful LEDs across from each other outside of the PPB provided a sufficient light source for photographing streambed components without the requirement of natural light or a flashlight. Both sunlight and a flashlight can cause glare inside the box.

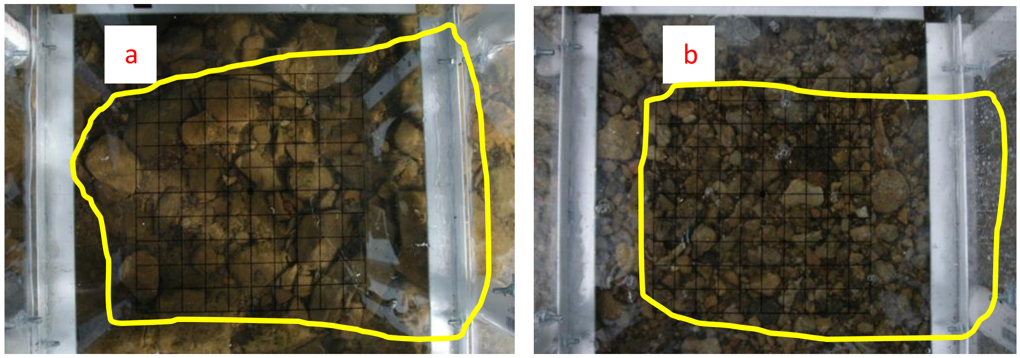


Illustration 4.7a and 4.7b. Light inconsistency (a) and light insufficiency (b) problems in image collection.

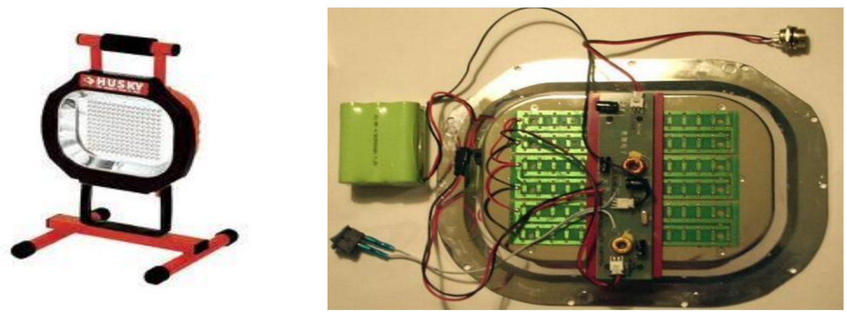


Illustration 4.8. LED-Husky 180 LEDs rechargeable work light.

(Source: http://reviews.homedepot.com/1999/100655277/husky-180-led-portable-work-light-reviews/reviews.htm).

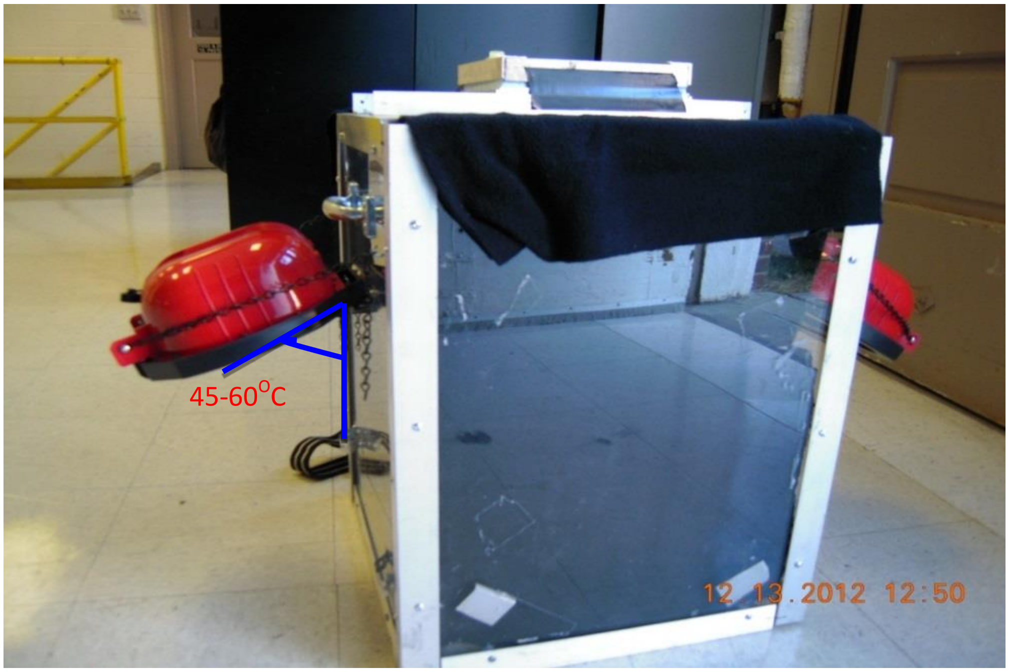


Illustration 4.9a. Installation of rechargeable LEDs on PPB.

Illustration 4.9b. End attachment and using chain in LED installation.

To eliminate the reflection effects from outside the box, and also shadows on a predefined area inside the box, a non-reflective cloth (Illustration 4.10a) covered the sides (inside and outside). A piece of non-reflective cloth also covered the upper side in order to remove reflection of natural light from the top of the box. The non-reflective cloth eliminated the issue of light inconsistency across the box. Preliminary field tests revealed that the two LEDs across from each other as a light source outside the PPB and the non-reflective cloth as a cover to control the light conditions and grainy and glare problems produced a sufficient and consistent light source inside the box.

Another issue was the problem of blurry. A number of factors cause blur, including lack of focus (entire frame); depth of field (focus on wrong element); camera shake (hand-held, shutter too slow); and motion (not fast enough shutter speed). Focus and depth of field are dependent upon the experience and skill level of the photographer. However, camera shake and motion blur (PPB shake and moving object) are two issues that are discussed in this section.

In order to affix the camera inside the holder box, Expanded Polystyrene Foam (EPF) was used (Illustration 4.10b) and shaped according to the camera shape (Illustration 4.13b) to tighten the camera inside the box and prevent shaking. Shaking PPB and moving objects in the frame also have contributed to image blur. Shaking the PPB is due to the current speed and wave, particularly during high events. Moving object issues are due to suspended fine materials in the water column.

a b

Illustration 4.10a and 4.10b. Non-reflective cloth (a) and Expanded Polystyrene Foam (b) used in camera box.

In order to deal with motion blur, several methods of the PPB deployment tested on the site included adjustable legs, increasing the water depth, and pushing the box through the water. Although adjustable legs established the PPB on the streambed and prevented shaking, it was cumbersome and time consuming to set up in the field, with limited efficiency in uneven and slippery conditions. The second attempt was to increase the water depth, which can reduce the water speed and lessen shaking and moving object problems. However, increasing the water depth was less efficient in most of the riffles studied due to the limited amount of stream flow. The last method was to push the PPB into the water column. Field tests confirmed that this method increased the image quality substantially. Details of this technique follow.

The PPB was pushed through the water column to contact the streambed substrate and was firmly held for 5 seconds on the substrate to avoid PPB shaking. An image of the streambed was recorded to conduct streambed component measurement and analysis. The entire process, including set up and recording the image, was 20 seconds in length, resulting in a significant improvement in the image quality.

By pushing the PPB into the water column, water surface became stagnant, and both current and wave were dumped. This allowed water flowing under the box to become still and to freeze moving objects. The result was no shaking of the PPB and no moving objects. This is a breakthrough in studies of streambed habitat. By contacting the PPB with substrate, blurry images due to shaking PPB and moving objects were avoided. Also, the minimum water depth needed to record an image from the streambed was no longer an issue. In setting up the box on the streambed surface, it is a possible to sample the streambed using the photographic technique, even with the presence of turbid water during high flow events, as no column of turbid water occurred between the camera and the substrate to prevent sampling. The contact of the PPB with the streambed surface also remove light reflection from outside the box and bubble.

Regarding the issue of PPB tilting, a small circular lever (Illustration 4.11a) was installed on the top of the holder box to monitor camera and PPB level while recording the image in the streambed.

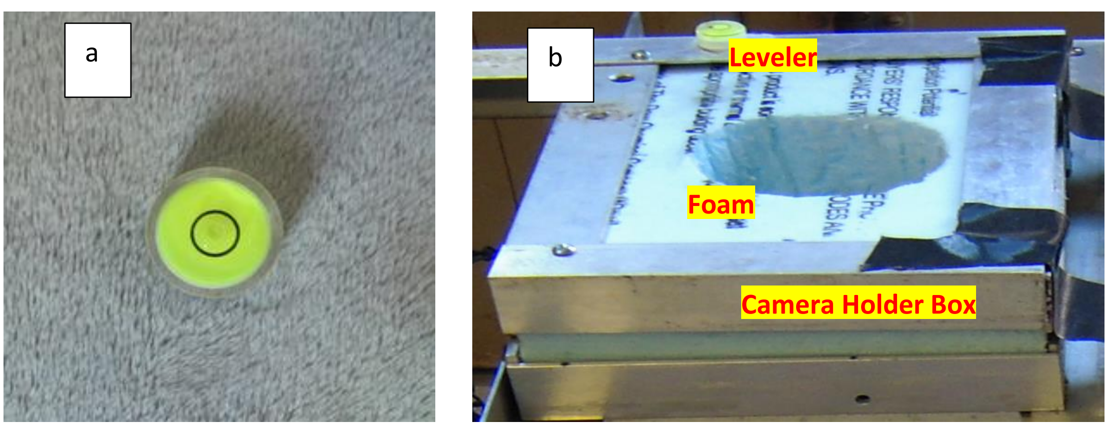


Illustration 4.11a and 4.11b. A small circular lever (a) and camera holder (b).

In terms of lens imperfection, Graham et al. (2005, 2010) reported that lens imperfection has an insignificant impact on estimating grain size in the photographic technique. Lens imperfection will be discussed further in the next section on Grid Technique. However, this issue has a limited effect on the end results.

In summary, PPB issues that included grainy, glare, blurry, tilt, and minimum depth requirement in collecting image data were avoided. The portable box is beneficial in recording an image from the streambed surface with conditions such as turbid water. The PPB also can be beneficial for management in collecting real time samples of spawning habitat reactions to the intrusion of fine sediments during the flood events.

Two handles were installed on the sides of the box to firmly hold the PPB while recording images, and two shoulder handles were installed for transport in the field (Illustration 4.12a and 4.12b).

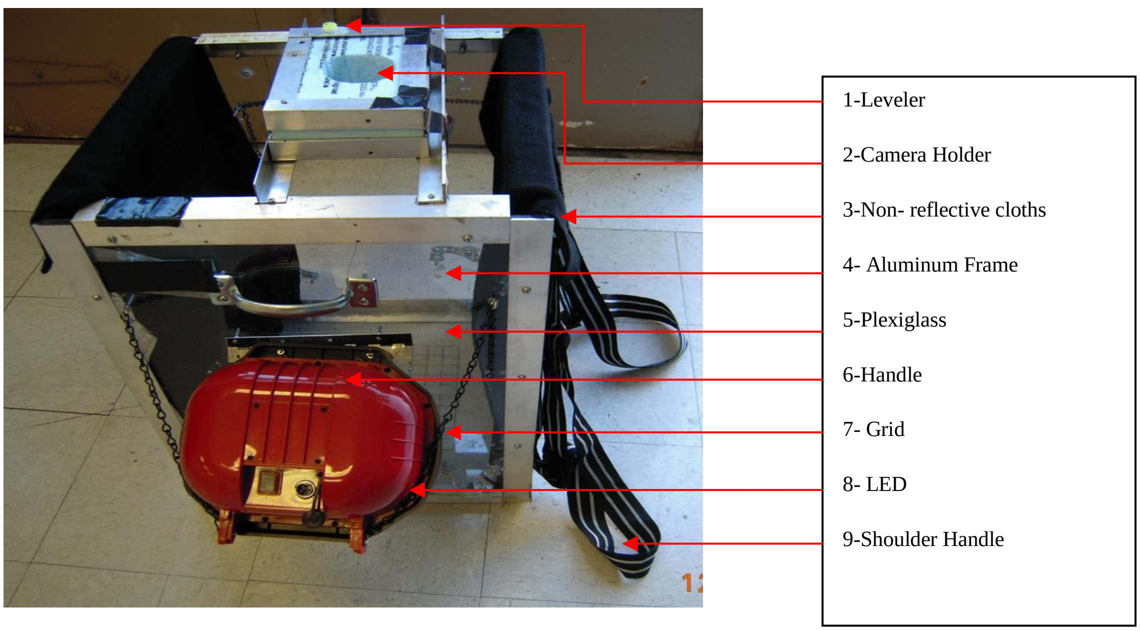


Illustration 4.12a. Portable Photographic Box (PPB) and parts.

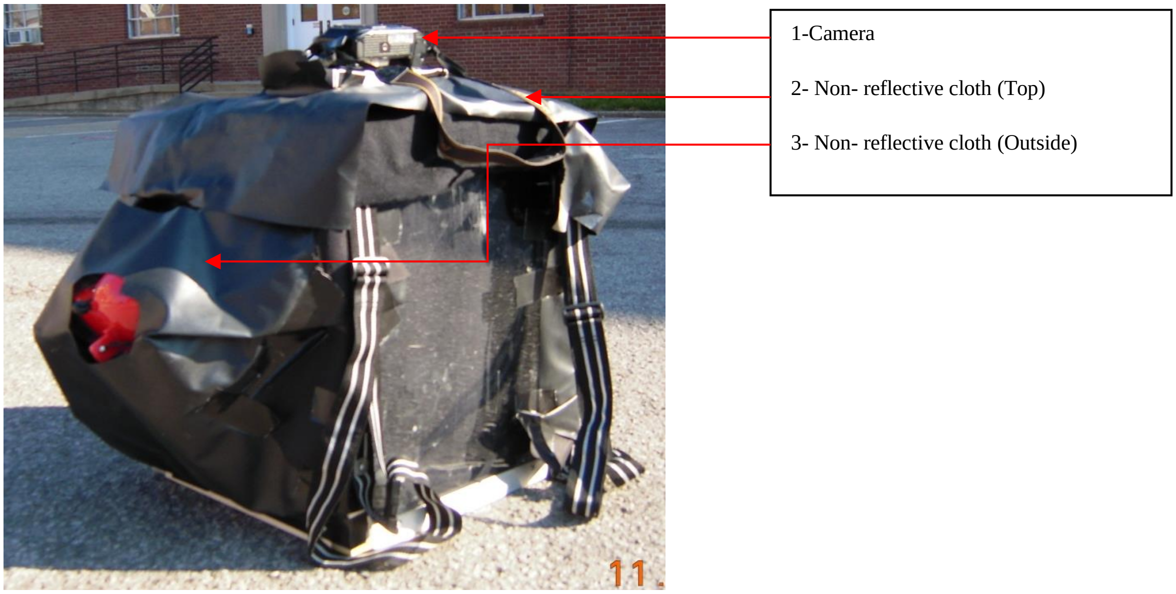


Illustration 4.12b. PPB and installed camera and non-reflective cloth on top and outsides.

The following section describes the construction of the Portable Photographic Box (PPB).

1. Construct a box with firm and scratch-resistant Plexiglass (square bottom dimension of 1.5 ft. by 1.5 ft. and height of 2 ft., with an open top)
2. Waterproof the box using aquarium glue to prevent water entering the box while recording
3. Install aluminum frame around the box to improve resistance against external forces
4. Install two LEDs outside the box, with a 45-60 degree angle toward the bottom
5. Install non-reflective cloth inside and outside the box to eliminate reflection from inside the box
6. Install a camera holder on top of the PPB and EPF inside the holder to prevent camera shake while recording
7. Install a lever on top of the camera holder box to monitor the PPB tilting
8. Install two handles for transport in the stream
9. Install two shoulder handles to transport in the field

The following steps are required to record an image from the streambed components.

1. Install the camera in the camera holder frame
2. Attach the top non-reflective cloth to the top of the PPB

3. Turn the LEDs and camera on
4. Stay downstream of box to prevent disturbing the water, and push the box to the bottom of the streambed
5. Hold the box firmly for 5 seconds and level the box using the leveler
6. Record an image

4.2.2 Image Processing Problems

The main limitation found in image processing is to accurately recognize the particle edge of two adjacent particles, which results in an overestimate and underestimate of the pebble size (Graham et al., 2005, 2010). Graham et al. (2010) suggested manual adjustment of grain size after auto digitization using the gravelometer software.

In this study, rather than the use of software to obtain streambed components and manual adjustment, manual digitization was utilized to isolate streambed components due to high quality picture requirements of the gravelometer to generate valid results. Over and under segmentation in materials is avoided through manual digitization of streambed components.

4.2.3 Image Analysis Issues

The weakest link in the use of photographic techniques for streambed component evaluation is the laboratory time required for processing and analyzing component information. Auto digitization was used to overcome this issue (Graham et al., 2010); however, the gravelometer distorted grain size distribution in favorite of gravels and required manual particle adjustment.

The amount of time needed for manual digitization in the proposed classification system is substantially reduced, as the image is digitized based on habitat components rather than on individual grains. Preliminary results confirmed that three minutes were required to manually digitize a picture. Moreover, eight hours are necessary to manually digitize a riffle population with an average 200 recorded images. This amount of time is equal to the time involved in digitizing and manually adjusting 200 pictures using the gravelometer software or equals the traditional method of grain size distribution of riffle such as pebble count. Therefore, the time required for digitization in the proposed classification system is reasonable for processing and analyzing streambed components.

Another critical issue in picture digitization is material cost, which includes camera and software. A typical camera can be used to record images from the streambed and, with manual digitization, no specific software is required. In this study, images were inserted into AUTO CAD and manually digitized. However, images also can be saved on a PC and opened in commercially available software, including Microsoft Word, and then digitized. This software, is accessible on a PC, therefore incurring to additional expense.

Table (4.3) summarizes complications in the implementation of photographic techniques and possible solutions. Column one shows the typical issues with recording high quality images from the streambed components. Columns two and three describe the possible explanation and solution for each problem.

Table 4.3

Image Processing and Image Analyzing Limitation of Photographic Technique in Grain Size Identification

Problem	Explanation	Solution
Grainy	Low intensity ambient light	Using LEDs installed outside PPB across from each other
Glare	Low quality picture due to back reflection from ambient light to camera	Using non-reflective cloth inside and outside the PPB
Blurry	Low quality picture due to movement of the camera and slow shutter speed	Using camera holder box and setting up PPB on the stream substrate
Lens distortion	Image distortion due to wide lens	Using grid sampling technique
Tilt	Image distortion due to tilted camera installation	Using a circular leveler
Minimum depth requirement	8 cm minimum required for lighting	Contacting PPB with streambed substrate
Under and over counting grains	Grain edge problem	Manual digitization
Long laboratory time requirements	Laboratory time involved in analyzing and processing for construction grain size distribution	Using proposed classification system to reduce the time involved from long to medium laboratory time
Material cost	Camera and software cost	Using available software and manual digitization

Illustartions 4.13 and 4.14 are examples of recorded images from streambed components using the PPB in the bluegrass area in Kentucky, USA.

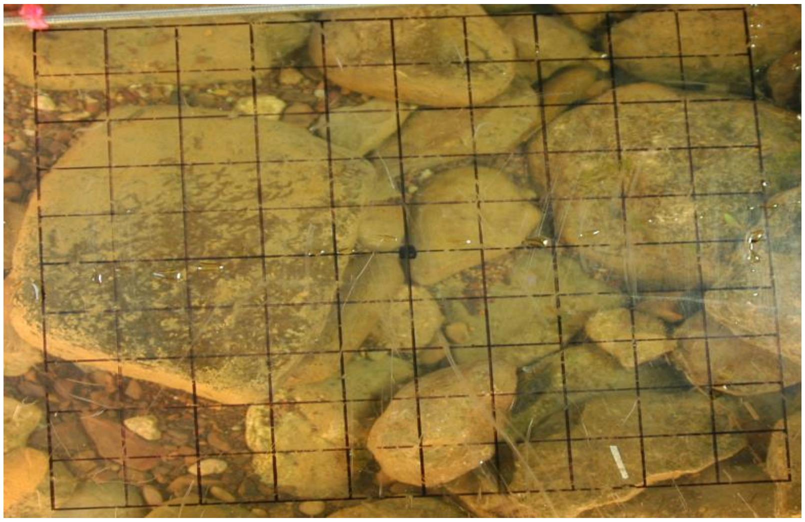


Illustration 4.13. Example of image recorded from the streambed components using PPB.

Illustration 4.14. Example of image recorded from the streambed components using PPB.

4.3 Grid Samples

The basis for grid sampling was presented in a study by Wolman (1954). The grid sample could sample the wide range of grain size surface strata. To obtain the sample, a grid is established over the stream reach of interest; the particles below each grid point are removed by hand and tallied.

The advantages of grid sampling are summarized as follows (Wolman, 1954; Kondolf, 1996):

- Procedure is simple to perform and limited specific field equipment is required to implement the grid sampling technique in the wetted areas.
- The sample is representative of the entire stream reach and suitable for large areas rather than small areas similar to a patch.
- Procedure is flexible and practical to many geographical streambed units.
- Correlations and comparisons can be made between subsets.
- Limited laboratory time is required.
- Grid sampling can be particularly useful when less prior knowledge exists on within field variability.
- Sampling bias is avoided that could result from the collection of an unrepresentative composite sample due to a high portion of subsamples collected from the same region or patch.

The disadvantages of the grid sample can be summarized as follows (Bunte & Abt, 2001):

- The technique is under sampling the fine material.
- The sample is less representative of the entire stream reach population with limited suitability for patch sampling.
- The sample is less repeatable and disturbs the streambed.
- The procedure is ambiguous.
- It is an expensive technique for sampling highly heterogeneous streambed populations that could result from the collection of a large portion of subsamples.

Despite the above problems, grid sampling was utilized in this study to sample streambed components in the field. In this regard, a combination method of the grid sampling and the photographic technique was developed to overcome the expense and accuracy issues of the grid sampling techniques.

In the proposed method, an attempt was made to find a balanced approach between accuracy, precision, expensive, and ease of use in the field regarding estimation of streambed components. In the previous section, efficiency of the photographic technique in the field was discussed by introducing the PPB in the proposed classification system. In this section, grid sampling applicability in the field is reviewed. Two important issues in the grid sampling method are patch size and cell size (Bunte & Abt, 2001). Both variables of patch size and cell size (cell resolution) are considered in the following section. Patch is composed of spatially distinct textural grains of differing particle size and sorting. Cell size is equally distant spacing between the intersection points of the grid.

4.3.1 Patch Size

The patch size refers to the size of an area that can be photographed in one shot. The maximum streambed area in which materials as small as 2 mm are recognizable in the proposed classification system is 1 ft. by 1 ft. based on fieldwork, as was concluded in the photographic section. Therefore, the maximum patch size is similar to the size recommended by Buffington and Montgomery (1999) and Fripp and Diplas (1993). If the patch size is greater than 1 ft. by 1 ft., more than one image will be needed to cover the area and the images matched or a panorama of the patch size would be used.

4.3.2 Cell Size (Cell Resolution)

Cell resolution, or cell size, is a key factor in the grid sampling technique, as both accuracy and economic issues are related to the cell size. Preliminary field data indicated that, when the cell size was too large, the accuracy of grid sampling in the evaluation of the streambed components is significantly reduced. In contrast, when the cell size is small, the time involved in the estimation of the streambed components is increased substantially and sampling grid is less economical. Given these limitations, the main goal of this study is to obtain a simple, but accurate, sampling grid that is a tradeoff between accuracy and simplicity in categorizing streambed components. The objectives are to find an appropriate cell size in the grid sampling method that balances accuracy and economy in the proposed classification system. In addition, the sampling grid should be inexpensive and easily accomplished in the field.

In order to find the appropriate cell size, 130 patches were visually inspected in accordance with the Buffington and Montgomery (1999) method and carefully photographed. Selection of patches covered a range of components. Each image was digitized manually, and the projected aerial percentage of each component was estimated and recorded under the title “True projected aerial percentage”.

To provide a measurable, but accurate, grid sampling method in estimating streambed components, the following visual method was accomplished. A virtual grid with the openings listed in Table 4.4 was included on each image, and the aerial percentage of each component was estimated in each cell of the grid with two trials. In the first trial, each cell was divided in two equal portions; and the component, which covers the area greater than one portion, was allocated the entire aerial percentage of the cell (Illustration 4.15a and 4.15b). The first trial refers to 50% of the incremental projected area. In the second trial, each cell was divided into three equal portions, of which each component occupied one, and a 33 aerial percentage of the cell was allocated to that component (Illustration 4.15c). The second trial refers to 33% of the incremental projected area.

The projected aerial percentage measured for both trials was compared with the true projected aerial percentage. Statistical analysis, using MINI TAB 16 with 50 patches and a 95% confidence interval revealed no significant difference between the first and second trials (the average difference was approximately 1%). Since the first trial required less time than the second (almost 50% less) the 50% incremental projected area was chosen as an incremental area to determine cell size.

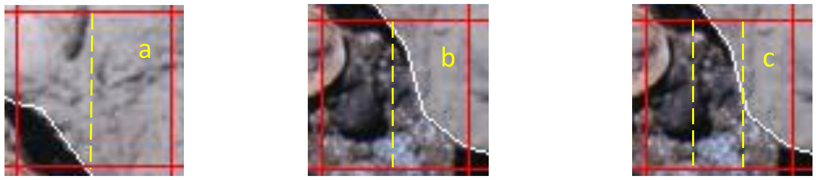


Illustration 4.15a,4.15 b, and 4.15c. Image (a) more than 50%, (b) less than 50%, and (c) less than 33% of cell is covered by the physical streambed component.

Illustration 4.15 shows both the first and second trials. The red square indicates a grid cell, and the white line describes the physical component. In addition, yellow lines sketch the cell portion based on the first or second trial. Both images describe a 50% incremental projected area. In 4.15a, more than 50% of the cell is covered by a physical component. Therefore, the entire aerial percentage of the cell is allocated to that physical component. In contrast, in image 4.15b, zero aerial percentage of the cells is allocated to the physical component as less than 50% is occupied by that component. Image 4.15c shows the second trial, in which the grid cell is divided into three equal portions. As none of the portions are completely covered by physical components, zero aerial percentage of cells is allocated to the physical component in that trial.

To determine the appropriate cell size, a grid with openings (Table 4.4) was included on each patch (photo).

Table 4.4 presents sampling grids with the related cell sizes. The first column shows the sampling grid, and the second describes the image cell. The third column indicates the cell size. Based on the previous discussion, the patch size was selected to be 25 by 25 cm. In the first attempt, the image (patch) was assumed to be one cell with a 25 cm cell size in each dimension (sampling grid 1). In the next attempts, cell size was divided into half of its size from the previous attempt to generate the next grid cell Therefore, 25 cm, 12.5 cm, and 5 cm were the first, second, and third sampling grids, respectively. . However, in the third attempt the cell size was adjusted to 5 cm rather than 6.25 cm (sapling grid 3). The fourth sampling grid was half of the third, and so on, with the smallest possible cell size of 0.625 cm.

Table 4.4

Grid with Varying Openings and Segmentations

Sampling Grid	Image Segmentation	Cell Size (cm)
1	1	25 by 25
2	4	12.5 by 12.5
3	25	5 by 5
4	100	2.5 by 2.5
5	400	1.25 by 1.25
6	1600	0.625 by 0.625

The following steps were implemented to determine the proper cell size. First, the image was loaded into Auto Cad software (Illustration 4.16) and manually digitized (Illustration 4.17). The aerial projected of each digitized component was determined using Auto Cad software and recorded as “true projected area”. Next, the sampling grid with the cell size of 25 by 25 cm was put on the digitized image (Illustration 4.18), and the aerial projected of each component was estimated visually using 50% incremental projected area and recorded as “25 by 25 cm projected area”. The grid sampling 2 with the cell size of 12.5 by 12.5 cm was then put on the digitized image (Illustration 4.19), and the 50% incremental projected area was estimated visually and recorded as “12.5 by 12.5 cm projected area”. This process was continued for grid sampling 3 (Illustration 4.20) with the cell size of 5 cm by 5 cm, sampling grid 4 with the cell size of 2.5 by 2.5 cm (Illustration 4.21), sampling grid 5 with the cell size of 1.25 by 1.25 cm (Illustration 4.22), and sampling grid 6 with the cell size of 0.625 by 0.625 cm (Illustration 4.23).

After estimating the projected area in 6 sampling grids, comparisons were made between the true projected area and each of the visual estimations using MINITAB 16 to track the significant difference of each grid sampling with the true projected area. The difference between the true and visual projected areas in a 95% confidence interval is presented in Chapter VI.

Chapter V presents the sampling methodology of the proposed classification system and analysis results of the sampled data of physical components.

Illustration 4.16. Recording inserting image in the software as a first step in digitizing streambed components.

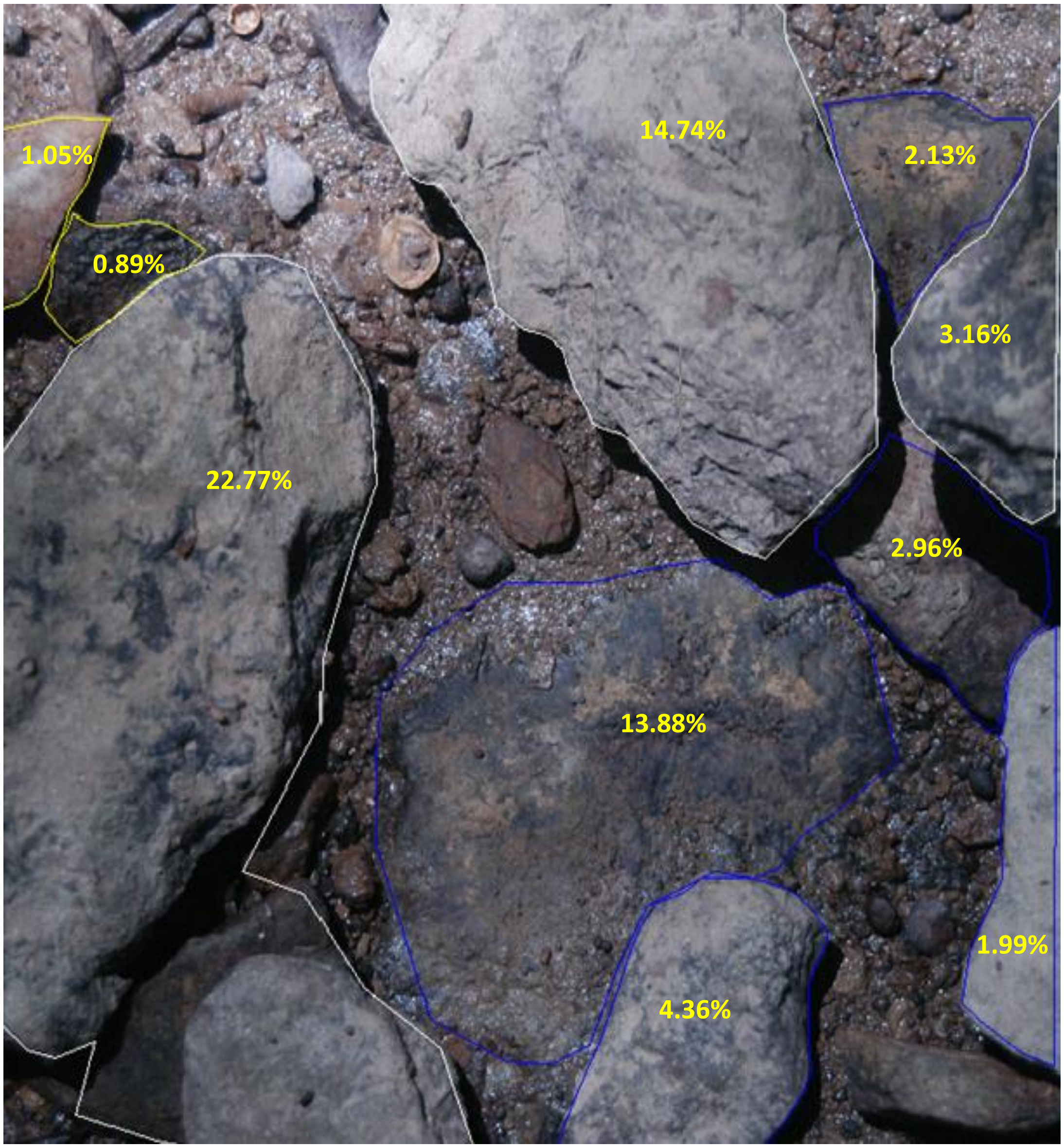


Illustration 4.17. Manual digitizing of recorded picture (second step).

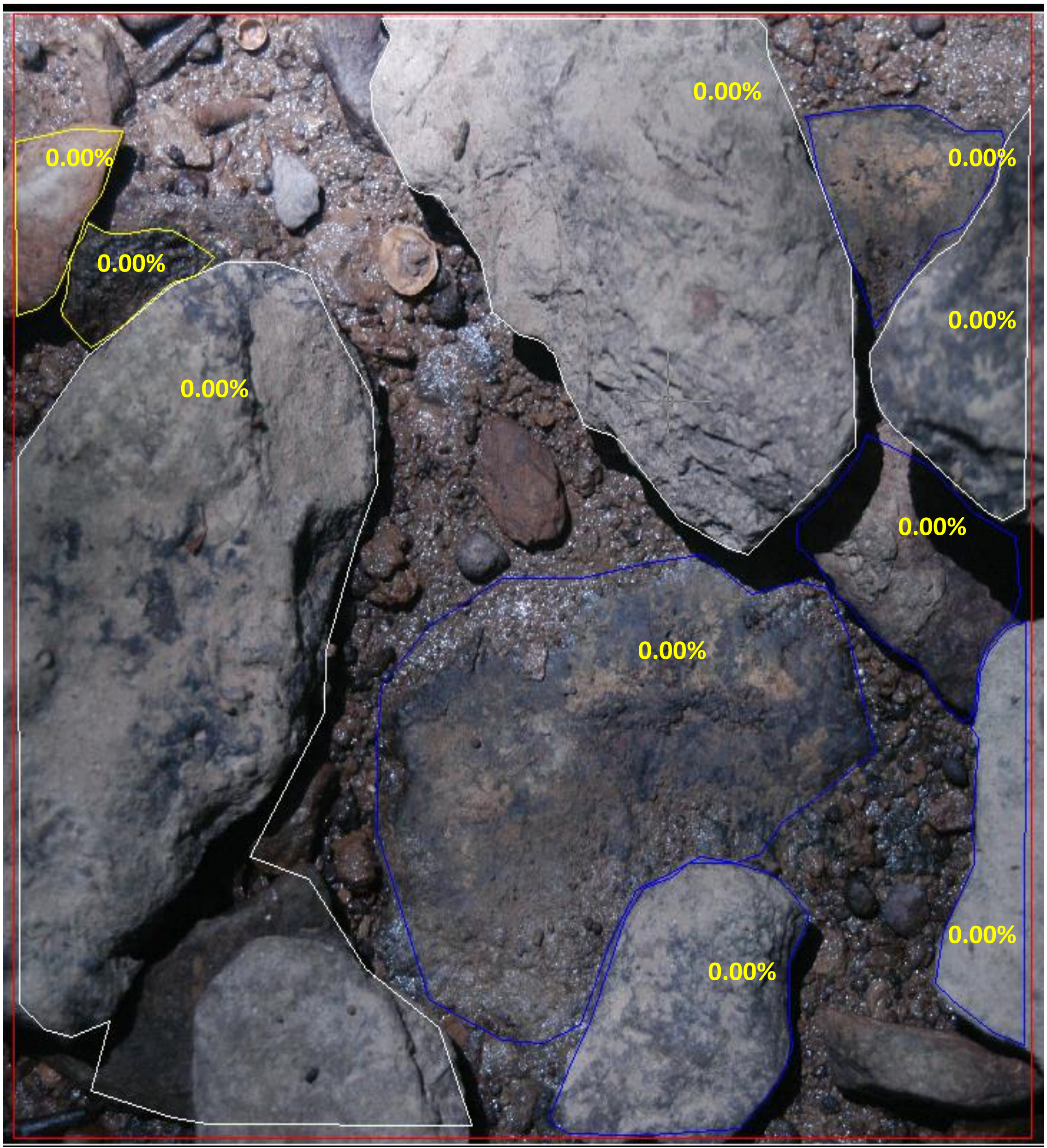


Illustration 4.18. Grid (red line) with 25 by 25 cm cell size on digitized picture (third step).

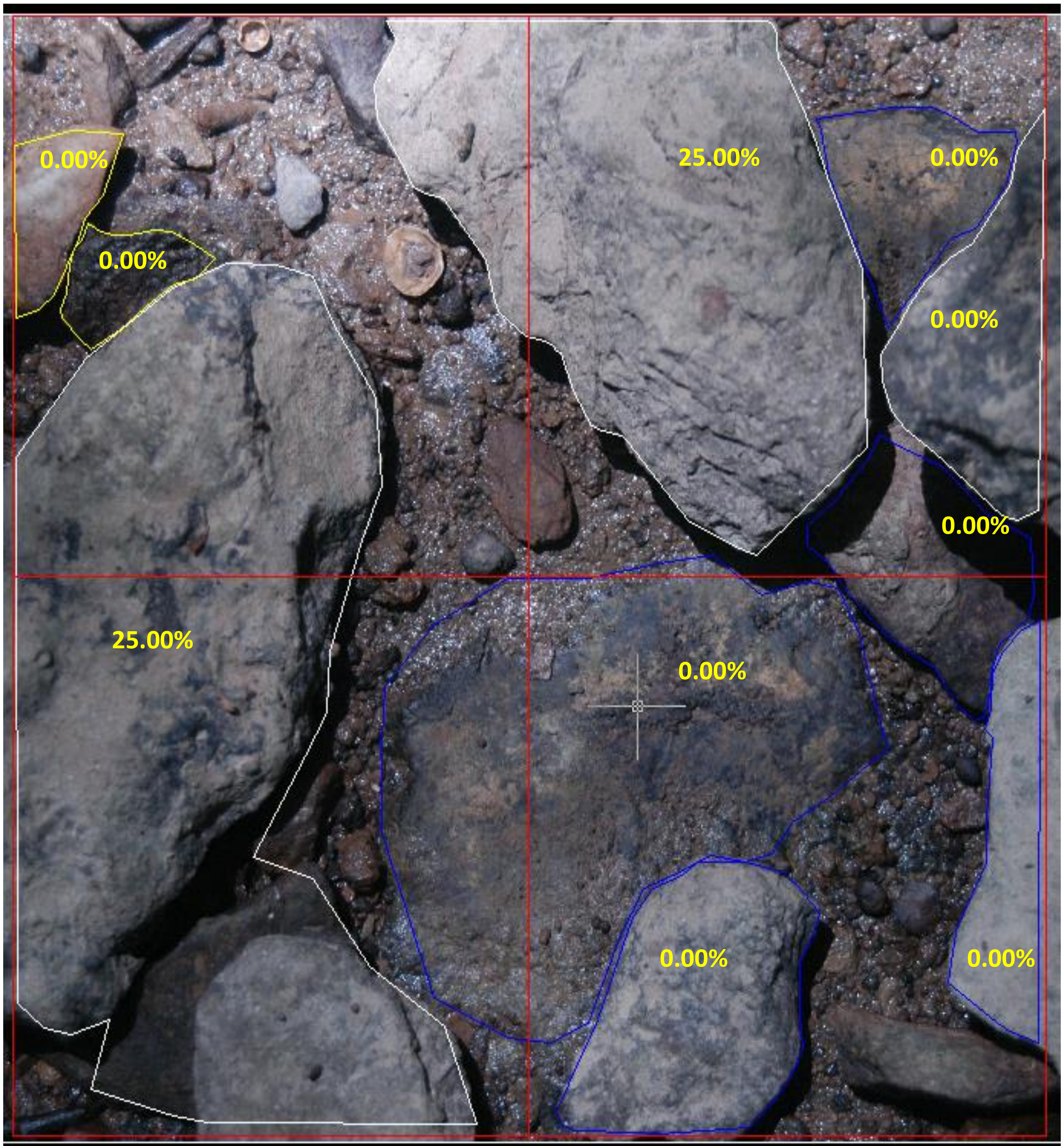


Illustration 4.19. Grid (red line) with 12.5 by 12.5 cm cell size on digitized picture (fourth step).

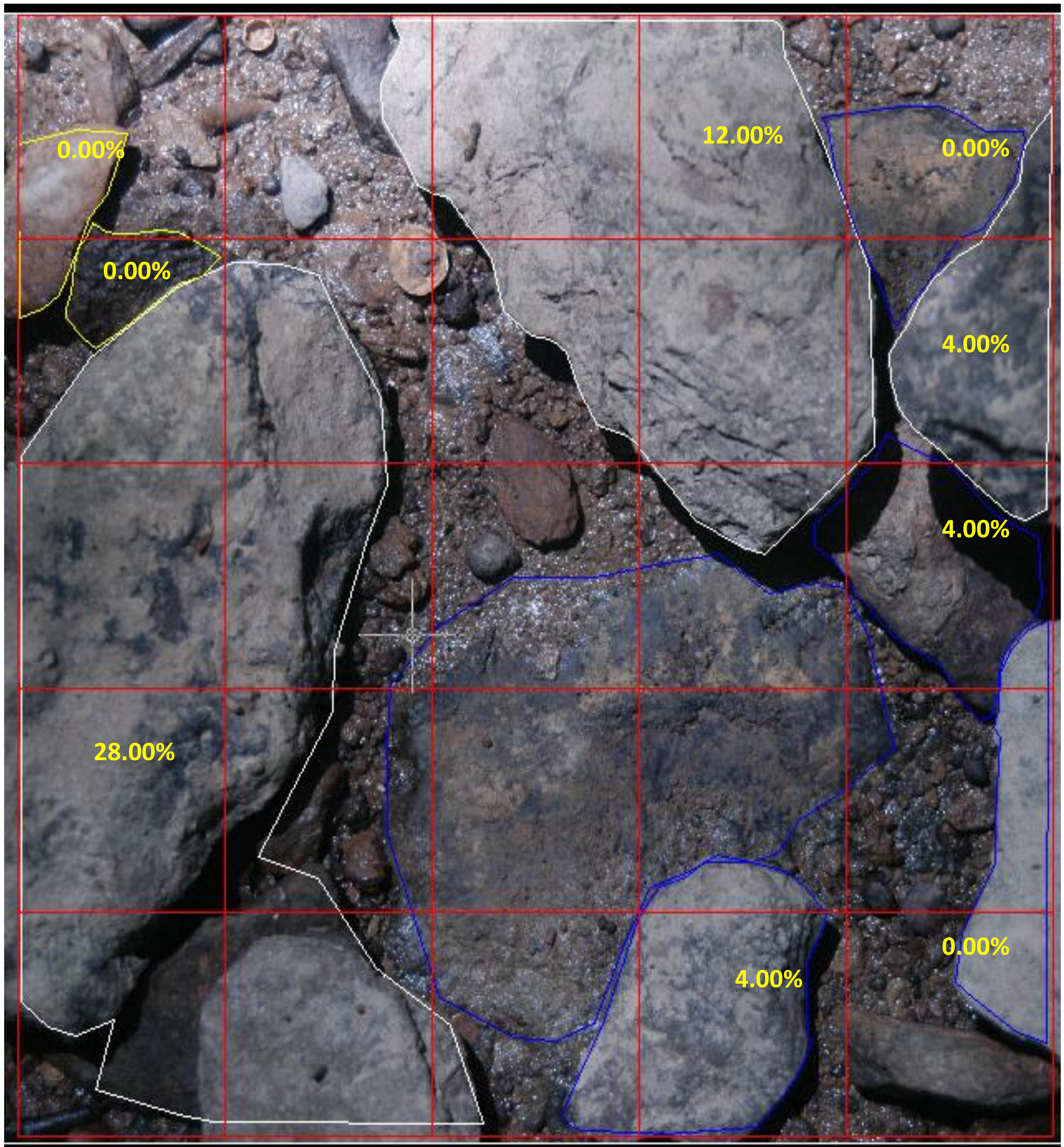


Illustration 4.20. Grid (red line) with 5 by 5 cm cell size on digitized picture (fifth step).

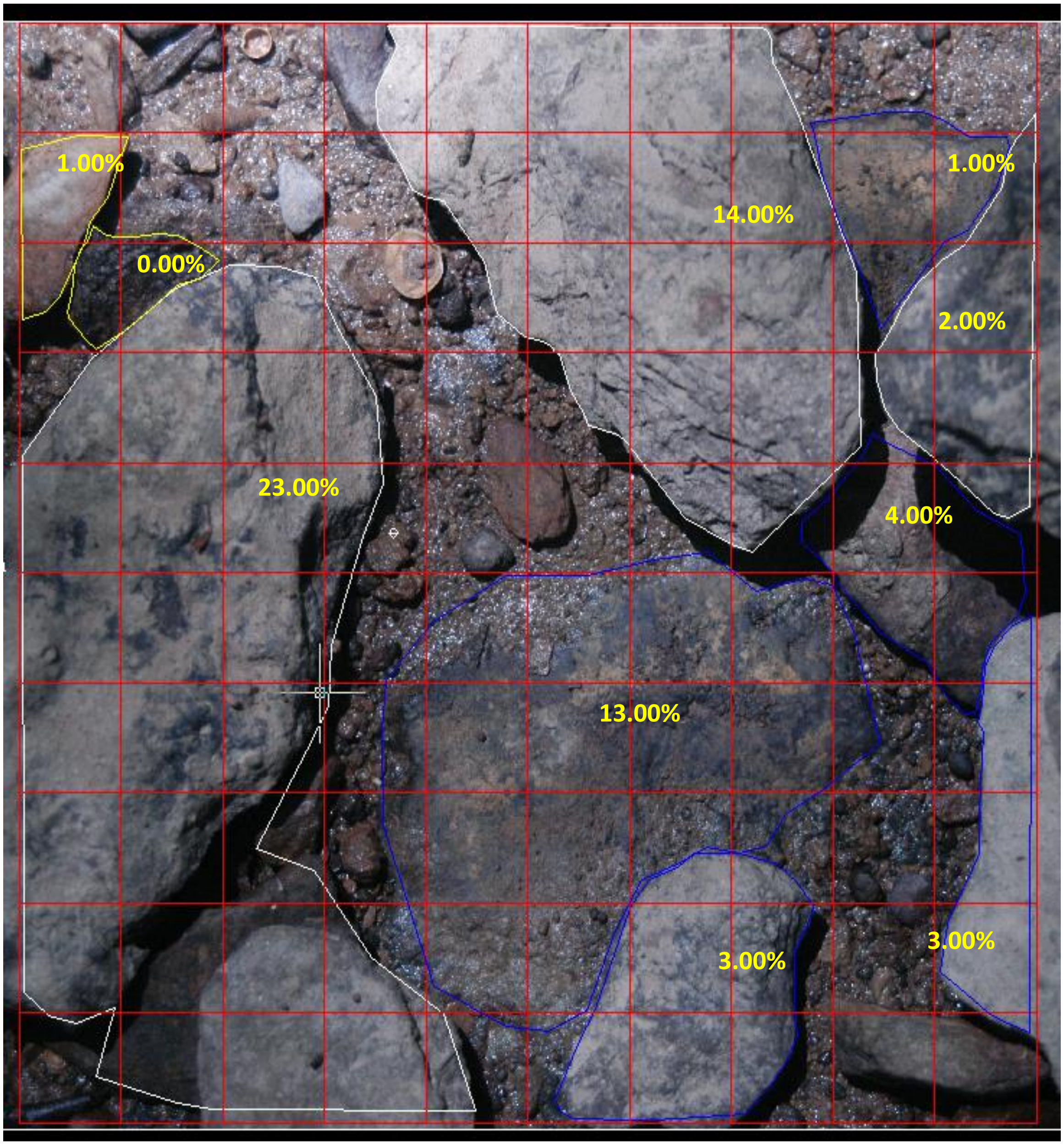


Illustration 4.21. Grid (red line) with 2.5 by 2.5 cm cell size on digitized picture (sixth step).

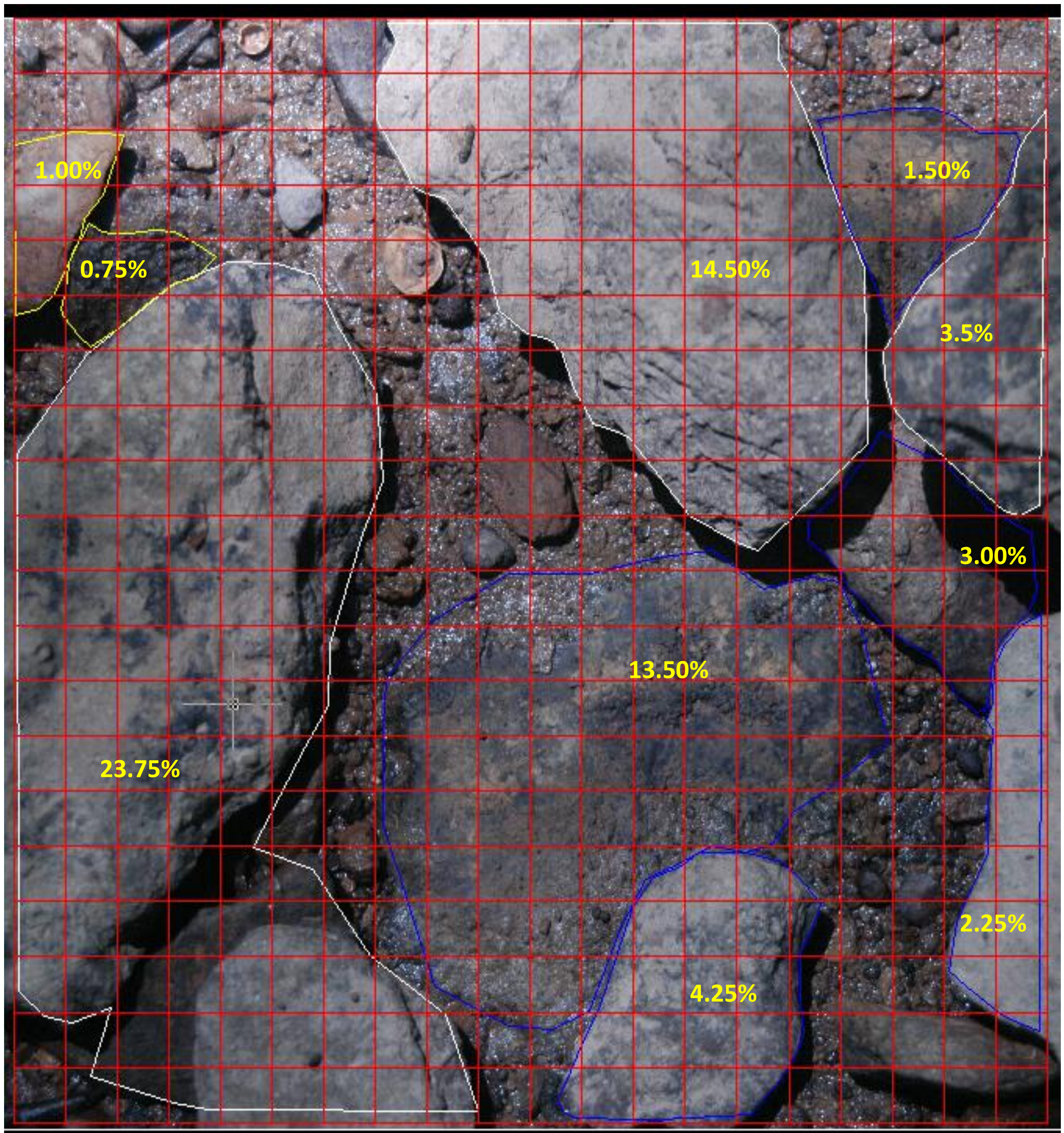


Illustration 4.22. Grid (red line) with 1.25 by 1.25 cm cell size on digitized picture (seventh step).

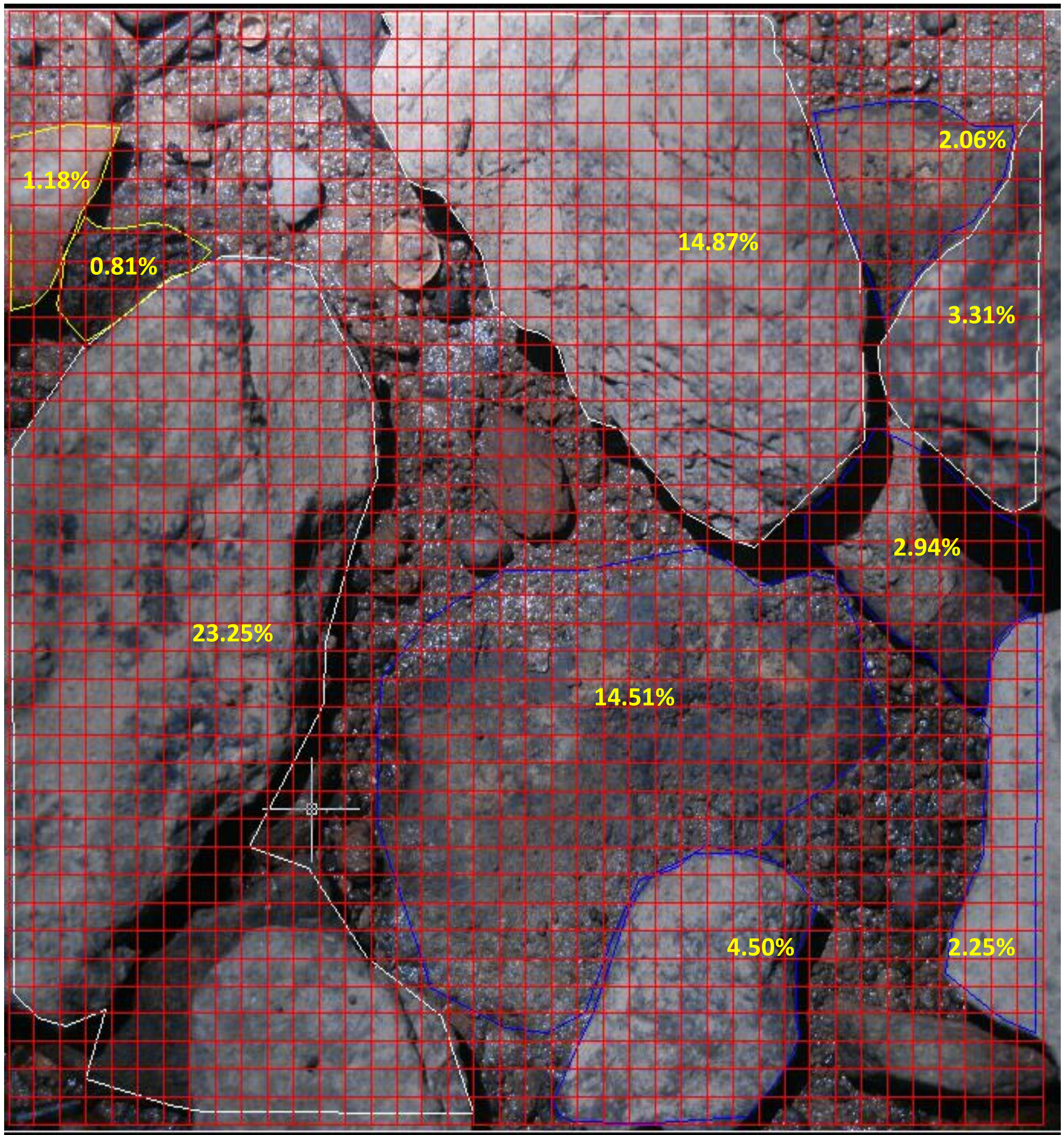


Illustration 4.23. Grid (red line) with 0.625 by 0.625 cm cell size on digitized picture (eighth step).

CHAPTER V

STREAMBED SAMPLING PROCEDURE

This chapter presents study characteristics and the method of sampling techniques used in this study to assess the streambed substrate components. These methods include the proposed method, the pebble count, and the rapid bioassessment. The first section describes the study area and site characteristics. The second section describes the proposed method properties including sampling scheme, the PPB deployment, sampling process, and a review of statistical analysis tests. The third section describes the pebble count and the rapid bioassessment sampling process.

5.1 Study Area and Site Characteristics

The study area is located in the bluegrass physiographic region of the state of Kentucky. Streams throughout the bluegrass region are characterized by low sinuosity, widespread channel incision, high banks that consist primarily of fine-grain layered material with relatively small amounts of basal gravel, and/or exposure of bedrock both in the bed and banks of the channel boundary. Most streams in the bluegrass area have experienced extensive human manipulation both in the channel and in the watershed throughout the past years. Some streams were restored recently, while others were not. A combination of restored and un-restored streams was selected for data collection. In addition, sampling sites were selected to contain a range of streambed physical components. Ten riffles in three streams were selected as a sampling population and encompassed Wilson, Harrison, and Overalls Creeks. Wilson Creek is a restored stream with six sites, including riffles 1, 2, 6, 7, 9, and 10, while Harrison and Overalls Creeks are both un-restored streams with two sites in each (Figure 5.1). Riffles 3 and 4 are in Harrison Creek while riffles 5 and 8 are in Overalls Creek.

Stream Description: The selected streams have a drainage area of less than 154 ml^2, are third-order streams, flow southwest, and are covered with forest. The streams are gravel bedded, with a typical riffle-pool channel morphology. Although valleys in the bluegrass area are controlled by bedrock, riffles 3 and 4 in Harrison Creek have bedrock outcrops in the bed, and riffles 5 and 8 in Overalls Creek have bedrock along the left bank. Riffle 2 in Wilson Creek has a layer of fine materials in the right bank. Bed and bank erosion are dominant in each riffle of Harrison and Overalls Creeks, while right bank erosion in riffle 2 of Wilson Creek is visible. Bank erosion is the in-channel source of fine material. Table 5.1 shows characteristics of study riffles in Wilson, Harrison, and Overalls Creeks.

Table 5.1

Characteristics of Study Riffles on Wilson, Harrison, and Overalls Creeks

Riffle Name	Stream	Drainage Area (ml^2)	Fine layer of Material	Bed & Bank Erosion	Bedrock Outcrops	Channel Alteration	Human Activities
1	Wilson Creek	5.73	-	-	-	Restored	-
2	Wilson Creek	5.73	Left Bank	Bank Erosion	-	Restored	-
3	Harrison Creek	9.55	-	-	Bed	Un-restored	Agri. Actives
4	Harrison Creek	12.26	-	-	Bed	Un-restored	-
5	Overalls Creek	2.86	-	-	Left Bank	Un-restored	-
6	Wilson Creek	5.73	-	-	-	Restored	-
7	Wilson Creek	5.73	-	-	-	Restored	-
8	Overalls Creek	2.86	-	-	Left Bank	Un-restored	-
9	Wilson Creek	5.73	-	-	-	Restored	-
10	Wilson Creek	5.73	-	-	-	Restored	-

Figure 5.1 shows the location of the study riffles on Wilson, Harrison, and Overalls Creeks. Six riffles are located in Wilson Creek, while Overalls and Harrison have two riffles each.

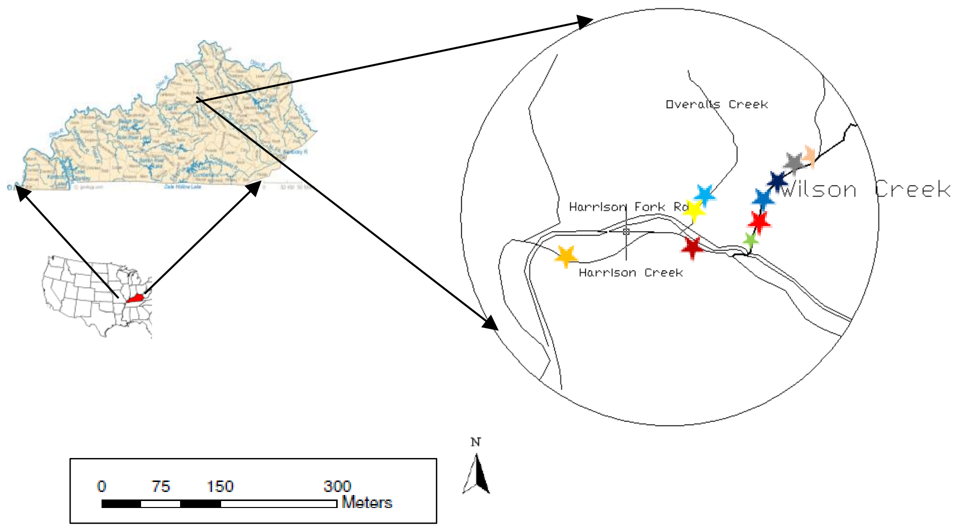


Figure 5.1. Location of study riffles on the Wilson, Harrison, and Overalls Creeks in the bluegrass area of Kentucky, USA.

Illustration 5.1 shows the location of study riffles and land cover on Wilson, Harrison, and Overalls Creeks in the bluegrass area of Kentucky, USA.

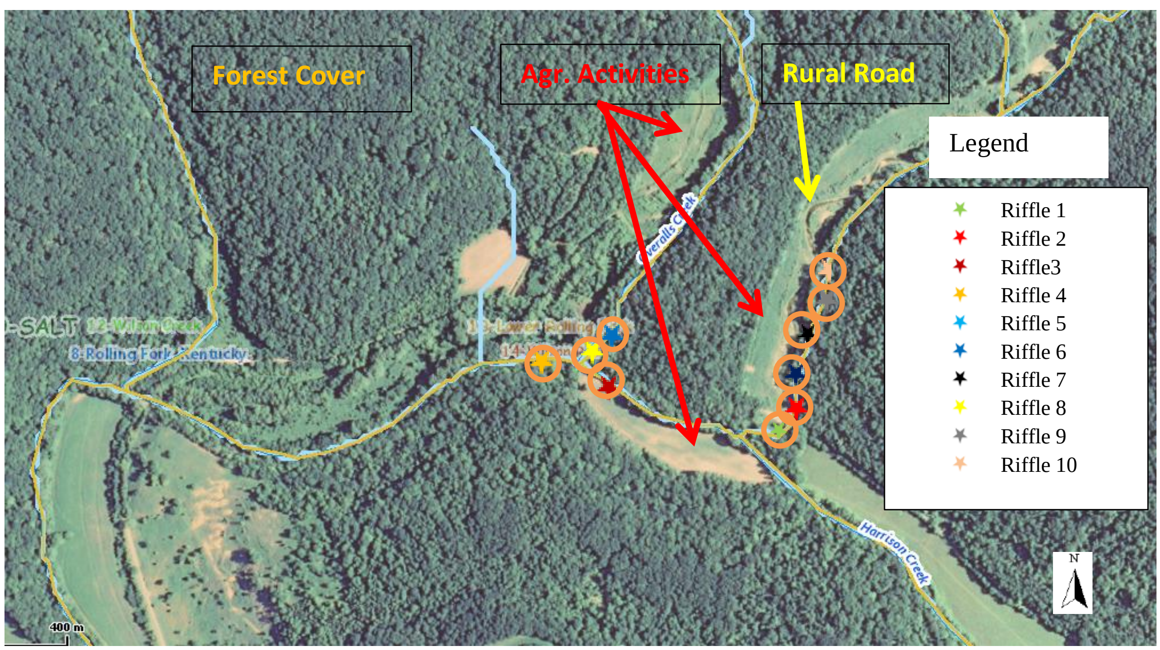


Illustration 5.1. Location of Wilson, Harrison, and Overalls Creeks. (Source: Google Map)

5.2 Proposed Method

This section provides sampling characteristics of the proposed method including sampling scheme, the PPB deployment, sampling process, and a review of statistical analysis tests to evaluate the streambed components of riffle population in the field. The objectives are to (1) characterize the streambed components in riffle scale using the PPB in the field and (2) find an easy-to-use and inexpensive methodology to sample in-situ riffle population. The sampling methodology is designed to sample sufficient patches in riffle in order to represent the riffle population with enough precision and accuracy based on the statistical analysis at the desired confidence level.

5.2.1 Sampling Scheme for Proposed Method

A sampling pilot of riffle using the PPB was accomplished to determine the number of replicates of sampling spots required at the desired confidence interval in riffle unit. Based on patch analysis in Chapter V, the PPB can record an image of 25 by 25 cm. Therefore, 25 cm was selected as the size of the square patch side in sampling layout that can be photographed in one try (Figure 5.2).

In order, to collect riffle population, the riffle area should be recognized visually, and the measurement would begin transversely from downstream to upstream of riffle by locating the PPB perpendicular to the stream flow. The PPB is placed at the bank toe and continues toward the opposite bank. In each location, an image was recorded using the PPB (Patch 1 in Figure 5.2) and the PPB moved to the adjacent spot located in line with the previous location (Cross Section B in Figure 5.2) for recording an image. This process was repeated until the entire cross section was sampled (Patch 2 in Figure 5.2). After completing the first cross section sampling, the PPB was moved up to the next cross section, which is located exactly upstream of the first, to establish another transect (Cross Section B in Figure 5.2). The sampling of the second cross section was accomplished by a method similar to the first cross section. This process was continued until the entire riffle data was sampled (Figure 5.2).

Implementation of this methodology in the field showed that 30 seconds were required to set up the PPB and to record an image. In order to record riffle population with 200 images, one hour of field time was necessary. Recorded images were compiled for each cross section and uploaded into Auto Cad software to evaluate each streambed component.

Streambed components from each cross section were compared with components from the entire riffle population to track statistical differences at the desired confidence interval. These findings provided the smallest number of patches required for sampling in order to represent the riffle population data at the desired confidence interval. The smaller the number of sample spots, the more easy and inexpensive the method. A total of 10 riffles in three streams, including Wilson Creek, Harrison Creek, and Overalls Creek, were selected to sample the streambed data.

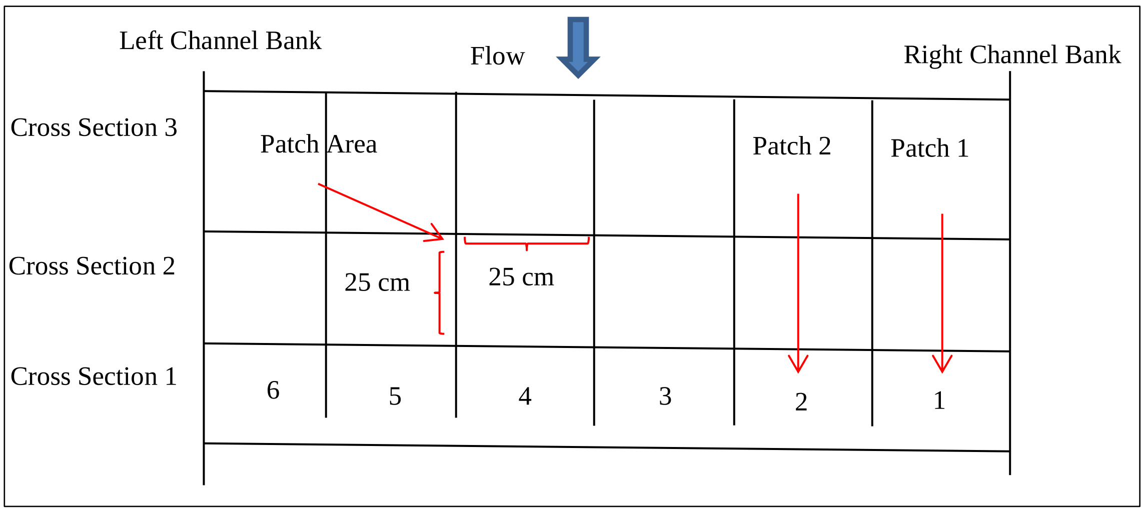


Figure 5.2. Sampling sketch of the proposed method, a combination of the photographic and grid methods.

Figure 5.1 describes the deployment of the proposed methodology in the field. Each patch has an area of 25 by 25 cm. Sampling methodology begins from downstream to upstream, and from right bank to left. In this figure, numbers 1 through 6 represent each sampled patch. Cross section also is represented by a number, such as Cross Section 1.

5.2.2 PPB Deployment in the Stream

In the first step, the area of a riffle should be observed and separated visually from the pool. Riffles are areas characterized by broken water surface, rocky or firm substrate, moderate or swift current, and relatively shallow depth (usually less than 18 inches). Riffles often are downstream of a pool, a deeper area of a stream with slow-moving water. Sampling population in a riffle begins from downstream (riffle tail) to upstream (riffle crest) to eliminate the effect of riffle disturbance by observers while sampling data. The PPB was then moved to the stream to record the image. The first patch was located on the bank toe (either left or right bank) and continued toward the opposite bank.

After identification of the riffle area to sample each spot, observers located the PPB in the first patch, stood downstream of the PPB to prevent disturbing the water, and pushed the box to the bottom of the streambed. The PPB was held firmly for a sufficient amount of time (5 seconds) to eliminate box shaking and to record an image.

5.2.3 Sample Processing

Recorded images were brought back to the office for digitizing and analysis. Images were uploaded into Auto Cad, manually digitized to measure the true projected aerial of each component, and recorded under the title “true projected aerial percentage”. In the second step, the sampling grid with the cell size of 25 by 25 cm was put on the digitized picture, and the projected area of each component was estimated visually using a 50% of the incremental projected area for each grid with opening (Table 4.4). A comparison was made between streambed components measured in the true projected area and each visual estimation, using MINITAB 16 Software to track the significant differences between the true projected area and each grid sampling.

5.2.4 Statistical Analysis

Statistical analysis was implemented utilizing MINITAB 16 Software, a statistics package developed at Pennsylvania State University, to determine the right cell size resolution for the sampling grid. A single factor ANOVA test and a paired t-test compared the significant differences between the “true projected aerial percentage” and the aerial percentage estimated visually in each grid sampling for each component using a 50% of the incremental projected area.

Statistical testing in this study included significant difference, normality checking, residual, and homoscedasticity for each patch and grid opening. A single factor ANOVA test was accomplished in order to compare the projected aerial percentage of all sampling grids and to analyze whether the means of the projected aerial percentage were equal.

Assumptions of single factor ANOVA: (i) Populations follow a normal distribution.

(ii) Populations have the same variance (or standard deviation). (iii) The samples are randomly selected and independent of one another.

The null hypothesis for an ANOVA always assumes the population means are equal. Hence, the null hypothesis is H_0: $\mu_1 = \mu_2 = \mu_3 = \mu_4 = \mu_5 = \mu_6$ - The mean projected aerial percentage is statistically equal across the six sampling grids.

Since the null hypothesis assumes all the means are equal, the null hypothesis can be rejected when the mean is unequal. Thus, the alternative hypothesis is H_a: $\mu_1 \neq \mu_2 \neq \mu_3 \neq \mu_4 \neq \mu_5 \neq \mu_6$ - At least one mean projected aerial percentage is statistically unequal.

A paired t-Test, two-sample assuming unequal variances, was conducted to determine significance differences between the "true projected aerial percentage" and the aerial percentage estimated visually of each component for each patch for $p = 0.05$ and $\alpha = 0.05$.

The t-test is a statistical hypothesis test in which the statistic follows a student's t distribution when the null hypothesis is supported. It can be used to determine whether two sets of data are significantly different from one another.

Unequal (or equal) sample size and unequal variance tests are used when the two population variances are assumed to be different (the two sample sizes may be equal) and should be estimated separately. The test statistic to evaluate the population means is:

$$t = \frac{\bar{x}_1 - \bar{x}_2}{\sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}} \qquad (5.1)$$

Where

$$s_{\bar{x}_1 - \bar{x}_2} = \sqrt{\frac{s_1^{\,2}}{n_1} + \frac{s_2^{\,2}}{n_2}} \qquad (5.2)$$

In this equation, s^2 is the unbiased estimator of the variance of the two samples, n_i = number of participants in group i, i = 1 or 2. For use in significance testing, the distribution of the test statistic is approximated as an ordinary student's t distribution, with the degrees of freedom determined using:

$$\mathrm{df} = \frac{\left[(SE_1)^2 + (SE_2)^2 \right]^2}{\frac{(SE_1)^4}{n_1 - 1} + \frac{(SE_2)^4}{n_2 - 1}} \tag{5.3}$$

After selection of the grid cell size, the t-test was implemented to determine the number of sampling spots to represent the riffle population at the desired level of confidence. In this regard, significant differences between streambed components determined from the riffle population and each cross section was determined for p = 0.05 and α = 0.05 in the selected grid size opening. This provides an easy and inexpensive method to sample riffle population with sufficient accuracy at the desired level of confidence interval.

In addition, statistical analysis was implemented to compare the proposed method with the common surface streambed sampling methods: pebble count and rapid bioassessment.

5.3 Surface Streambed Sampling Methods

5.3.1 Wolman Pebble Count

Riffle sampling using the pebble count method begins at the downstream transect and proceeds upstream, similar to the proposed method. At each transect, the sampling is conducted beginning from one bank, taking paces across the rifle to reach the opposite bank.

In each riffle, slightly more than 200 particles were collected and the b-axis of each pebble recorded (Figure 5.3.a). Pebbles were selected at the intersection of each sampling grid and were measured using a gravelometer graduated in millimeters (Figure 5.3.b). The first pebble was collected at the edge of the wetted width of the channel, along one of the banks at the downstream end of the riffle, and continued for each pace until reaching the opposite bank. One pace (25 cm) was taken upstream to the next transect, and the same collection order was conducted (Figure 5.4). Pace with 25 cm length was selected to be consistent with the proposed method. Cautions were exercised to avoid duplicated counting of a pebble larger than 25 cm.

In the pebble count method, material less than 4 mm is classified under the name “fine material” as picking up this material with a hand is difficult.

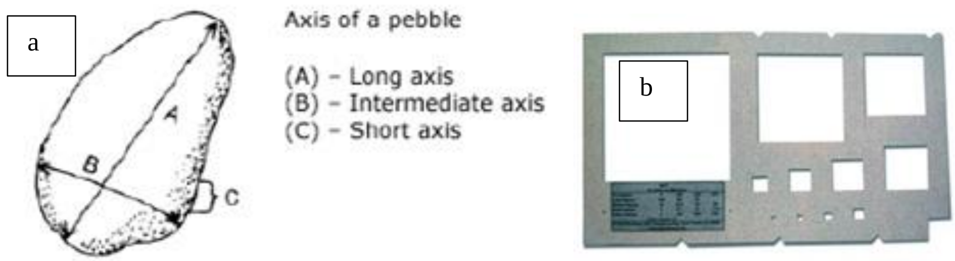


Figure 5.3a and 5.3b. Axis of pebble (a) and gravelometer (b).

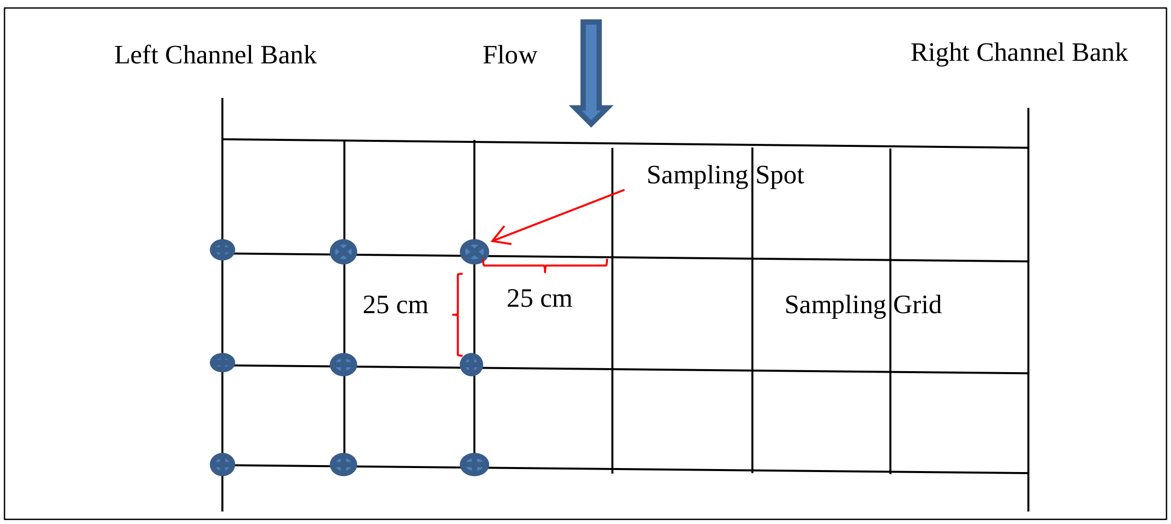


Figure 5.4. Sampling sketch of the pebble count method.

Figure 5.4 describes the grid sampling deployed in the field. The grid sampling opening is square with 25 cm cell size. Pebbles were selected from underneath the grid intersections (dots).

5.3.2 Rapid Bioassessment

The rapid bioassessment uses a 10 cm diameter hoop to estimate the percent of surface area covered or surrounded by fine sediment within that hoop. Definition and estimation of variables in the rapid bioassessment were accomplished in accordance with the rapid bioassessment protocol (Kaufmann et al., 1999). Embeddedness is “the degree to which fine sediments (materials less than 2mm) surrounded or covered coarse materials (materials larger than 2mm) on the surface of a streambed” (Kaufmann et al., 1999).

Measurement methodology according to the rapid bioassessment technique is "estimating the percentage of embeddedness and epifaunal substrate inside a 10 cm diameter hoop visually on the 25 percentage increment" (Kaufmann et al., 1999). Following this protocol, percentage of embeddedness and epifaunal substrate is evaluated in four classes: 0-25% = excellent, 25-50% = good, 50-75% = fair, and 75-100% = poor condition (Figure 1.1). To assess the cross section, components inside the hoop are evaluated subjectively at five spots located at the percentage of 0, 25, 50, 75, and 100 of the wetted width of the channel and average to describe the subject transects (Figure 1.2). For riffle evaluation, embeddedness is estimated in three cross sections (tail, middle, and crest) spaced at an interval of three to four times of channel width and averaged as riffle parameters in accordance with the rapid bioassessment method (Figure 5.5).

Figure 5.5 describes the embeddedness measurement sampling sketch based on the rapid bioassessment technique. Embeddedness was estimated using a 10 cm diameter hoop visually in five spots and three cross sections. Cross section measurements included estimation of embeddedness in the percentage of 0, 25, 50, 75, and 100 of the wetted width of the channel in tail, middle, and crest of riffle. Riffle embeddedness equals the average of 15 sampling points (dots) in this figure.

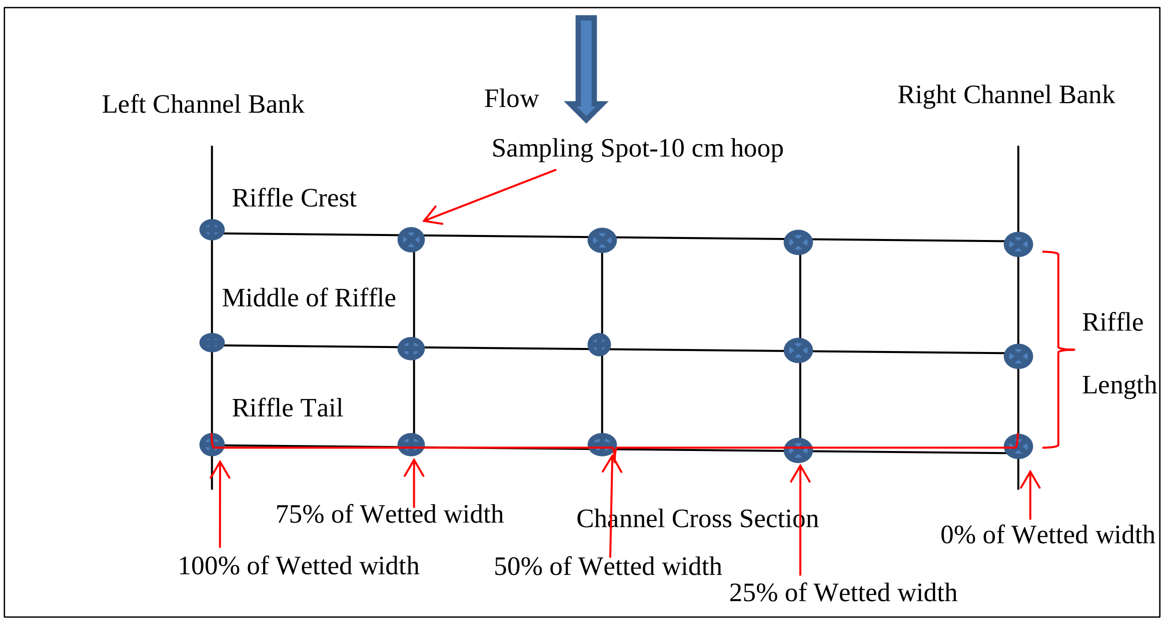


Figure 5.5. Sampling sketch of the embeddedness measurement according to the rapid bioassessment method.

CHAPTER VI

RESULTS

This chapter presents a comparison of methods used for streambed surface sampling. The first section describes variations in the physical size of the area sampled in experiments. In this application, the area size or region sampled is defined using the terms "grid or cell resolution", and "grid or cell size". The second section describes the proposed method for sampling streambed material components, and the third compares results from the proposed approach with existing methods, including (1) pebble count and (2) rapid bioassessment.

Statistical analysis was implemented by MINITAB 16 software to determine the appropriate cell size resolution for the sampling grid and direct sampling methodology for riffle population.

6.1 Statistical Analysis of Sampling Grid Cell Resolution

As mentioned earlier, recorded images were digitized manually in Auto Cad to determine the true projected aerial variable and estimated visually to evaluate 50% of incremental projected variable for openings in accordance with Table (4.4). A comparison between both variables using MINITAB 16 software shows the statistical difference between both approaches. The goal was to find an appropriate cell size based on grid opening in Table (4.4) in the proposed classification system to sample in-situ riffle population with sufficient accuracy at the desired level of confidence interval.

Statistical analysis includes significant difference, normality checking, residual, and homoscedasticity of each grid opening. To find the appropriate cell size, 70 to 113 patches (each recorded using an image) with the size of 25 by 25 cm were recorded in the three streams in the bluegrass area of Kentucky. A single factor ANOVA test and the paired t-test were utilized to compare the statistical differences between the "true projected aerial percentage" and the aerial percentage estimated visually of each component for each patch, and also the aerial percentage estimated visually between sampling grid openings for $p = 0.05$ and $\alpha = 0.05$. In addition, checking normality, residual, and homoscedasticity for each patch and grid opening was accomplished using t-test in MINITAB software to determine the appropriate cell size in sampling grid and 50% incremental projected area in visual estimation technique at the desired level of confidence. Visual estimation with 50% incremental projected area is beneficial in determining an inexpensive and easy field method to determine the streambed components. This method improves the common issues in sampling streambed components, including inaccuracy, cost, and inconvenience.

6.1.1 Statistical Analysis of the Visual Projected Aerial Percentage of Sampling Grid Openings _ Significant Difference

The difference between each grid opening and the true projected area was recorded for 70 to 113 patches under "Ae %," referring to the percentage of aerial error. This variable indicates the deviation of visual estimation of each grid opening from the true projected aerial percentage of that opening. A single ANOVA test was accomplished in order to analyze the means of six sampling grids.

Table 7.1 presents results of the single ANOVA. As F (= 8.15) > Fcrit (=2.235) in Table 7.1, the null hypothesis is rejected with 95% confidence (1- α) that the means of streambed bed components measured using six sampling grids are statistically unequal. However, in a single factor ANOVA test, one dissimilar mean can reject the null hypothesis, and an additional test such as Tukey should be conducted to determine dissimilar mean(s).

Table 6.1

Single Factor ANOVA Test Comparing Means of Grid Sampling Openings for A = 0.05

Groups	*Count*	*Sum*	*Average*	*Variance*		
Column 1	113	-391.942	-5.599	229.785		
Column 2	113	8.057	0.115	45.200		
Column 3	113	4.057	0.057	4.327		
Column 4	113	23.057	0.329	3.738		
Column 5	113	13.307	0.190	1.641		
Column 6	113	6.120	0.087	0.214		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1935.426	5	387.085	8.151	2.36E-07	2.235
Within Groups	19658.590	414	47.484			
Total	21594.020	419				

The ANOVA single factor, Tukey test was used to compare the measured aerial percentage of each streambed components for sampling grid openings and track the significant difference and find dissimilar mean(s) for the p-value for $\alpha = 0.05$. This statistical analysis is presented in Table 6.2.

Table 6.2 presents the p-value for $\alpha = 0.05$ for sampling grid openings based on the Tukey test. The first row describes the sampling grid openings, and the second row shows the difference between grid openings. The value of $p > 0.05$ indicates no significant difference between grid openings. Therefore, sampling grid 1 and 2 have a statistical significant difference with sampling grids, whereas sampling grids 3, 4, 5, and 6 have no statistical significant differences with sampling grids.

Table 6.2

p-Value for α=0.05 for Varying Openings

Sampling grid 1 vs. sampling grids	Sampling grid 2 vs. sampling grids	Sampling grid 3 vs. sampling grids	Sampling grid 4 vs. sampling grids	Sampling grid 5 vs. sampling grids	Sampling grid 6 vs. sampling grids
0.026	0.036	0.19	0.47	0.21	0.20

6.1.2 Statistical Analysis of the Visual Projected Aerial Percentage of Sampling Grid Openings _ Normality Test

Normality tests are used to determine whether the data set is well modeled by a normal distribution and to compute how likely an underlying random variable is to be normally distributed. MINITAB 16 software was utilized to test the normality of data obtained by each sampling grid. Figures 6.1 and 6.2 and Figures 1-4 in Appendix I show the normality test results.

In the normality test using MINITAB, the primary concern is p-value, which, if less than α, means the data are non-normally distributed. Based on these figures, p-values of sampling grids, other than sampling grid 4, for α = 0.005 are less than 0.005 and are non-normally distributed.

In sampling grid 3, p-value is 0.147 (> 0.005), and the null hypothesis is accepted. Therefore, the sampling grid 3 data are not non-normal and should be transformed for more statistical analysis. Box-Cox transformation was implemented for transformation of data.

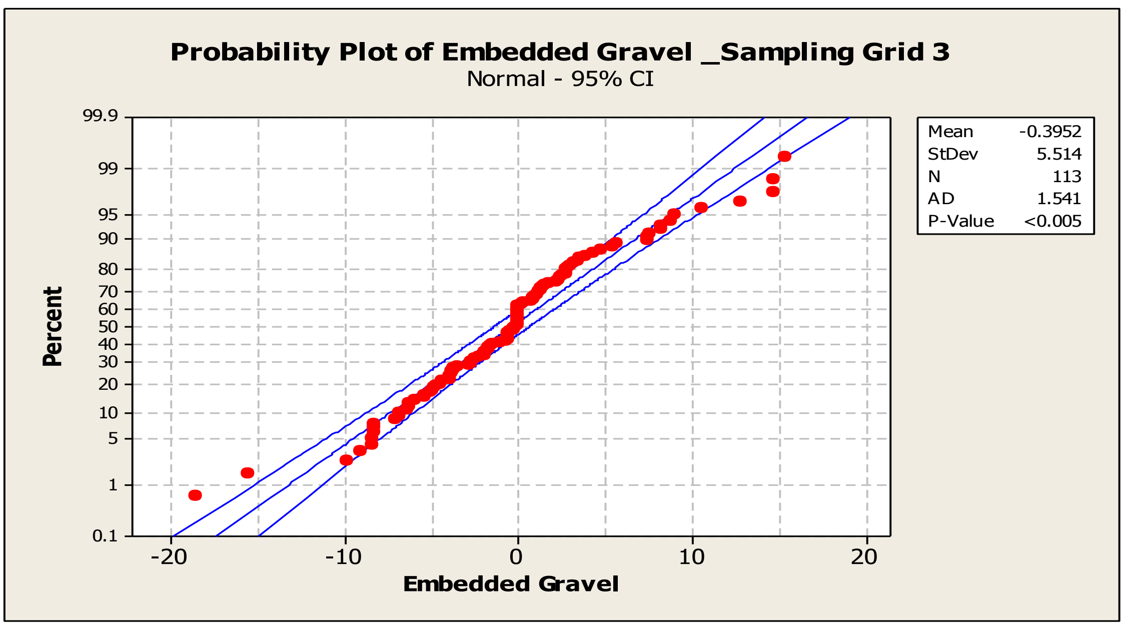


Figure 6.1. Normality plot for embedded gravel component for sampling grid 3 with cell size of 5 by 5 cm.

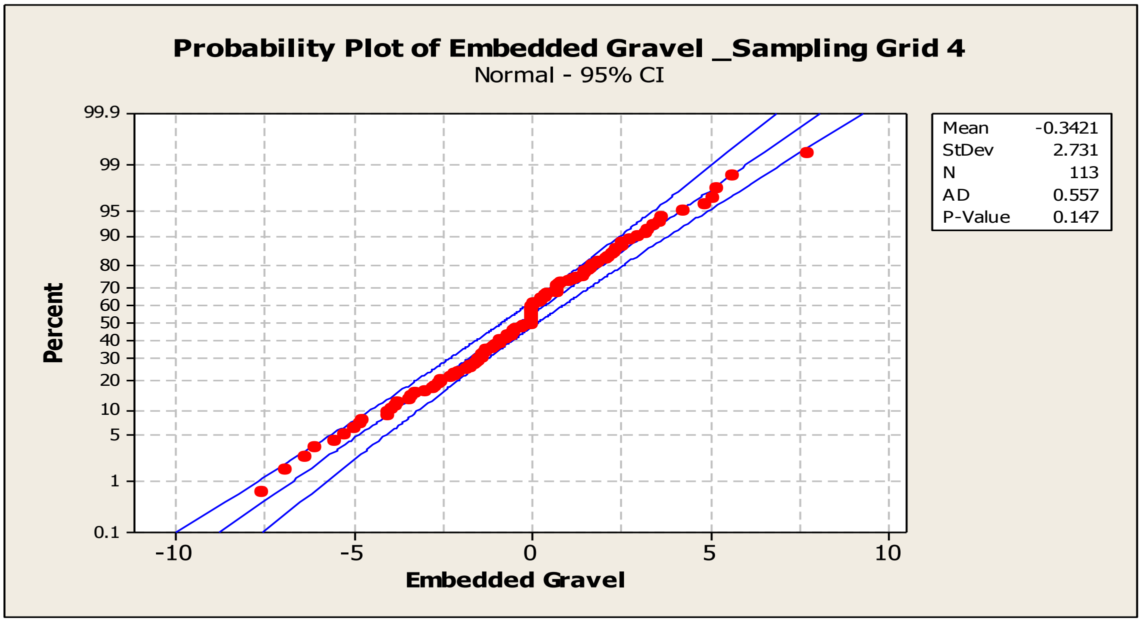


Figure 6.2. Normality plot for embedded gravel component for sampling grid 4 with cell size of 2.5 by 2.5 cm.

6.1.3 Statistical Analysis of the Visual Projected Aerial Percentage of Sampling Grid Openings _ Residual

The residual of an observed value is the difference between the observed and estimated values. The observed value and the estimated value are the true and visually estimated projected aerial percentage of each component for sampling grids, respectively. Residual was accomplished for each sampling grid using MINITAB 16 software and shown in Figures 6.3 and 6.4 and Figures 5-8 in Appendix I. In these figures, PI and CI are prediction interval and confidence interval, respectively. The prediction interval (PI) represents the range that a single observation is likely to fall within, with a certain probability. The confidence interval (CI) represents the range that the mean value is likely to fall within, with a certain probability. The probability in this study is 95%.

For sampling grid 1, 95% PI is between +50 to -50 percent, while sampling grid 2 is between +15 to -15 percent. Sampling grids 3 and 4 have the PI boundary of +10 to -10 percent and +5 to -5 percent, respectively. The PI is between +4 to -4 percent for sampling grid 5 and +2.5 to -2.5 percent for sampling grid 6. In sampling grids, the width of the prediction interval is nearly constant over the full range of the data, and 95% CI equals and is between +1 to -1 percent. The prediction interval is always wider than the corresponding confidence interval due to the added uncertainty involved in predicting a single value versus the mean value. Except in sampling grids 1 and 2, other sampling grids have a random pattern, indicating a good fit for a linear model.

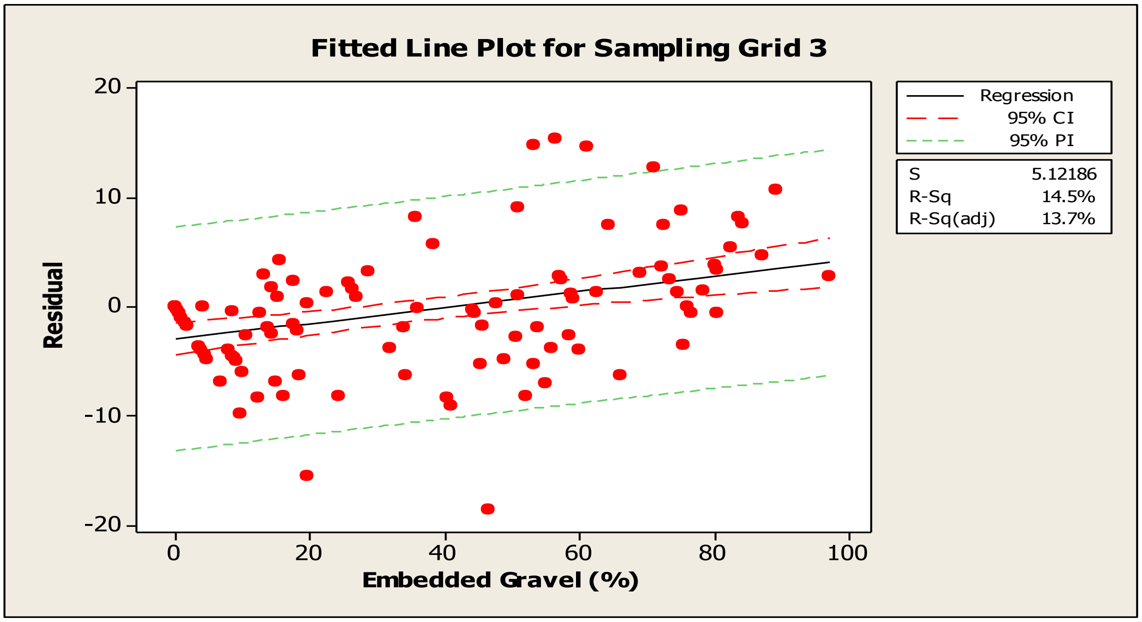


Figure 6.3. Residual plot for embedded gravel component for sampling grid 3 with cell size of 5 by 5 cm.

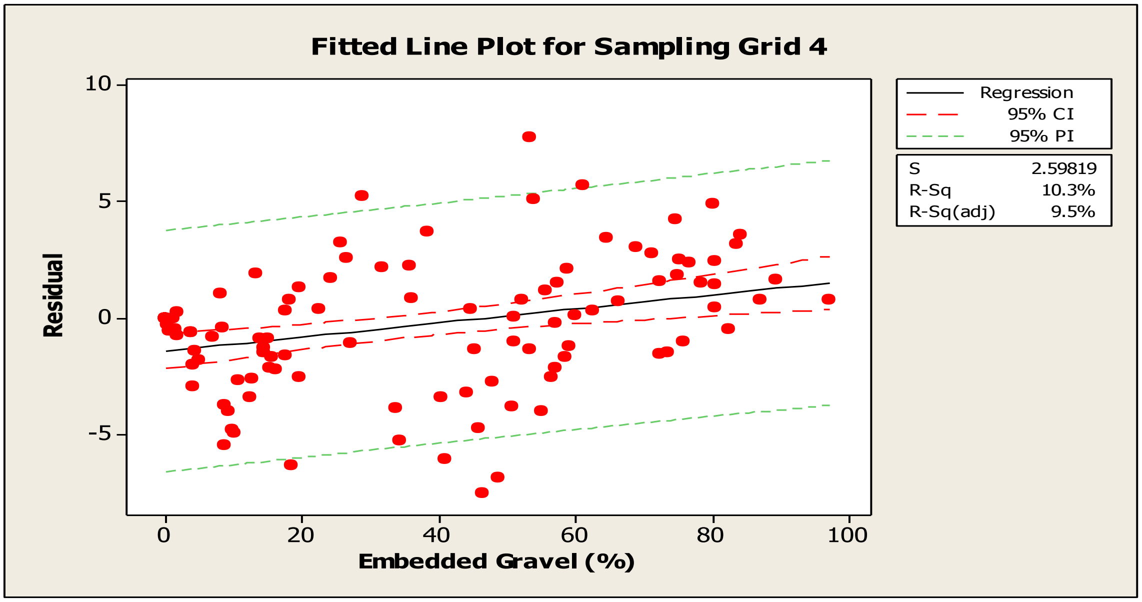


Figure 6.4. Residual plot for embedded gravel component for sampling grid 4 with cell size of 2.5 by 2.5 cm.

6.1.4 Statistical Analysis of the Visual Projected Aerial Percentage of Sampling Grid Openings _ Homoscedasticity

Homoscedasticity means “having the same scatter.” In terms of data, it means having data values that are scattered, or spread out, to the same extent. Therefore, homoscedasticity refers to the assumption that the dependent variable exhibits similar amounts of variance across the range of values for an independent variable. Homoscedasticity facilitates analysis, as methods are based on the assumption of equal variance. If assumptions are satisfied, residuals should vary randomly around zero, and the spread of the residuals should be the same throughout the plot (no systematic patterns). Homoscedasticity is possibly violated if; (1) the residuals seem to increase or decrease in average magnitude with the fitted values, which is an indication that the variance of the residual is not constant; (2) the points in the plot lay on a curve around zero, rather than fluctuating randomly; and (3) few points in the plot lay far from the rest of the points.

To evaluate the homoscedasticity of data, the residual of 70 to 113 recorded images in the field are plotted against the true projected area in Figures 6.5 and 6.6 in this section and Figures 9-12 in Appendix I. Except in sampling grids 1 and 2, the other figures show a constant spread (or variance) around zero, which is an indication of homoscedasticity in the data. In addition, residuals spread randomly above and below throughout the range, which is an indication of no bias in the data. Therefore, grid samplings 3, 4, 5, and 6 comply with the homoscedasticity assumption, whereas sampling grids 1 and 2 have the systematic pattern that indicates violation of the homoscedasticity assumption.

Figures 6.5 and 6.6 show the residual vs. true projected area for 70 to 113 patches recorded in three streams in the bluegrass area. The x-axis in these figures describes the residual, while the y-axis shows the true projected area of embedded gravel as one of the streambed components in the proposed classification system.

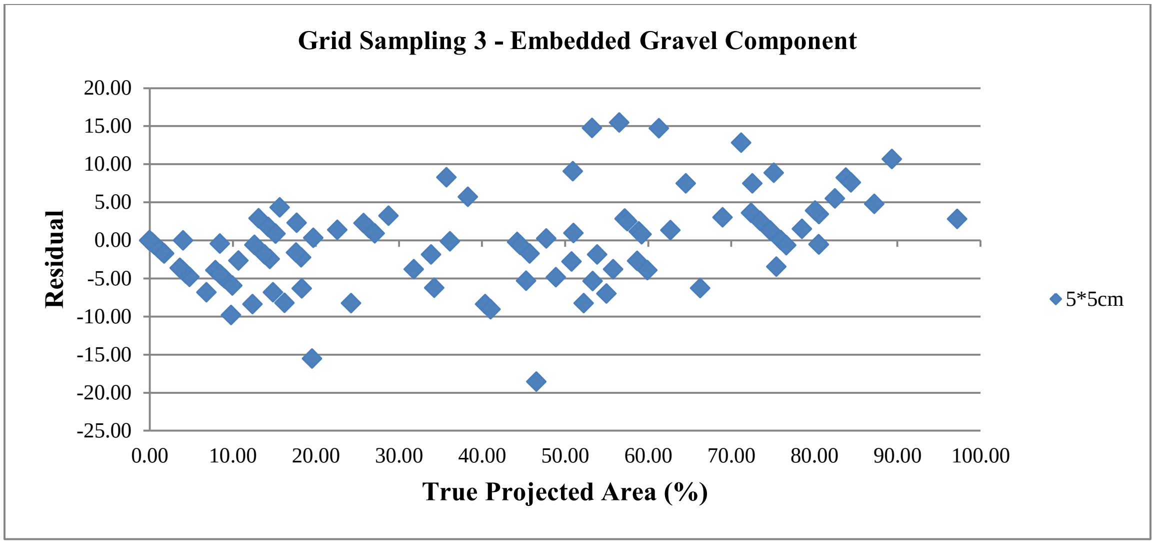


Figure 6.5. Projected aerial error (%) for 113 populations _ embedded gravel component in sampling grid 3 with cell size of 5 by 5 cm.

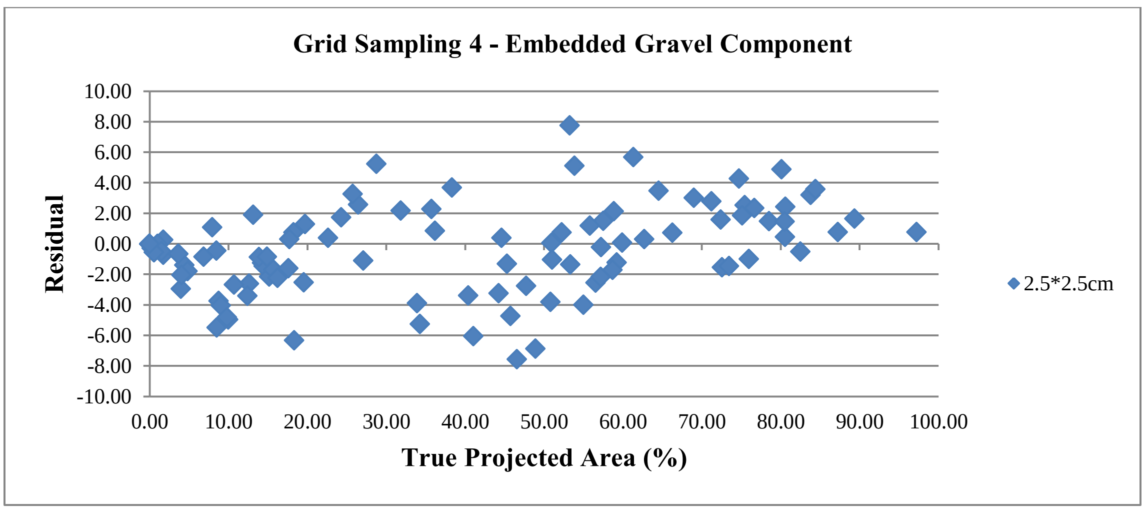


Figure 6.6. Projected aerial error (%) for 113 populations _ embedded gravel component in sampling grid 4 with cell size of 2.5 by 2.5 cm.

To compare the spread of variance for sampling grids, the embedded gravel as a streambed component was plotted using Boxplot in MINITAB 16 (Figure 6.7). In Figure 6.7, the y-axis shows the sampling grids, and the x-axis describes the spread of variance. The spreads are indicated by the length of boxes. The larger the variance, the greater the scatter or spread of the data. Sampling grid 1 has the greatest spread, whereas sampling grid 6 has the least amount of spread. Sampling grids 4 and 5 also show the small amount of variances.

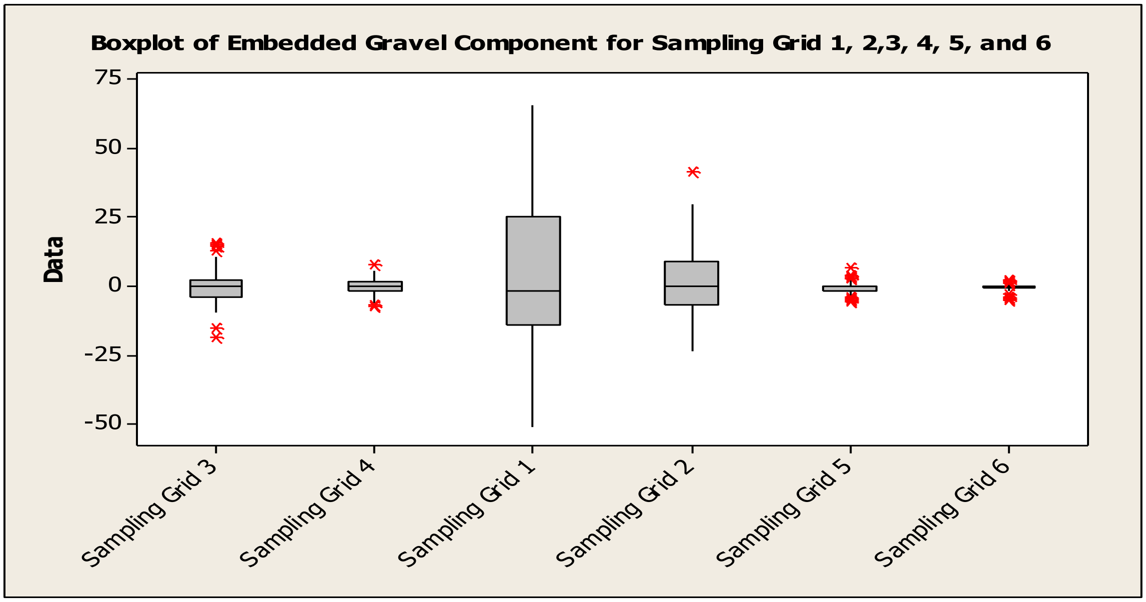


Figure 6.7. The spread of variance of sampling grid.

Table (6.3) summarizes the descriptive statistics of sampled streambed components of the sampling grids using MINITAB 16 software. Descriptive statistics variables include mean, variance, and median. Based on Table 7.3, sampling grid 1 has the largest variance, which equals 777.73, whereas the smallest variance is in sampling grid 6, which is 1.432. Variances of sampling grids 2, 3, 4, and 5 are 165.43, 30.4, 7.46, and 4.186, respectively.

Table 6.3

Descriptive Statistics Variable for Sampling Grids

Variable	N	N*	Mean	SE Mean	StDev	Variance	Minimum
Sampling Grid 3	113	1	-0.395	0.519	5.514	30.400	-18.556
Sampling Grid 4	113	1	-0.342	0.257	2.731	7.460	-7.556
Sampling Grid 1	70	1	0.50	3.33	27.89	**777.73**	-50.94
Sampling Grid 2	70	1	1.15	1.54	12.86	165.43	-23.88
Sampling Grid 5	70	1	-0.442	0.245	2.046	4.186	-5.875
Sampling Grid 6	70	1	-0.307	0.143	1.196	**1.432**	-5.063

Variable	Q1	Median	Q3	Maximum
Sampling Grid 3	-3.813	-0.157	2.283	15.457
Sampling Grid 4	-1.749	0.000	1.385	7.763
Sampling Grid 1	-13.96	-1.61	25.27	65.75
Sampling Grid 2	-6.92	-0.37	9.12	41.14
Sampling Grid 5	-1.571	-0.281	0.000	6.763
Sampling Grid 6	-0.653	-0.013	0.072	2.062

6.1.5 Summary of Sampling Grid Characteristics

Table 6.4 summarizes the statistical analysis of streambed components including the sum of significant difference, normality test, residual, and homoscedasticity. In addition, required digitization time as a key factor in streambed component sampling is considered.

Table 6.4

Statistics Analysis of Sampling Grids

Sampling grid Number	Significant Difference with paired sampling grids	Normality Test	Residual (PI %)	Homoscedasticity Test	Required Digitization Time
1	No significant difference	Non-normal	+50 to -50	Violates the assumption	10 sec
2	No significant difference	Non-normal	+15 to -15	Violates the assumption	20 sec
3	Significant difference	Non-normal	+10 to -10	Complies the assumption	30 sec
4	Significant difference	Not Non-Normal	+5 to -5	Complies the assumption	3 min
5	Significant difference	Non-normal	+4 to -4	Complies the assumption	5 min
6		Non-normal	+2.5 to -2.5	Complies the assumption	10 min

Sampling grid 1: Sampling grid 1 shows the statistically insignificant difference with other sampling grids. Data produced by sampling grid 1 is non-normal, with residual (PI %) of ±50 %. Data sampling by grid 1 violates the homoscedasticity assumption, with the required digitization time as low as 10 seconds per image.

Sampling grid 2: Similar to sampling grid 1, sampling grid 2 shows an insignificant difference statistically with other sampling grids. Data produced by sampling grid 2 is non-normally distributed, with residual (PI %) of ±15 %. Data sampling by grid 2 violates the homoscedasticity assumption, with the required digitization time of 20 seconds per image.

Sampling grid 3: Sampling grid 3 produces non-normal data, with the residual of ±10 %. Data comply with the homoscedasticity assumption and show a significant statistical difference with other sampling grids. The digitization time requirement is 30 seconds per image.

Sampling grid 4: The sampling grid 4 data are not non-normally distributed, with the residual of ±5 %. Data show a statistical significant difference with other sampling grids and comply with the homoscedasticity assumption. Required digitization time is 1 minute per image.

Sampling grid 5: Sampling grid 5 produces the non-normal data, with the residual (PI %) of ±4 %. Data comply with the homoscedasticity assumption and show a statistical significant difference with other sampling grids. Five minutes is required to digitize an image using sampling grid 5.

Sampling grid 6: Data sampled by grid 6 are non-normal data, with the residual of ±2.5 %. Data comply with the homoscedasticity assumption. Required digitization time is 10 minutes per image.

In general, sampling grids 1 and 2 were omitted from further consideration due to large residual, ± 50 and ±15 %, respectively, and insignificant statistical difference with the other grid samplings. These two sampling grids are non-normal and violate the homoscedasticity assumptions. Sampling grids 5 and 6, with a relatively high digitization time requirement of 5 and 10 minutes per image, respectively, were removed from further field evaluation due to an economical issue in mass field data collection. Among sampling grids 3 and 4, sampling grid 4 is selected for field data collection, as residual in grid 4 is half the residual of grid 3. In contrast to grid 3, data produced by grid 4 is not non-normal. A limited digitization time difference exists between both grid samples, and produced data by both sampling grids show insignificant differences.

Table 6.4 summarizes the statistics analysis of the six sampling grids. The first column lists the sampling grids with statistical tests, including significant difference, normality test, residual, and homoscedasticity, as well as required digitization time of sampling grids in the other columns, respectively.

Figures 6.8, 6.9, and 6.10 show the relationship between residual and sampling grids. The y-axis shows the residual, and the x-axis describes the grid sampling number. Figure 6.8 describes the relationship between residual and sampling grids for 70 to 113 patches, while Figure 6.9 shows the relationship between the residual and sampling grids for streambed components proposed in the proposed classification system in a patch. Figure 6.10 describes the relationship between the averaged residual and streambed components for 70 to 113 patches sampled in three streams, including 10 riffles in the bluegrass area.

Based on these figures, residual is decreased from grid sampling 1 through grid sampling 6. As sampling grid 1 has the cell size of 25 cm, and sampling grid 6 has the cell size of 0.625, the conclusion can be drawn that, as cell size decrease, residual also decrease. However, the variation of residual is relatively small after sampling grid 4.

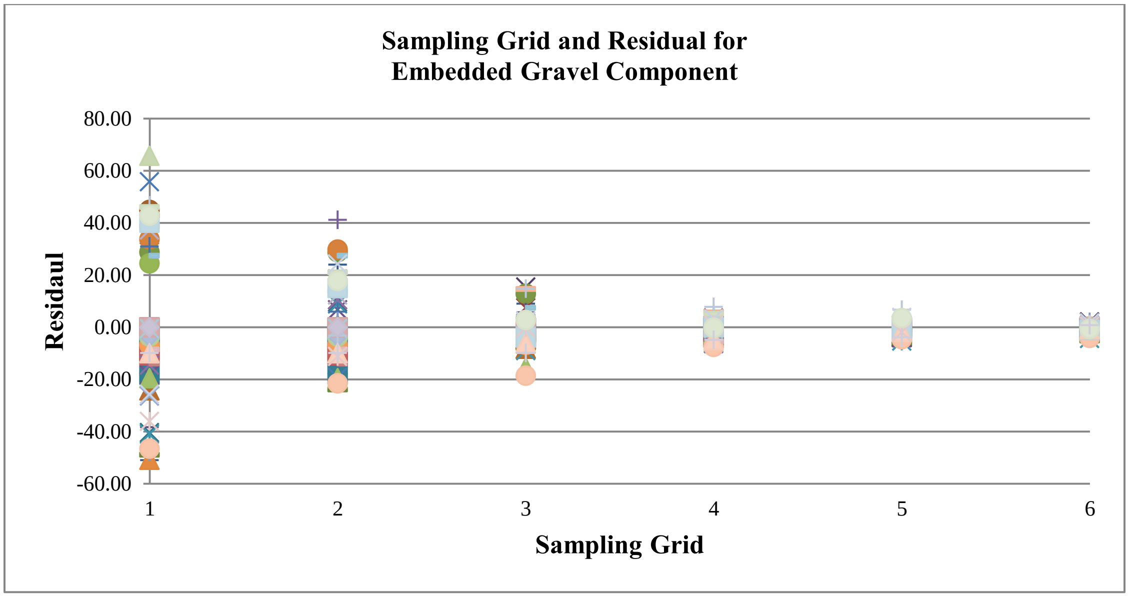


Figure 6.8. Sampling grid and residual for embedded gravel component for 70 to 113 populations collected from streams.

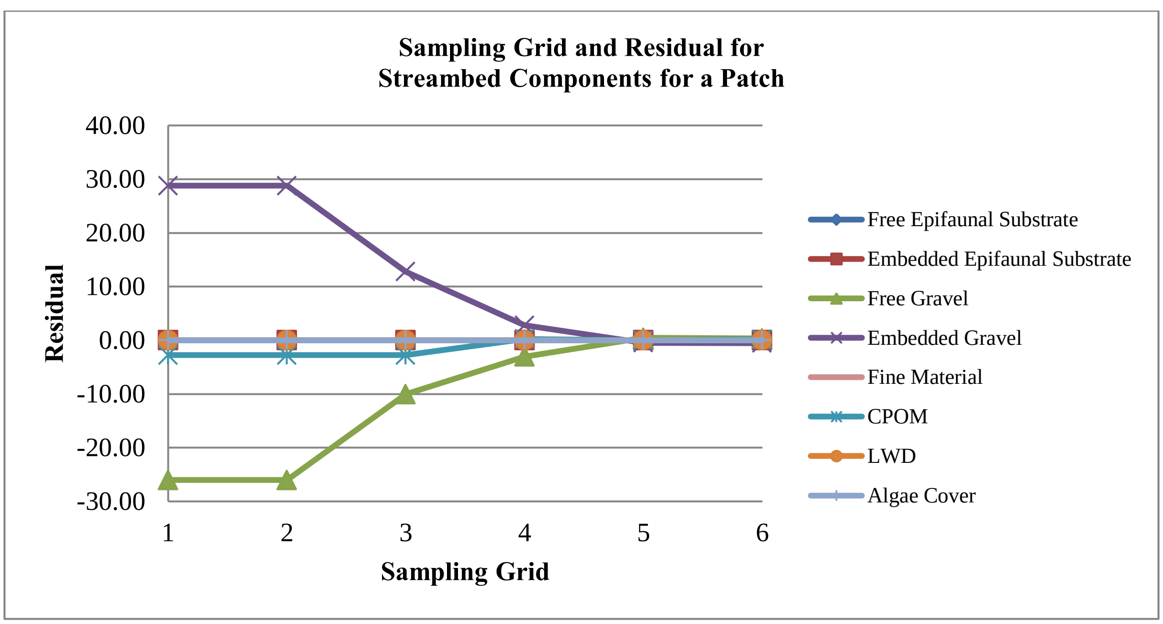


Figure 6.9. Sampling grids and residual of streambed components for patch 15.

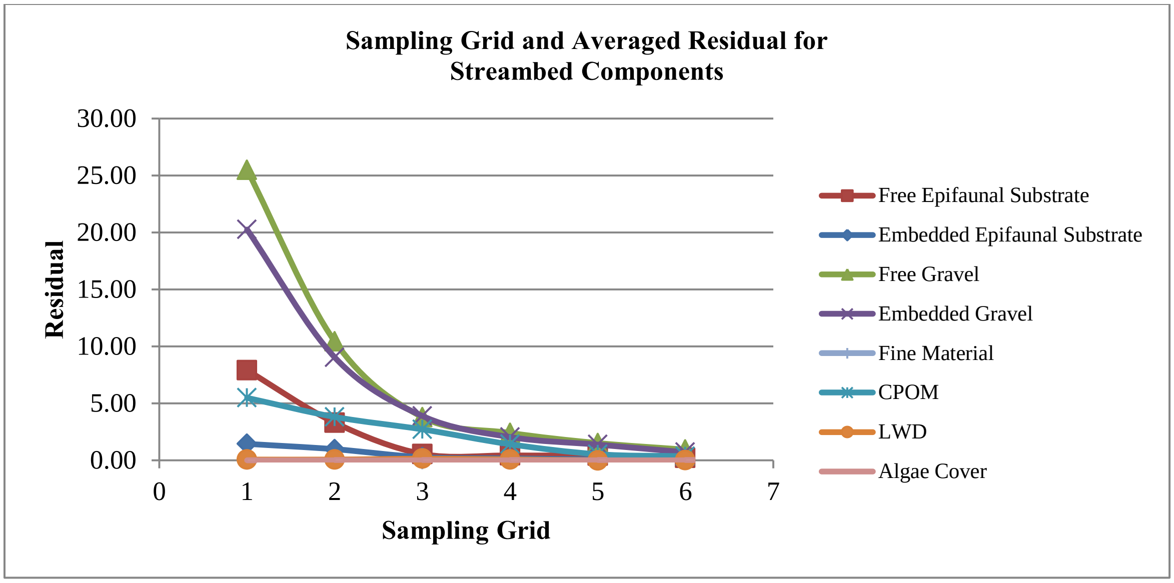


Figure 6.10. Sampling grid and average residual for streambed components for 70 to 113 populations collected from streams.

Tables 6.5 and 6.6 present the statistical properties of residual for 70 to 113 recorded images in three streams. They describe the residual and variance for sampling grids and streambed components, respectively. In both tables, the first column describes the streambed components, and other columns highlight the residual properties of sampling grids.

Table 6.5

Average of Residual of Sampling Grids for Streambed Components for 70 to 113 Record Patches

Physical Component	Sampling Grid 1	Sampling Grid 2	Sampling Grid 3	Sampling Grid 4	Sampling Grid 5	Sampling Grid 6
Embedded Epifaunal Substrate	1.45	0.98	0.28	0.18	0.09	0.06
Free Epifaunal Substrate	7.91	3.31	0.56	0.43	0.42	0.21
Free Gravel	25.50	10.43	3.79	2.41	1.52	0.94
Embedded Gravel	20.26	9.03	3.89	2.04	1.38	0.71
Fine Material	0.00	0.00	0.00	0.00	0.00	0.00
CPOM	5.48	3.81	2.72	1.41	0.54	0.36
LWD	0.07	0.07	0.06	0.06	0.00	0.00
Algae Cover	0.00	0.00	0.00	0.00	0.00	0.00

Table 6.6

STDEV of Residual of Sampling Grids for Streambed Components for 70 to 113 Record Patches

Physical Component	Sampling Grid 1	Sampling Grid 2	Sampling Grid 3	Sampling Grid 4	Sampling Grid 5	Sampling Grid 6
Embedded Epifaunal Substrate	5.36	4.20	0.74	0.39	0.38	0.24
Free Epifaunal Substrate	15.16	6.72	2.08	1.93	1.28	0.46
Free Gravel	30.36	15.99	9.39	7.77	2.12	1.43
Embedded Gravel	27.89	12.86	5.93	2.92	2.05	1.20
Fine Material	0.00	0.00	0.00	0.00	0.00	0.00
CPOM	7.03	4.77	2.61	1.73	0.82	0.62
LWD	0.60	0.60	0.13	0.01	0.01	0.01
Algae Cover	0.00	0.00	0.00	0.00	0.00	0.00

In Table 6.5, the free gavel component in sampling grids has the maximum amount of residual. Fine material and algae cover were the absent streambed components in this grid. Based on Table 6.5, the cell size is smaller and the residual is less. Therefore, the smallest amount of residual is for sampling grid 6, with cell size of 0.625 by 0.625 cm; whereas the largest amount of residual is for sampling grid 1, with cell size 25 by 25 cm.

Table 6.6 has a similar trend, with the free gravel component having the highest amount of variance. Sampling grids 1 and 6 show the smallest and greatest amount of variance, respectively.

6.2 Statistical Analysis of Riffle Population Methodology

A key objective of the study was to determine a methodology for sampling riffle population in the proposed classification system. Images of 10 riffles in three streams in the bluegrass area of Kentucky, were recorded. The image recording process in each riffle was explained in Chapter V and Figure 5.2. Projected aerial percentage of each streambed component in each image was estimated visually using 50% incremental projected area and sampling grid 4 with cell size of 2.5 by 2.5 cm. In this analysis, CS is the abbreviation for cross section.

Statistical analysis, including significant difference and residual between each CS and riffle population, was implemented utilizing MINITAB 16 software to determine the sampling methodology for riffle population at the confidence level of $p = 0.05$ and $\alpha = 0.05$. Statistical analysis of riffle sampling population is beneficial in finding an easy and inexpensive field method to sample riffle population at the desired confidence level. Comparison of riffle and CS was due to similarity in variation of flow depth and velocity across CS and riffle (Curran & Wilcock, 2005; Buffington & Montgomery, 1999). Therefore, sampling streambed components in a CS can be beneficial in tracking changes in streambed components in riffle population, as the sampling CS is much easier and more convenient in comparison to sampling the entire riffle population. The following section presents the statistical analysis of the first riffle population, and statistical analysis for the rest of the sampled riffles is presented in Figures 1-7 in Appendix II.

Statistical Analysis of the First Riffle Data: The first riffle is located in Wilson Creek, with a drainage area of 5.73 ml^2 and restored more than six years ago. Limited signs of bank erosion and human activities were noted in the channel and buffer zone. It has neither a layer of fine material nor a bedrock outcrop.

Tables 6.7 and 6.8 summarize the projected aerial and residual for each component for riffle 1. Table 6.7 shows the average residual for each CS, while the variance of residual is described in Table 6.8. To cover the entire riffle, 153 images were recorded using the PPB. Based on Table 6.7, free gravel and the free epifaunal substrate are the main substrate variables, with an average of 59.62% and 26.21%, respectively; whereas LWD is absent in the streambed composition. The other components contain less than 10% of streambed compositions each. In riffle 1, 1.54% of area is covered by algae. Maximum residual is for free gravel component in the third CS, which is 8.45 (Table 6.8).

Table 6.7
Projected Areal Percentage of Each Component in Riffle 1

CS Name	Free Gravel	Embed. Gravel	Free Epif. Subst.	Embedd. Epif. Subst.	Fine Material	CPOM	LWD	Algae Cover
First	63.72	6.22	27.00	1.50	0.39	0.00	0.00	1.17
Second	62.56	6.50	26.50	3.67	0.17	0.00	0.00	0.61
Third	51.47	15.05	26.63	3.68	0.84	0.32	0.00	2.00
Fourth	58.86	8.43	27.19	3.38	0.24	1.81	0.00	0.10
Fifth	59.20	8.53	23.33	6.00	0.00	0.00	0.00	2.93
Sixth	61.94	6.82	24.53	2.65	0.29	0.29	0.00	3.47
Seventh	56.45	5.10	30.75	5.90	0.00	0.10	0.00	1.70
Eighth	65.20	4.80	23.72	5.00	0.52	0.44	0.00	0.32
Average Riffle	**59.92**	**7.68**	**26.21**	**3.97**	**0.31**	**0.37**	**0.00**	**1.54**

Table 6.8

Residual of Each Component in Riffle 1

CS Name	Free Gravel	Embed. Gravel	Free Epif. Subst.	Embedd. Epif. Subst.	Fine Material	CPOM	LWD	Algae Cover
First	-3.80	1.46	-0.79	2.47	-0.08	0.37	0.00	0.37
Second	-2.63	1.18	-0.29	0.31	0.14	0.37	0.00	0.93
Third	8.45	-7.37	-0.42	0.29	-0.54	0.05	0.00	-0.46
Fourth	1.07	-0.75	-0.98	0.59	0.07	-1.44	0.00	1.44
Fifth	0.72	-0.85	2.87	-2.03	0.31	0.37	0.00	-1.40
Sixth	-2.02	0.86	1.68	1.33	0.01	0.08	0.00	-1.93
Seventh	3.47	2.58	-4.54	-1.93	0.31	0.27	0.00	-0.16
Eighth	-5.28	2.88	2.49	-1.03	-0.21	-0.07	0.00	1.22

A single factor ANOVA test revealed the means of streambed CS components measured using sampling grids not statistically different, as F (=2.073) < Fcrit (=2.736). To evaluate the significant differences between each streambed component measured in CS and the riffle populations, t-test was implemented using MINITAB 16 software. Analysis results are presented in Table 6.9 for the p-value for $\alpha = 0.05$. The first row lists the CS, and the second row describes the p-value for $\alpha = 0.05$ for each CS. An insignificant difference was found between streambed components measured in riffle population and each CS, for a 95% confidence interval ($p > 0.05$).

Table 6.9

p-Value for α=0.05 for Each Row in Riffle 1

First CS	Second CS	Third CS	Fourth CS	Fifth CS	Sixth CS	Seven CS	Eighth CS
0.92	0.94	0.82	0.98	0.98	0.95	0.95	0.88

Figure 6.11 in this section and Figures 8-16 and Table 1-27 in the Appendix II show the prediction interval (PI) and confidence interval (CI) for each streambed component measured in CS for riffle 1. In these figures, PI and CI are the prediction and confidence intervals, respectively. Based on these figures, the observation is more likely to fall in a range of ±3% to ±4% difference from streambed components measured in riffle population, with 95% probability. The residual is indicated in the x-axis, and the amount of streambed components is shown in the y-axis.

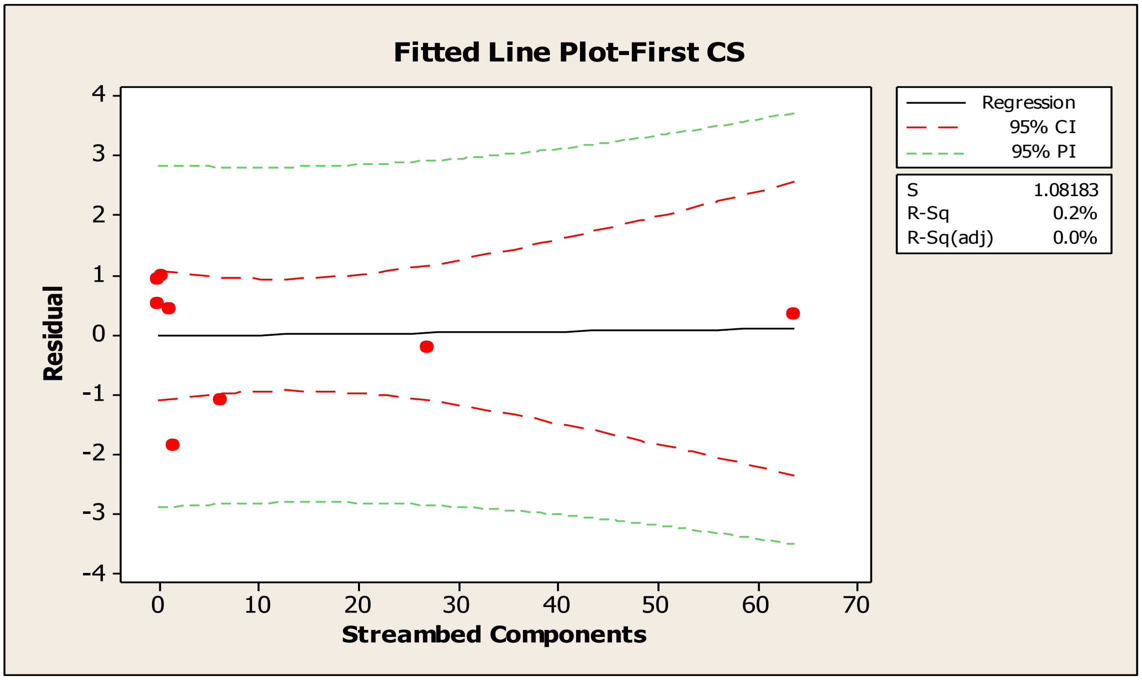


Figure 6.11. Residual plot for streambed components with 95% PI and CI for first CS riffle 1.

The comparison of results between the sampled transects (CS) and riffle population for the 10 riffles in the three streams in this section and in the Appendix shows a statistically insignificant difference between the data sampled for each transect and riffle population data, for 95% confidence interval. The maximum residual was approximately 20% (free gravel in second CS, riffle 3, Table 5, and Appendix II).

6.3 Statistical Analysis of Surface Sampling Methods of Riffle Population

The following section presents data sampled using the common methods of streambed surface samplings, including the pebble count and the rapid bioassessment. The first and second sections present the sampled data using the pebble count and the rapid bioassessment, respectively. The third section compares and contrasts variables from the proposed method with both the pebble count and rapid bioassessment techniques.

6.3.1 Pebble Count

Figure 6.12 presents the data sampled using the pebble count in 10 riffles in three streams. The data sampling procedure and limitations of sampling riffle using the pebble count are explained in Chapter V. The number of pebbles collected for each riffle was slightly more than 200 (Rice & Church, 1998).

In Figure 6.12, the median diameter is graphed in mm on the x-axis, while percent fine is described in percentage on the y-axis. Riffles 3 and 5 show distinct fine grain size distribution in comparison to the other sampled riffles. These riffles are located in the Harrison and Overalls Creeks, respectively, and both are un-restored. In contrast, riffle 4, an un-restored riffle in Harrison Creek, has slightly coarse grain size distribution relative to the other sampled riffles. More discrepancy exists among D_{16} in comparison to D_{50} and D_{84} on average in the 10 riffles.

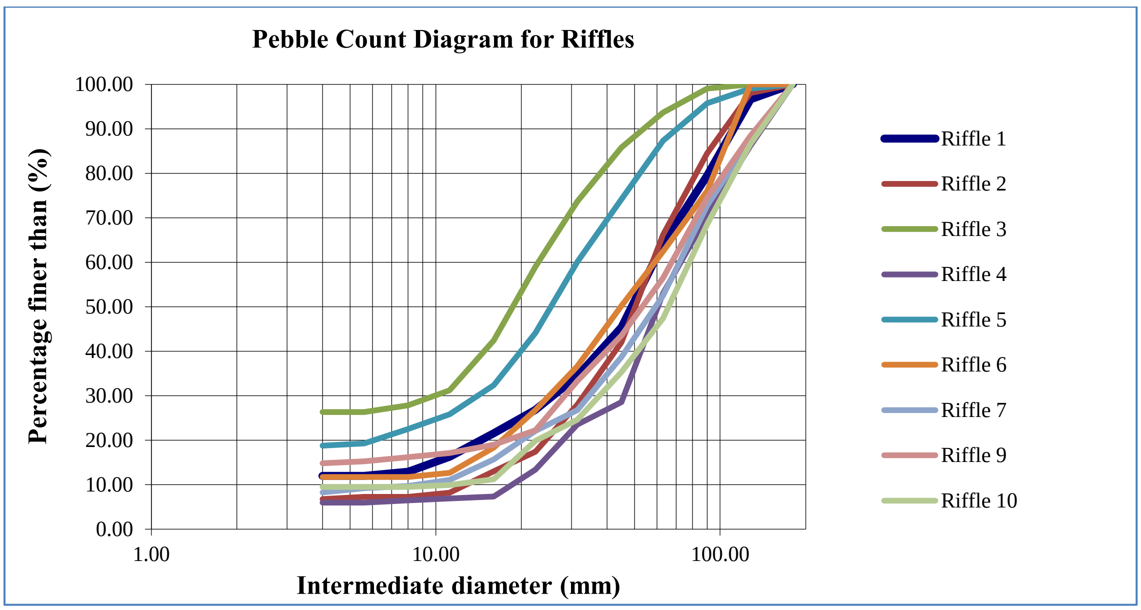


Figure 6.12. Pebble count diagram of 10 riffles in three streams.

6.3.2 Rapid Bioassessment

Table 6.10 and Figure 6.13 describe the sampled data using the rapid bioassessment in the 10 riffles in the three streams. Limitations and the procedure of sampling streambed components using rapid bioassessment are explained in Chapter V.

The first column in Table 6.10 lists the name of the riffle studied, and columns 2 through 6 describe the amount of embeddedness for riffle tail, middle, crest of riffle, and riffle average in percentage. Based on this table, sampled riffles are in good condition, although riffles 4 and 10 are in excellent condition from the point of view of embeddedness measurement in the rapid bioassessment protocol. On average, in 10 riffles, the middle of riffle has a higher amount of embeddedness relative to the riffle tail and riffle crest.

Table 6.10

Embeddedness Measurement in Riffles in the Bluegrass Area Based On the Rapid Bioassessment Protocol

Riffle Name	No. of Pebble	Riffle Tail (%)	Middle of Riffle (%)	Riffle Crest (%)	Riffle Average (%)
1	209.00	40.00	60.00	20.00	40.00
2	207.00	20.00	40.00	40.00	33.33
3	205.00	40.00	60.00	20.00	40.00
4	217.00	20.00	20.00	20.00	20.00
5	213.00	40.00	50.00	55.00	48.33
6	213.00	60.00	40.00	20.00	40.00
7	217.00	20.00	40.00	20.00	26.67
8	216.00	40.00	35.00	60.00	45.00
9	216.00	40.00	40.00	50.00	43.33
10	232.00	40.00	25.00	0.00	21.66
Average	**215.00**	**36.00**	**41.00**	**30.50**	**35.83**

6.3.3 Comparison of Streambed Components in the Streambed Sampling Methods

The following Figures (6.13 through 6.16) show the variations of streambed components measured in 10 riffles using the pebble count, the rapid bioassessment, and the proposed techniques. These figures compare fine material, free and embedded gravel, and free and embedded epifaunal substrate in three methods. Other physical variables, including LWD, CPOM, algae cover, are not included in the comparison. As the definition of streambed components in the proposed method is dissimilar among the three methods, an equivalent amount of the same parameter is used in these figures, based on the Wentworth scale, to provide comparison of possible methods.

Figure 6.13 shows the grain size distribution of the 10 sampled riffles using the proposed method. The y-axis describes the amount of grain (%), and the x-axis shows the intermediate diameter (mm).

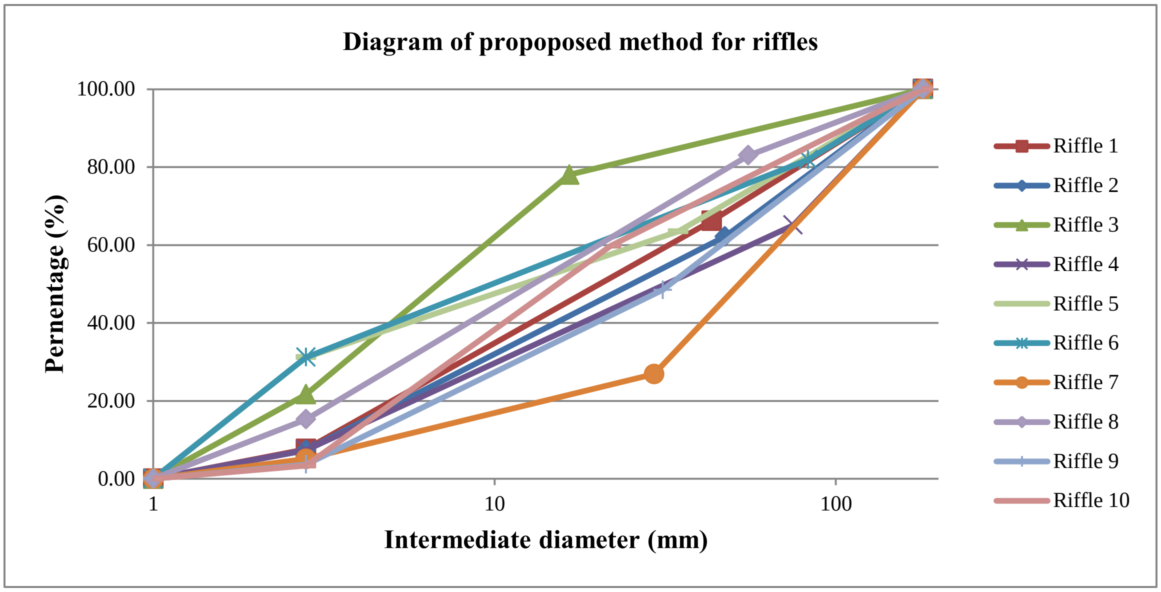


Figure 6.13. Proposed diagram of 10 riffles in three streams.

Figures 6.14 and 6.15 compare common physical components including fine material, free and embedded gravel, and free and embedded epifaunal substrate using the proposed and pebble count methods. The definition of streambed components in the rapid bioassessment method is dissimilar to the definition of the streambed components in pebble count method; therefore, comparison of streambed components in rapid bioassessment with the proposed method are presented separately in Figure 6.16.

Figure 6.14 compares the gravel component in the pebble count method with the gravel components, including free and embedded gravel, in the proposed method. The y-axis describes the percentage of fine material for each riffle, and the x-axis shows the riffle number.

The distribution of gravel components in both methods is similar, and the measured variable using the proposed method shares the greater value than that of the pebble count method. The dash line shows the difference between the gravel measured in both proposed and pebble count methods. The maximum difference is 39.95% for riffle 10, and the smallest difference is 0.48% for riffle 5 in Wilson Creek. Data show limited particular trend with the random spreading.

Measured gravel in both methods has significant difference (p > 0.05). Riffles 1, 2, 3, 4, 9, and 10 share more than 10% in difference between the two methods for evaluating the gravel component. Whereas, riffles 5, 6, 7, and 8 have less than a 6% difference in estimating the gravel component in both methods.

Riffles 3 and 10 show the highest amount of variability among the riffles, with more than 30% difference between the two techniques. In riffles 1, 2, and 9, the difference between the measured variables in the two methods is approximately 20%. The other riffles show the least difference between the two methods in evaluation of the gravel (< 10%). The difference may be due to random error or variability due to the insufficiency of numbers of pebbles collected in the pebble count.

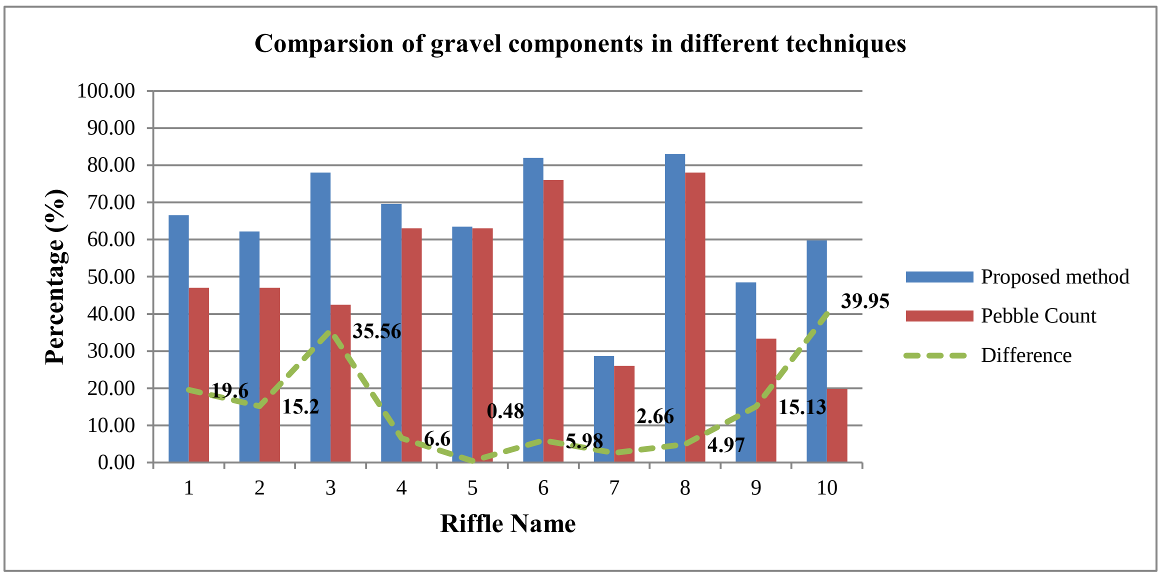


Figure 6.14. Comparison of gravel component (%) in riffles using the proposed and pebble count methods.

Figure 6.15 compares the epifaunal substrate component in the pebble count method with the same components, including free and embedded epifaunal substrate, in the proposed method. The y-axis describes the percentage of fine material for each riffle, and the x-axis shows the riffle number. The dash line shows the difference between the epifaunal substrate measured in both the proposed and the pebble count methods.

In contrast to the gravel component, the pebble count method overestimates the epifaunal substrate component relative to the proposed method. The maximum difference is -40.76% for riffle 10, and the smallest difference is -2.48% for riffle 4 in Overalls Creek. Data show limited special trend with the random spreading.

The difference between the epifaunal substrate measured using both methods followed the same trend in the gravel component, and the same justification can be applied. Riffles 3 and 10 show the highest difference between the two methods for the epifaunal substrate. Similar to the gravel component, riffles 1, 2, and 9 have approximately 20% difference in estimating the epifaunal substrate using both methods. Riffles 4, 5, 6, 7, and 8 have the smallest amount of difference (almost 10%) in comparison to the other riffles.

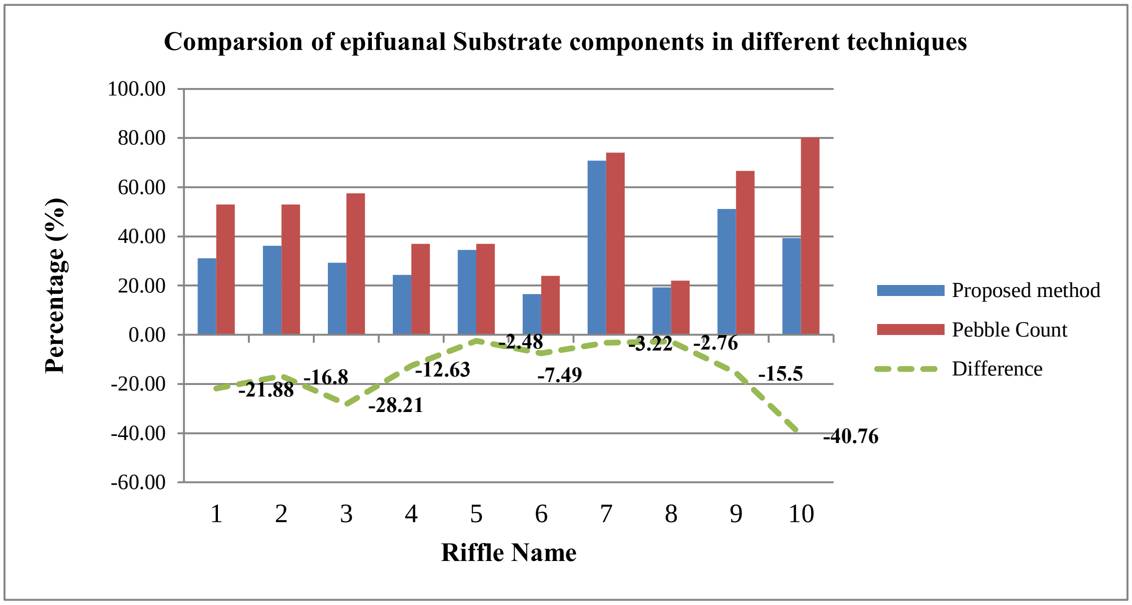


Figure 6.15. Comparison of epifaunal substrate component (%) in riffles using the proposed and pebble count methods.

Figure 6.16 presents the comparison of embeddedness variable in the proposed and the rapid bioassessment methods. Due to dissimilarity between the definition and binning scale in the pebble count, and the rapid bioassessment methods, the pebble count method was eliminated for evaluation of the embeddedness parameter. The y-axis describes the percentage of embeddedness for each riffle, and the x-axis indicates the riffle number.

Based on Figure 6.16, the rapid bioassessment method overestimates the embeddedness variables in all 10 riffles relative to the proposed method. The maximum difference using both methods is -47.5% for riffle 1, and the smallest difference is -0.2% for riffle 2 in Wilson Creek. The average difference is -25%. Data show limited special trend with the random spreading.

The difference in evaluation of the embeddedness in the rapid bioassessment method may be a result of sampling location. Eighty percent of sampling spots in the rapid bioassessment method are located near the channel bank, which has more fine material content; only 20% of sampling spots are located in the middle of the channel area, with low fine material content (Kauffman, 1999). Consequently, the rapid bioassessment method estimates higher amounts of embeddedness, as a result of fine material in comparison with the proposed method.

Riffles 1, 2, 6, 8, and 9 have the highest difference (approximately -30%) between the measured embeddedness using the two methods due to the relatively high amount of fine materials near the bank toe, with the low amount of fine material in the channel. Riffles 3, 7, and 10 show that the difference in the measured methods is approximately -15%. In riffles 3 and 10, the right bank toe, and in riffle 7 the left toe bank store less fine materials. The middle of the channel in these riffles contains a substantial amount of fine materials.

Riffles 4 and 5 show the smallest amount of difference between the embeddedness using the two techniques (< -5%). Riffle 4 has a low amount of fine material in the middle of the channel and right toe of the channel, while riffle 5 has a consistent amount of fine materials spread equally in the riffle. Therefore, the measured embeddedness in both methods is relatively the same, as long as the amount of fine material is consistently spread on the riffle surficial area.

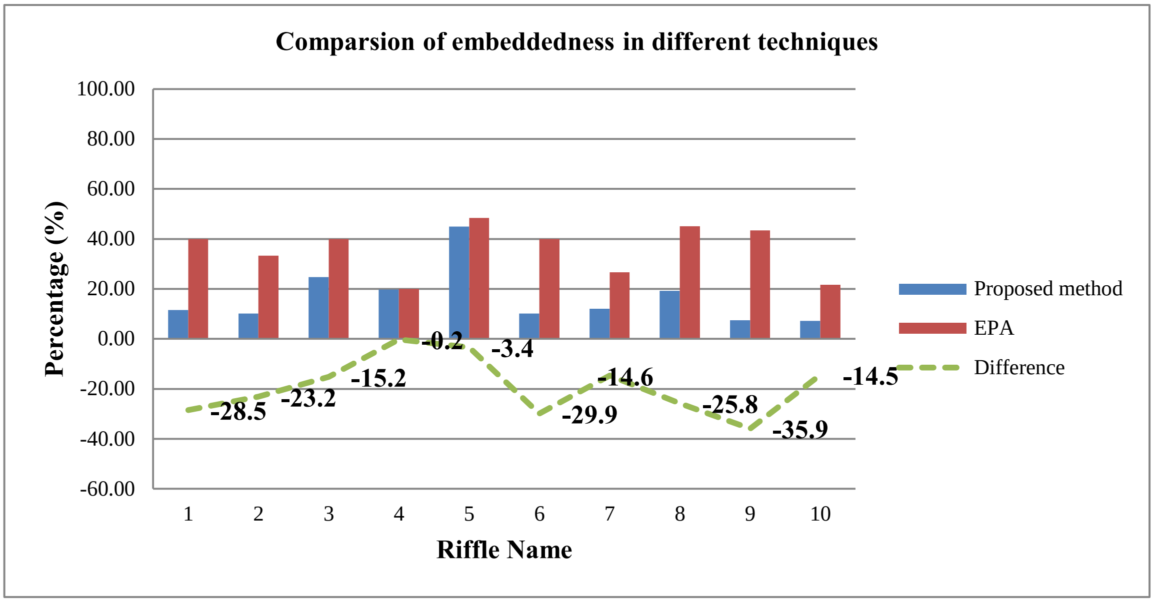


Figure 6.16. Comparison of embeddedness (%) in riffles using the proposed and rapid bioassessment methods.

6.3.4 Comparison of the Streambed Components in Riffles

Figure 6.17 in this section and Figures 1 -9 in Appendix III present the comparisons of methods including the pebble count, rapid bioassessment, and proposed technique in measuring riffle components in the 10 riffles. The y-axis shows the component percentage, and the particle size is shown in the x-axis. The three methods differ in almost every streambed component, thus slight adjustments were necessary to better compare the results. A common riffle length was selected for all methods, and sampling locations needed to be as similar as possible without compromising the characteristics of the procedures. All samples were collected by one operator.

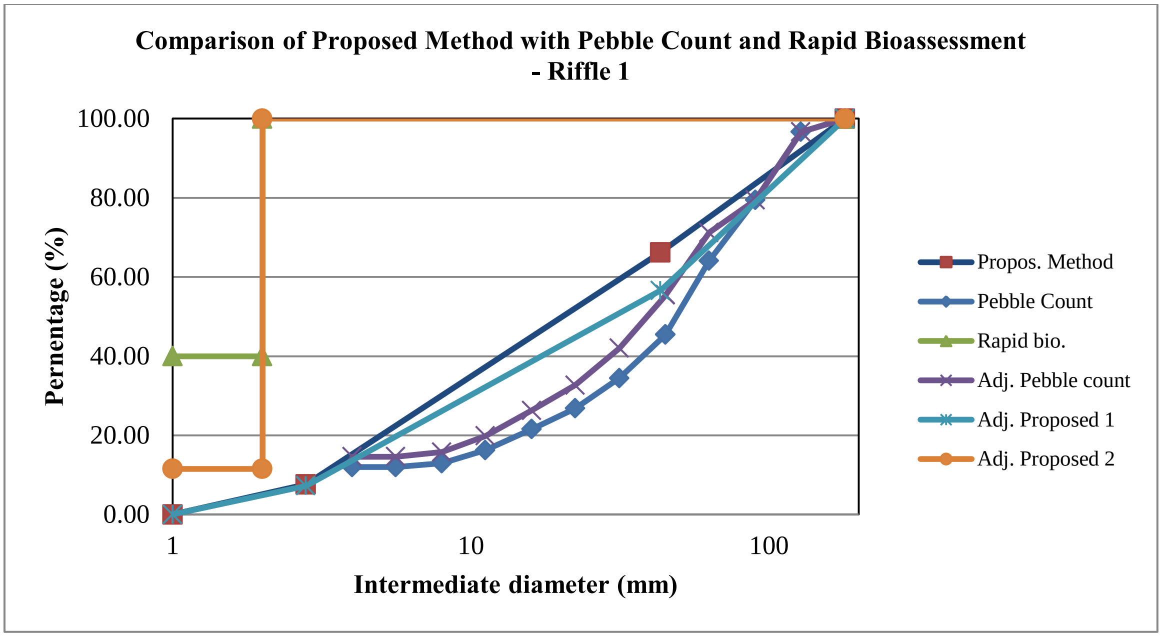


Figure 6.17. Comparison of sampling methods in riffle 1.

The pebble count graph shows the particle grain size distribution from samples collected using the pebble count method. In the rapid bioassessment method, the embedded and un-embedded aerial percentage of the streambed components are described based on the rapid bioassessment protocol. Moreover, the proposed method shows the aerial percentage of the streambed components that were categorized according to the proposed classification system.

In this research study, the proposed method removes the error related to particle identification and sample size by using photographic technique and systematically sampling the entire riffle, respectively. Therefore, those results were considered to be the best obtained estimation of the true distribution of streambed components within the riffle. The distribution of streambed components obtained from the proposed method and the pebble count technique varied greatly, with a similar pattern in the 10 riffles, other than riffle 8.

Sampling results among the protocols differed at the middle of the grain distribution diagrams and the pebble count method produced the coarser grain size distribution in comparison to the proposed method. In addition, the fine tail shows less variability than the coarse tail. The pebble count method indicated that, in all riffles except 5 and 6, the fine materials were approximately 3% less than in the proposed method. In riffles 5 and 6, the fine materials were nearly twice and triple in the proposed method relative to the pebble count. The underestimation of the fine tail in the pebble count is due to sampling locations, as that method samples the area close to the water line and bank, up to 5% less than the amount sampled by the proposed method. These areas have more fine content (Kaufmann et al., 2001). Moreover, riffle 5 showed signs of spot bed and bank erosion, while riffle 6 showed the sign of spot erosion on both banks.

The D_{50} particle size obtained in the pebble count in all riffles except 3, 7, and 10 were nearly twice as large as those obtained from the proposed method. In riffles 3 and 10, the difference was triple, whereas, D_{50} in both methods for riffle 7 reached the same amount. The bed material D_{84} sizes showed the smallest difference among the procedures, reaching nearly the same amount in both methods, except riffle 5 because channel incised the left bank. The D_{50} particle size in riffles 4, 7, and 9 were the same; however, in the other riffles it was slightly higher in the pebble count method than the proposed method.

As noted previously, the graph obtained by the pebble count was coarser than the graph in the proposed method. Sampling location, and the combination of both identification and measurements of particle, may cause the coarseness of the pebble count data. In the pebble count method, every 25 cm one pebble was selected and measured, whereas the projected aerial of the entire riffle was estimated in the proposed method. Thus, in sampling a riffle in the proposed method, up to 5% more pebbles were selected from or close to the waterline, which are areas containing more fine material. Second, in the pebble count method, particle measurement was fulfilled in the field using the gravelometer, which provides the sieved particle volume data. However, in the proposed method, the data is the projected aerial percentage of each streambed component. Hence, in order to compare results from both methods, the pebble count data would need to be adjusted. The adjustment is based on the particle shape, in accordance with Shirazi et al. (2009) and Church et al. (1987), for ellipsoidal particle shape, with c/b = 0.60, $D_{(sieve)}/b = 0.82$. Therefore, particle sizes for the computed cumulative percent frequencies were decreased by 18%. The adjustments that are described under the title "adj. Pebble count" generally moved the pebble count's grain size distributions closer to those collected by the proposed method.

The difference in D_{50} for both methods changed to almost 50% in riffles 1, 2, 3, 4, 5, and 8. In riffles 6 and 10, the difference in D_{50} obtained in both methods was nearly 100%; however, in riffles 7 and 9, a similar amount of D_{50} was determined by both methods. Conversely, the proposed method measured the particle size visually, with a maximum 5% error based on the analysis of the sampling grid previously mentioned. Therefore, adjustment of the proposed method of sampled data also is necessary.

The third difference relates to the classification system. The proposed system was developed in a wider class size relative to the pebble count method. According to Faustini and Kaufmann (2007) and Bunte et al. (2009), the wide size binning produces the finer center and the coarser end tails of grain size distribution, at 15-20%. These adjustments were accomplished for the riffle data under the title “adj. proposed 2”. Despite these adjustments, some differences were noted between the size distribution produced by the pebble count and the proposed method as the pebble count had more gravel than the proposed method. This may be due to sample size and that more particles are required to be sampled in the pebble count method to improve precision in determining the streambed components (Rice & Church, 1996).

Figure 6.17 in this section and Figures 1-9 in Appendix III include graphs for sampling streambed components using the rapid bioassessment method for each riffle. In the rapid bioassessment method, streambed components are separated into embedded and un-embedded materials. Thus, adjustments were necessary to compare study results for the three protocols. In the proposed method, fine material, embedded gravel, and embedded epifaunal substrate components are equivalent to the embedded component, while free gravel and free epifaunal substrate components are equivalent to the un-embedded materials based on the rapid bioassessment protocol. In this regard, the adjusted proposed method graph is shown under “adj. Proposed 2” in these figures. However, the direct comparison of the rapid bioassessment and pebble count methods is not possible, as the definitions of components in the two methods are dissimilar. Thus, compression was limited to the rapid bioassessment and proposed methods.

Based on these figures, except in riffles 4 and 5, the amount of the embedded components in the rapid bioassessment method is greater than those in the proposed method, a difference greater than threefold between the two protocols. This is perhaps due to sampling location. In the rapid bioassessment method, 40% of the data was sampled from the waterline, where more fine material is stored. In the proposed method, less than 15% of the data were sampled from the waterline. The difference in the embedded components using both methods was highest in riffles 6 and 9, four to six times higher, respectively. Both riffles are located in Wilson Creek and are restored riffles. In riffle 6, the amounts of the embedded gravel are quite high in the percentages of 0, 25, and 75 of wetted width for riffle tail transect. In riffle 9, the amount of the embedded epifaunal substrate in the sampling points were high, 50% and 75%, for riffle tail and middle transects. As the number of sampling points is low in the rapid bioassessment method, the embeddedness in these riffles is increased substantially when few spots are located in the highly embedded area.

Embedded materials in riffles 4 and 5are more consistent. In riffle 4, fewer amounts of embedded materials were found, whereas the embedded materials were more pronounced in comparison to riffle 4. In both riffles, the spread of embedded materials was consistent over the riffle length. In contrast, limited consistency in spreading of streambed materials was found in the other riffles over the riffle length.

The consistency refers to the consistency between the amount of embeddedness in three transects in each riffle using the rapid bioassessment method. These include riffle tail, middle of riffle, and riffle crest transects. Consistency in embeddedness was noted between transects in riffles 4, 5, and 9, whereas less consistency was found in embeddedness between transects in the rest of the riffles. In the riffles with consistency, other than 9, the amount of embeddedness estimated using the rapid bioassessment method was close to the amount evaluated using the proposed method. Conversely, in the riffle without consistency in embeddedness between transects, the amount using the rapid bioassessment method was overestimated two to six times the amount using the proposed method. Thus, in the riffle with consistency, two out of three had a similar amount of embeddedness in both methods. In riffles without consistency, all showed dissimilar amounts using both methods. This indicates that, in riffles with consistency, 67% of the embeddedness estimated using the rapid bioassessment method is similar to that in the proposed method. One hundred percent of the embeddedness estimated using the rapid bioassessment method in riffles without consistency was varied from that in the proposed method. The conclusion can be drawn that the rapid bioassessment method can estimate embeddedness accurately in riffles that show consistency between transect embeddedness.

6.4 Comparison of Streambed Components in Streams

Figures 6.18, 6.19, and 6.20 present comparisons of the three methods including proposed, pebble count, and rapid bioassessment techniques in measuring streambed components in three streams in the bluegrass area of Kentucky. Streambed components in riffles were averaged to determine the components. Figure 6.18 shows the comparison of these methods in Wilson Creek, which has 6 riffles, including riffles 1, 2, 6, 7, 9, and 10. While Harrison Creek includes riffles 3 and 4, and Overalls Creek has two, including riffles 5 and 8. A comparison of the three methods in each stream reveals that the pebble count method was coarser (in the center) than the proposed method, with similarity in diagram patterns. After adjustment for sampling location of the pebble count method, methods of particle identification, and size measurement effects in the proposed method, sampling grid, and the wide size binning effects, both graphs moved closer together. However, similar to graphs in riffle analysis, a difference still remains between both graphs. The difference in D_{50} for both methods changes from twice to almost 15% in Wilson and Harrison Creeks and 50% in Overalls Creek. The D_{84} was fairly similar in both protocols.

The fine tail materials obtained by the proposed method were larger by 4% to 7% than those in the pebble count method. This is due perhaps to sampling location, as the proposed method sampled the area close to the waterline, and the bank toe was almost 5% higher than the pebble count. Area close to the waterline and bank toe store more fine materials, according to Kaufmann et al. (2001). These figures also present the data sampled from the rapid bioassessment method. A comparison of the proposed and the rapid bioassessment methods indicates that the rapid bioassessment method overestimated the amount of sampled embedded materials similar to riffle embeddedness. The smallest difference was for Harrison Creek, which was 15%. The largest difference was Wilson Creek, with a difference of 3.5 times. A comparison of the sampled data in the three methods indicated that the difference between the pebble count and rapid bioassessment methods with the proposed method was less pronounced in stream scale, in comparison to riffle scale. This may be due to the effects of averaging study results over multiple riffles in each stream.

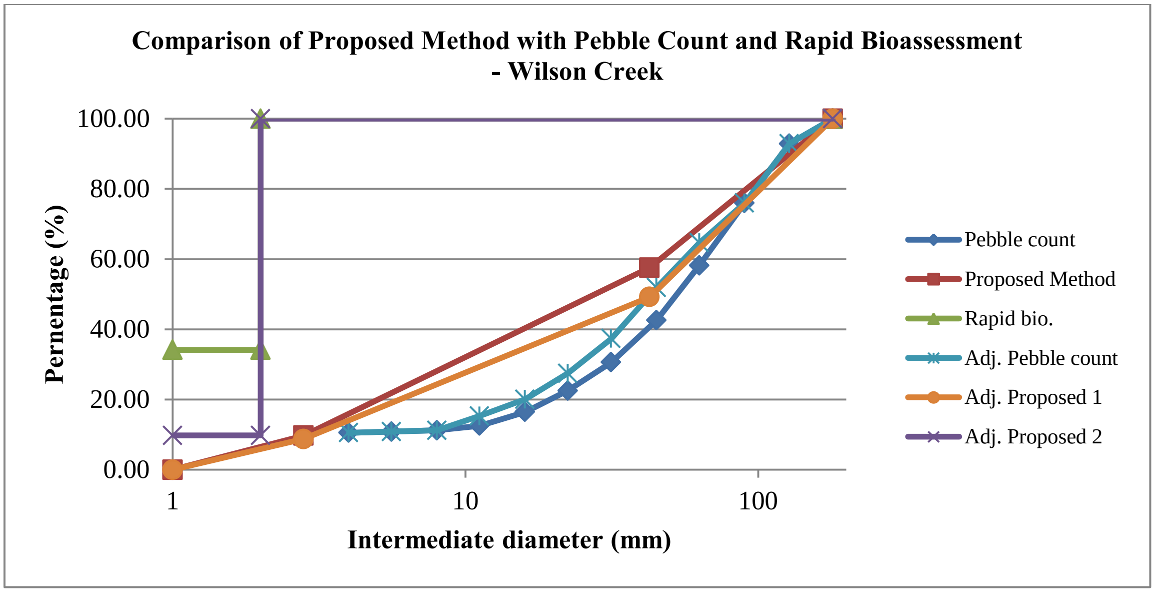


Figure 6.18. Comparison of sampling methods in Wilson Creek.

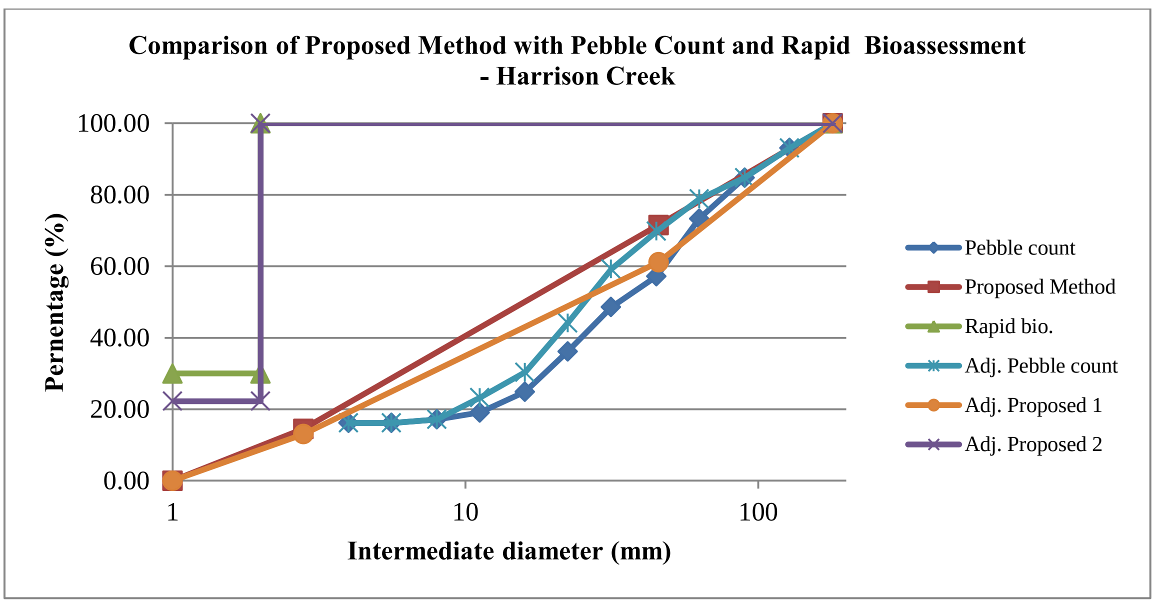


Figure 6.19. Comparison of sampling methods in Harrison Creek.

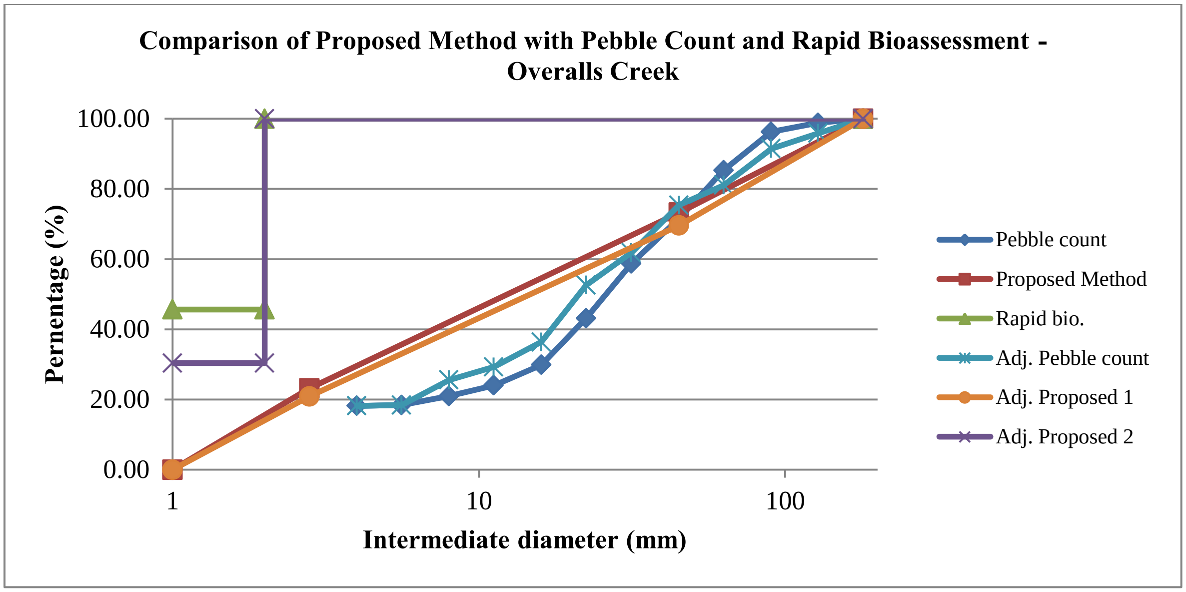


Figure 6.20. Comparison of sampling methods in Overalls Creek.

CHAPTER VII

WATER QUALITY VARIABLES (DISSOLVED OXYGEN AND TEMPERATURE)

In this study, dissolved oxygen and temperature were used as quality factors and evaluated separately in the field. As equipment is unavailable to sample both physical streambed components and quality factors simultaneously, two-stage streambed evaluation is recommended for field sampling component characteristics. However, the relationship between physical parameters and quality factors was developed in this project as an aid in correlating the amount of dissolved oxygen and temperature based on physical component characteristics. Thus, it is likely that measuring dissolved oxygen and temperature will be required any time data are collected.

This chapter presents a brief review of possible devices to find a proper device collecting water factors in each patch in the field. In addition, results of DO and temperature measurements in the field is provided.

The objectives of this research are: (1) to measure the dissolved oxygen and temperature in the field in an efficient and inexpensive way, and (2) to find the relationship between quality variables and streambed components.

7.1 Dissolved Oxygen and Temperature Measurement

Several types of equipment were evaluated in the field to determine an efficient and easy method of measuring DO and temperature in each streambed component. Equipment includes Piezometer, DO sensor, wooden stake, dye trace, syringe, and color changes.

Piezometer has long been used to measure stream and ground water quality parameters (Datry et al., 2004; Jahangir et al., 2012). O'Reilly et al. (2012) used a DO sensor in the field to determine DO in the water column for evaluating stream water quality. Rather than measuring DO directly, Marmonier et al. (2004) inserted untreated wooden stakes to assess the dissolved oxygen in the streambed. Four weeks incubation time was recommended to evaluate the oxygen in the streambed based on changes in color of the wooden stake. Another indirect technique in measuring DO is the use of dye trace to investigate the flow path (Paula et al., 2004). This method, which applies to groundwater studies, visually examines the flow path to separate the groundwater and subsurface flows. In addition, syringe and color changes of streambed materials were used to examine water quality parameters. A syringe extracted water from the bed and determined the DO by sensor. Color changes were visually inspected in solid color of streambed components.

A field test was conducted to determine the possibility of using each type of equipment. Piezometer and wooden stake were limited to cobble and fine material streambed, due to the difficulty of installation. In contrast, dye injection was useful in a range of streambed conditions. The syringe had limited efficiency in measuring water from fine and gravel materials due to needle blockage by fine materials. In coarse particles, syringes disturbed the bed when extracting water from the substrate, which can increase the error in measuring DO content. Color changes of components was applicable for stable components sitting in the same place for long periods of time (Illustration 7.1). It also can be a result of the rapid biological activities in the short period of time. Both syringe and color changes were removed from the possible equipment chases of measuring DO due to limited efficiency in field. In addition to the DO measurements, the evaluation of temperature was accomplished using a temperature sensor.

Table 7.1 summarize the applicability of each equipment for estimating DO in field based on the preliminary tests.

Table 7.1

Methods of DO Measurement in Patches

Physical Component	Piezometer	Wooden stakes	Dye injection	Syringe	Changing color
Embedded Epifaunal Substrate	✓		✓		✓
Free Epifaunal Substrate	✓		✓		✓
Embedded gravels		✓	✓		
Free gravels		✓	✓		
Fine Materials		✓	✓		

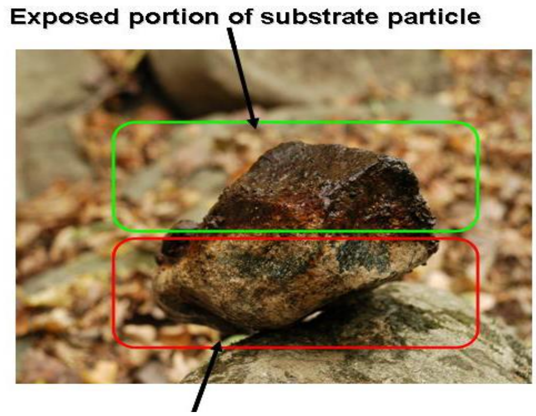


Illustration 7.1. Color changes of the streambed components in the field.

7.1.1 Piezometer

The L-shaped, open-ended piezometers were constructed of PVC pipes with varying lengths and diameters. Two pieces of PVC pipe, with diameters of 1 and 5 cm, were attached by a right angle joint. The piezometer was employed with the smaller leg was inserted into the streambed to a depth of substrate (under the first layer of epifaunal surface) and parallel to the streambed. The smaller leg had a smaller diameter to prevent streambed disturbance with random holes to collect water from the subsurface. The larger leg was above the surface to prevent surface water in the pipe and wide enough to be used by the YSI sensor in reading the DO and temperature content (Illustration 7.2).

Piezometers were placed in the 20 epifaunal substrates, including 10 free and 10 embedded epifaunal substrates in three riffles in Wilson Creek. The small leg was secured and covered by epifaunal substrate to prevent falling into the water and to collect water under the substrate. The YSI multi-parameter probe was inserted downhole to measure DO and temperature weekly for two months. The accuracy of YSI was ±2% of the reading, or 0.2 mgl^{-1} for DO and 0.01^{0}C for temperature based on the manufacturer's manual. The piezometer had limited efficiency in fine material and gravel components due to installation and efficiency issues.

Illustration 7.2a and 7.2b shows the L-shaped piezometer with varying lengths and diameters. Random holes collect water underneath the streambed components.

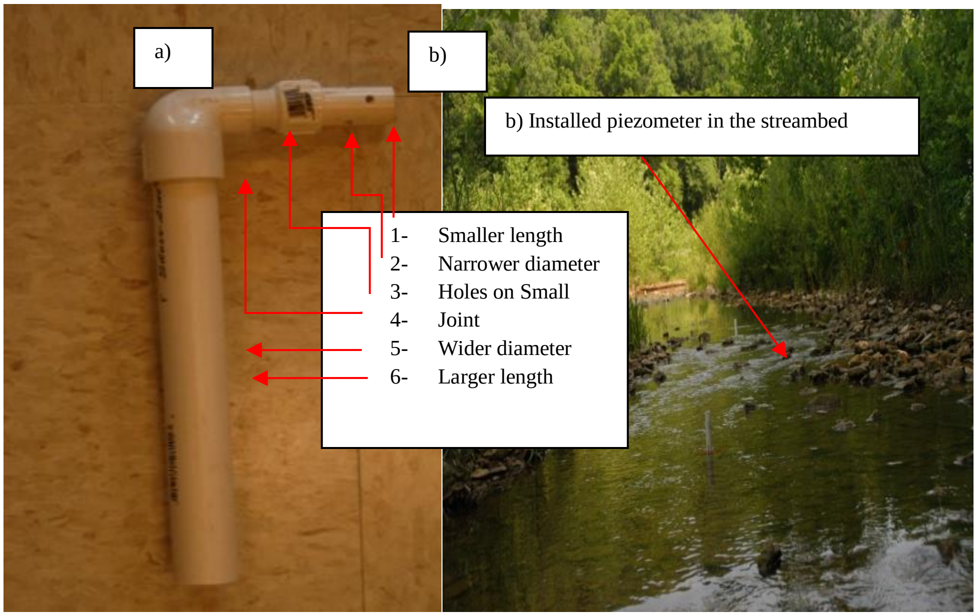


Illustration 7.2a and 7.2b. a) L-shape piezometer and holes on small diameter, and b) installed piezometer in the field.

7.1.2 Tracer Test

Tracer tests are used extensively to investigate subsurface water movement and groundwater hydrology. Tracer tests involve injecting a chemical tracer into a hydrological system and monitoring its recovery at various observation points in time. The test results are used to analyze flow pathways, velocities and travel times, hydrodynamic dispersion, recharge, and discharge. An ideal water tracer has the following characteristics (Kaufman & Orlob, 1956; Church, 1978; Davis et al., 1980; McLaughlin, 1982):

1. The tracer is conservative in behavior and moves in a manner similar to water without sorption to soils, sediments, or rocks and degradation during the time frame of interest.

2. The tracer has low background concentration to be discernible from the background of the system.

3. The tracer is insensitive to changes in solution chemistry. The fate and transport behavior are unaffected by changes in pH, alkalinity, or ionic strength of the aqueous solution.

4. The tracer is detectable either by chemical analysis or by visualization.

5. The tracer generates a low toxicological effect on the study environment.

The main purpose in employing the tracer test was to predict the possible flow path in the streambed patches and correlate it with the amount of oxygen content in the physical streambed components. Many tracer dyes are used as hydrological tracers; however, the most prominent are Fluorescein/Uranine and Rhodamine WT. Fluorescent dyes are used for investigating flow path, particularly in the following circumstances:

- Insufficient lighting (e.g., sewers or cave waters)
- Precise quantitative data are required, measured by a fluorometer.
- Very small amounts of the dye are allowed to be added (1 part per trillion may be detected).

In this study, Fluorescent FLT Yellow/Green (TC = $1.0*10^0$) (Smart & Karunaratne, 2001), which is a liquid tracer dye and meets rapid bioassessment standards, was injected in 50 patches. These patches consisted of 10 patches for each physical streambed component, including free and embedded epifaunal, free and embedded gravel, and fine material patches. Evaluated patches were located in varying flow conditions, including fast and slow moving such as thalweg, packet pools, a cobble lees, and stagnant water, to observe and track the flow path. Fluorescent FLT Yellow/Green was injected in the subsurface and flow path and dispersion were visually inspected for each patch. The measurement of dye concentration was not included in DO evaluation, as no distance or delay time was involved in tracer tests.

7.1.3 Wooden Stake

Rather than using sophisticated techniques, Marmonier et al. (2004) used a simple method to assess the dissolved oxygen in the streambed layer, the main advantages being the low cost and simplicity in assessment. In addition, this method is non-disruptive in fine material and gravel streambeds. Wooden stakes consistently detected the dissolved oxygen content of the streambed components after four weeks of incubation time in four French streams with streambed component compositions (Marmonier et al., 2004). The estimated dissolved oxygen by wooden stakes was integrated over several weeks, rather than micro scale and short-term measurement, based on changes in the color of the wooden stake. The validity of this method was investigated by Marmonier et al. (2004).

Untreated wooden stakes were installed in 30 patches in three riffles, including fine material, free, and embedded gravel patches in Wilson Creek to evaluate the dissolved oxygen. Insertion of a wooden stake in a cobble streambed was inefficient as a result of streambed disturbance. Illustration 7.3 shows an installed wooden stake in the streambed, with an orange disk placed on the top to be seen in recovery time. After at least four weeks of incubation time (Marmonier et al., 2004), the wooden stakes were removed and inspected for color changes. Changes in the solid color of each stake was visually determined using Musell Soil Color Charts and recorded for dissolved oxygen analysis in laboratory tests. A laboratory test was conducted to correlate the color changes with the amount of dissolved oxygen. Details are presented in the next section.

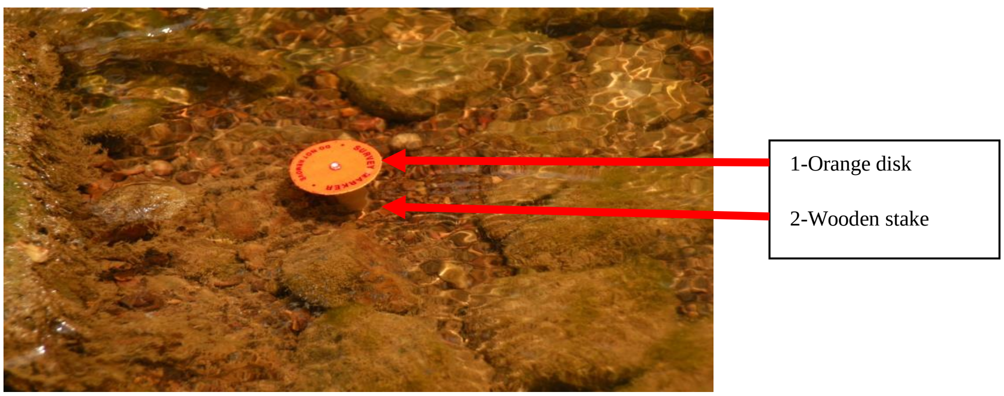


Illustration 7.3. Deployed wooden stake in streambed with orange disk installed on top.

7.1.4 Laboratory Test

In order to correlate the color changes of the wooden stakes with the amount of oxygen content in the substrate, an experimental test was conducted in the laboratory. A bucket of streambed materials and stream water was transported, and 30 untreated wooden stakes and an L-shaped piezometer were installed in the bucket (Illustration 7.4). The amounts of the dissolved oxygen and temperature inside the piezometer and in the column of water were recorded daily using the YSI sensor. The L-shaped piezometer represents the amount of DO and temperature from the subsurface layer due to water collected through the holes inside the piezometer. Meanwhile, a wooden stake was removed, and changes in solid color were visually investigated and recorded using Musell Soil Color Charts. A comparison of DO and temperature and changes in stake color is beneficial in finding the threshold of hypoxia and anoxia in the streambed layer. Calibration of the YSI sensor was done before each test to verify the accuracy of the probe.

Illustration (7.4) shows the DO measurement in the laboratory. Buckets were filled with streambed water, streambed materials, a wooden stake, and the piezometer.

Illustration 7.4. Bucket with piezometer and wooden stake inside.

7.2 Results

The results of the dissolved oxygen concentration and temperature are presented in two sections. The first section describes data from the laboratory test. This section presents data of the measured variables in the water column and inside the piezometer. A single factor ANOVA test and the paired t-test were utilized to compare the significant differences between both measurements for $p = 0.05$ and $\alpha = 0.05$. In addition, visual inspection of color changes in each wooden stake was done. A comparison of this analysis provides the correlation between the DO content and changing color of the stake.

The second section describes the field data in the piezometer, wooden stake, and tracer tests. A single factor ANOVA test and the paired t-test were utilized to compare the significant differences between the dissolved oxygen content and temperature in the water column and inside the piezometer for $p = 0.05$ and $\alpha = 0.05$. Visual inspection of the changes in color of the wooden stake and visual tracking of the flow path in tracer tests also were accomplished in the field.

7.2.1 Experimental Results

This section presents the data, including DO and temperature on the piezometer and wooden stake, in the laboratory test. The piezometer facilitated the measurement of dissolved oxygen underneath the surface layer of streambed components in the laboratory. Figure 7.1 shows the amount of dissolved oxygen in the piezometer installed in the bucket, and the water column data describes the amount of dissolved oxygen in the water column of the bucket. In addition, hypoxia and anoxia thresholds were 2.0 and 5.0 mgl^{-1} of dissolved oxygen, according Water (1995).

Based on this figure, the amount of dissolved oxygen in the water column varied widely, but followed a similar pattern. The amount was greater than that of the dissolved oxygen in the piezometer. On average, the amount of dissolved oxygen in the piezometer was 30% less than the amount of oxygen in the column of water. The difference is statistically significant for a single factor ANOVA test and p = 0.05 and α = 0.05 since F (=46.65) > Fcrit (=4.13). The dissolved oxygen content in the piezometer was in the hypoxia range, whereas the dissolved oxygen content in the water column was > 5 mgl^{-1}.

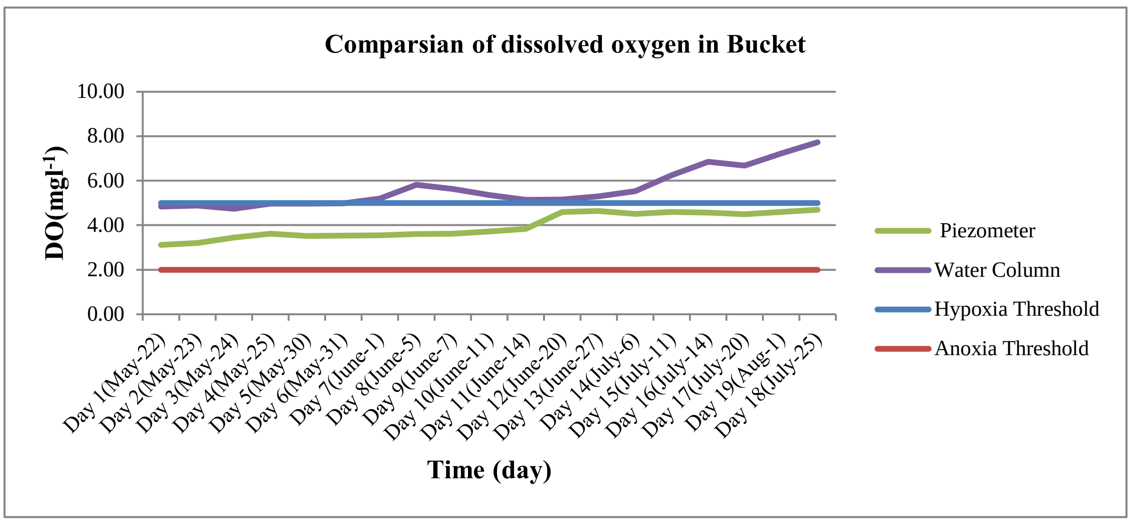


Figure 7.1. Dissolved oxygen measured in the piezometer and the water column in the laboratory.

Temperature: Figure 7.2 presents the temperature measured in the piezometer and the water column in the bucket. The temperature obtained from the piezometer and the water column showed the temperature underneath the streambed substrate and the water column. The pattern in the temperature of water column was similar to that in the piezometer, and both graphs reached the same amount through the test period. The difference in both temperatures is not statistically significant for a single factor ANOVA test and p = 0.05 and α = 0.05 as F (=46.65) > Fcrit (=0.0005).

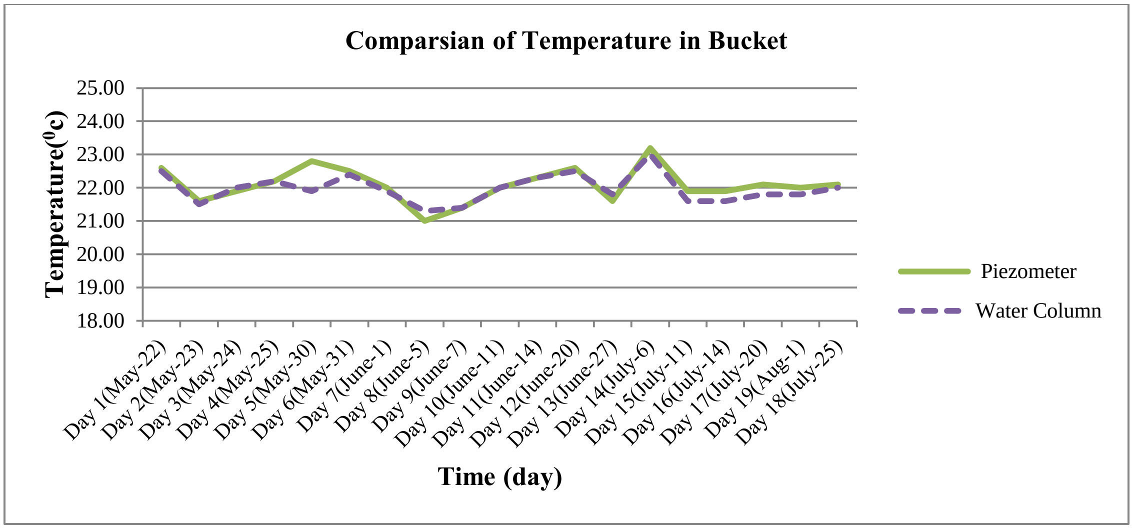


Figure 7.2. Temperature measured in the piezometer and water column in the laboratory.

Wooden stake: Visual inspection of wooden stakes indicated that, after four weeks of incubation time, the color of the untreated wooden stakes changed from the original color of Chrome 10 PB 7 to a dark color of Gley 2.5 PB 2.5 based on Musell Soil Color Charts. A dark colored wooden stake is a sign of hypoxia (DO< 2 mgl^{-1}), which is consistent with findings from the Marmonier et al. (2004) study.

7.2.2 Field Results

This section presents the data on the piezometer and the wooden stake, and the tracer test data obtained in the field. Based on the Table 7.1, the piezometer was used to sample the dissolved oxygen and temperature in the free and embedded epifaunal substrates. Wooden stakes estimated the dissolved oxygen in the fine material, free gravel, and embedded gravel substrate compositions. In addition, tracer tests were accomplished to visually inspect the flow path in all physical streambed components, including fine material, free gravel, embedded gravel, free epifaunal substrate, and embedded epifaunal substrate components.

Piezometer: Ten piezometers were installed in three riffles in Wilson Creek in the free epifaunal substrate, as well as 10 piezometers in the embedded. In each piezometer, the dissolved oxygen concentration and temperature were sampled using the YSI sensor. Measured DO and temperature were compared and contrasted with the measured dissolved oxygen and temperature in the water column.

Dissolved oxygen (DO) concentration: The dissolved oxygen concentration sampled in the water column had the highest amount of DO concentration, in comparison to the DO measured in both the free and embedded epifaunal substrates (Figures 7.3 and 7.4). The dissolved oxygen concentrations in the water column were not statistically higher than those in the piezometers in free epifaunal substrate ($p > 0.05$), whereas it was statistically greater than the dissolved oxygen in the embedded epifaunal substrate ($p < 0.05$) based on the paired t-test.

A comparison of the dissolved oxygen in the free and embedded epifaunal substrates revealed that the amount in the free epifaunal substrate was statistically greater than that of the embedded epifaunal substrate ($p < 0.05$). The amount of dissolved oxygen concentration in the water column and free epifaunal substrate was higher than the hypoxia threshold during the test period. In contrast, the amount of dissolved oxygen in the embedded epifaunal substrate was lower than hypoxia thresholds after the fourth week. Although the low DO concentration typically continued during the flood, it lasted for several weeks after the rain event.

In circumstances where the flood event was greater than Q_{2yr}, such as the events in the ninth and eleventh weeks that partially or completely disturbed the embedded epifaunal substrate, the DO concentration was increased. This included flood disturbance of patches 6, 9, and 10 in the eleventh week and patch 8 in the ninth week. In the completely disturbed patches, such as patches 6 and 10, the amount of DO concentration was markedly increased from the anoxia condition to normal condition (> 5 mgl^{-1}). In the partially disturbed patches of 8 and 9, the amount of DO concentration was increased from anoxia condition to hypoxia condition of 4 mgl^{-1}. The disturbance in embedded epifaunal substrate was due to the rain event greater than Q_{2yr}.

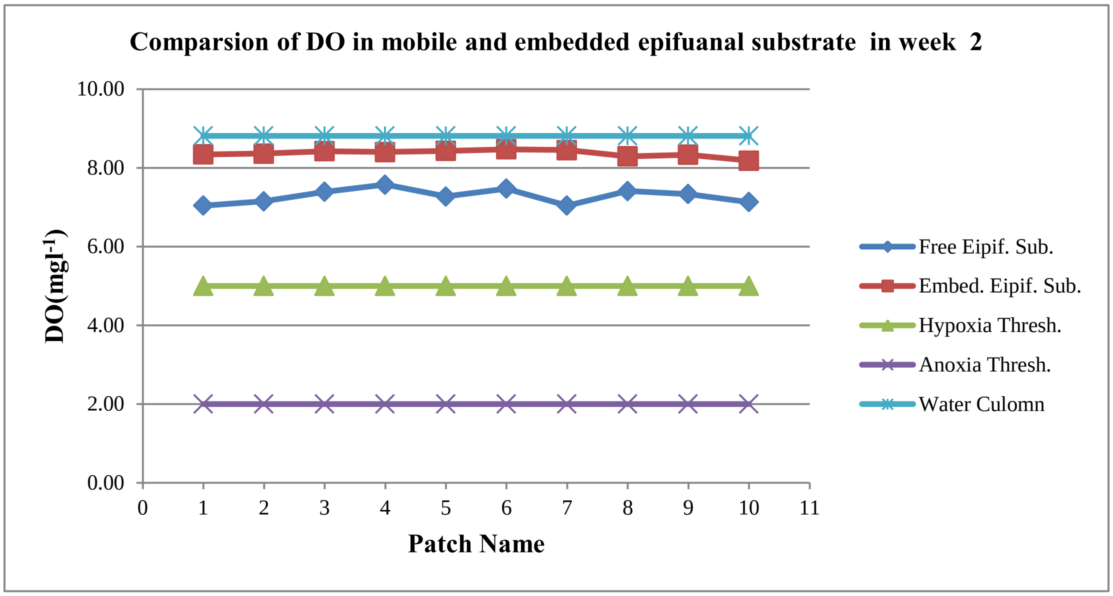


Figure 7.3. Comparison of DO in the free and embedded epifaunal substrates with DO water column, hypoxia, and anoxia conditions in the field.

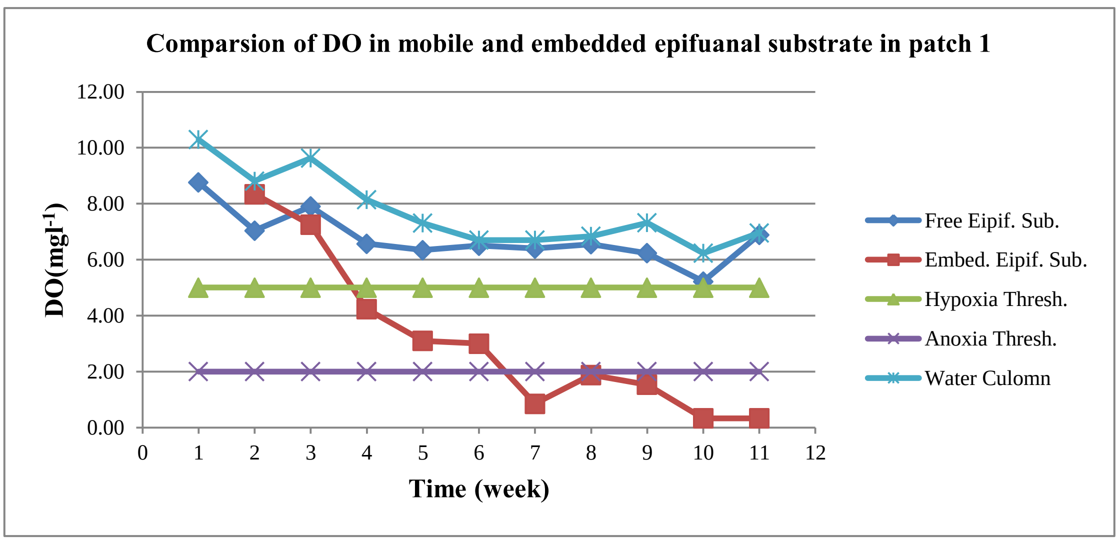


Figure 7.4. Comparison of DO in the free and embedded epifaunal substrates with DO water column, hypoxia, and anoxia conditions in the field.

Temperature: A statistical analysis showed that the temperature measured in the water column was not statistically higher than that in both the free and embedded epifaunal substrates ($p > 0.05$), due to the close layer of sampling points to the water column.

Wooden stake: Wooden stakes were installed in the fine material, free gravel, and embedded gravel streambed components. After four weeks of incubation time, visual inspection began.

Approximately 30% were lost or washed away during storm events, including one in the fine material patch, and 4 and 3, respectively, in the free and embedded substrates. The color of the stakes in the fine material streambed component was changed to solid dark after four weeks of incubation, which is an indication of hypoxia. A strong smell similar to rotten eggs from stakes installed in the fine material patches also may be an indication of anoxia.

In the free gravel substrate, the color of top 5 cm of the wooden stake was not changed from the original color. However, the changing color of wooden stakes deeper than 5cm was not consistent. In some cases, the color in depth > 5 cm was not changed, whereas the color changed to gray, heavy gray, dark, or solid dark in others. This indicated a sufficient amount of DO concentration in the top 5 cm of the surface layer in the free gravel substrate. When the depth exceeds 5 cm, hypoxia can be dominant.

In the embedded gravel substrate, the color of the stakes was changed to gray and dark. This shows that hypoxia was dominant in the embedded gravel patches with the DO concentration of less than 5 mgl^{-1}.

Tracer Test: The tracer test was accomplished in the 50 patches, including fine material, free gravel, embedded gravel, free epifaunal substrate, and embedded epifaunal substrates, to track the flow path. Fluorescent FLT Yellow/Green was injected in the subsurface and the flow path and dispersion were visually inspected for each patch.

In fine material and embedded patches, including embedded gravel and embedded epifaunal substrates, the dye was trapped inside the subsurface layer and restricted from moving out of the bed. This may be a sign of current restriction, when the current was limited to flow freely inside and outside of these patches. In contrast, injected dye in free gravel and free epifaunal substrates was immediately dispersed out of the patches with the current. This may indicate that the amount of dissolved oxygen concentration in patches is similar to the dissolved oxygen in the water column.

Table 7.2 summarizes DO and temperature conditions in the studied riffles. The conditions in each patch were compared with the amount of DO and temperature in the water column.

Table 7.2

DO and Temperature Conditions Measured in Studied Patches

Physical Component	DO	Temperature
Embedded epifaunal substrate	Hypoxia	Similar to water column
Free epifaunal substrate	Similar to water column	Similar to water column
Embedded gravels	Hypoxia	Similar to water column
Free gravels	Similar to water column	Similar to water column
Fine materials	Anoxia	Similar to water column

CHAPTER VIII

DISCUSSION

The rapid bioassessment was limited to two habitat classification to two physical streambed components: embeddedness and epifaunal substrate. Several other aspects of streambed habitat were not considered. For example free gravel is an important streambed component for fish spawning, although it was not included in the rapid bioassessment protocol. Table (8.1) presents the amount of free gravel for each riffle based on this study and reveals that the amount of free gravel is between one to more than two thirds of the riffles population.

Table 8.1

The Amount of Free Gravel in Each Riffle Based on the Proposed Classification System

Riffle Name	1	2	3	4	5	6	7	8	9	10
Free Gravel (%)	59.92	54.82	56.37	57.46	32.32	73.71	23.55	67.75	44.82	56.41

Temperature in the first subsurface layer may be similar to the surface layer, based on findings from this study; however, the dissolved oxygen concentration varied for streambed components that where embedded or not embedded. Results indicated that the hypoxia or anoxia conditions can be extended for several weeks. This is in contrast to the free epifaunal substrate, which recovers the normal dissolved oxygen concentration soon after a storm event.

The epifaunal substrate is defined in the rapid bioassessment method as cobble sized components. The size of streambed material that may be stable depending upon the geometry, sedimentology, and hydraulic conditions of the channel (Buffington & Montgomery, 1997) and varies among streams. In this protocol, no document supports that the cobble sized material as a lower boundary for stable habitat. Without answering this issue, the rapid bioassessment method may have a limited reliability in facilitating the inventory of unhealthy streams. In this research, the shear stress calculation and Q_{2yr} were used to determine the epifaunal substrate size as a lower boundary for stable epifaunal substrate. Based on this table, two riffles have the epifaunal substrate size in the range of the cobble (65-256 mm), and other riffles have the size of less than the cobble. Therefore, the coble sized material as lower boundary for habitat stability may not be reliable material size for each stream.

The rapid bioassessment approach grouped together the streambed physical materials with varying sizes and properties to assess impaired streams.

Table 8.2

Measured Embeddedness Based on the Rapid Bioassessment and the Proposed Classification Systems

Riffle Name	1	2	3	4	5	6	7	8	9	10
Rapid bioassesment (%)	40.00	33.33	40.00	20.00	48.33	40.00	26.67	45.00	43.33	21.67
Prop. Method (%)	11.50	10.14	24.77	19.76	44.96	10.07	12.03	19.24	7.42	7.20

Effect of Particle Measurement: Visual estimation in the rapid bioassessment method tends to overestimate the amount of embedded components, with oversampling of the embeddedness parameter in 80% of the measured sites in this study (Table 8.2). This effect perhaps is exacerbated when combined with the effects of deep and swift flow with restricted light conditions.

Using the self-lighted Portable Photographic Box (PPB) is beneficial in recording the image of the streambed components under a range of light and stream flow conditions. The PPB can record images when it contacts the streambed, which improves recording in swift current or in turbid stream water conditions. Manually digitized images may eliminate the issue of results discrepancies between users; however, it increases the measurement time requirement of the streambed components. The sampling grid with varying openings was superimposed on the recovered images. After analysis of several grid openings and opening measurement scenarios, a 50% incremental projected area and sampling grid with cell size of 2.5 by 2.5 cm was selected as the measurement scenario and the sampling grid, respectively.

As one of the main reasons for development of the rapid bioassessment was to minimize the required field and laboratory time, use of the PPB adds time to the sampling streambed components in comparison to the rapid bioassessment method. Recording an image in the field requires 20-30 seconds, with almost two hours needed to record mid-size riffle with 200 images. Manual digitization of 200 images, with a 50% incremental projected area and sampling grid with a cell size of 2.5 by 2.5 cm, also requires six hours. Combined, eight hours (a full business day) is needed to sample and digitize the entire riffle population.

Effect of sampling methodology: The sampling approach in the rapid bioassessment method is less suited to characterize a riffle as a morphologic unit. Nearly 80% of sampling spots in the rapid bioassessment method are located near the channel bank, with half located in the waterline, which naturally has more fine material content. Only 20% of sampling spots are in the middle of the channel area with low fine material content. Therefore, it is not surprising that the rapid bioassessment method tends to overestimate the riffle embeddedness.

Extensively sampling a small area containing more fine sediment, and excluding the large un-sampled area with a low amount of fine sediment in the riffle, may lead to contradictory results in the evaluation of the embeddedness. Findings from this research showed that, in 80% of measured riffles, the amount of embeddedness was overestimated by the rapid bioassessment, in comparison to the proposed method.

Effects of Sample Size: Sample size in the rapid bioassessment protocol is small and typically limits the ability to adequately characterize distribution in streambed component distribution. Most of the previous research on the sample size (Rice & Church, 1996; Green, 2003) investigated the sufficient number of pebbles in the pebble count method. This research investigated the percent of surface area needed to accurately represent the surficial projected area of the riffle streambed area population.

Various scenarios were designed to determine an inexpensive sampling methodology of streambed components in the field at a level of accuracy. These scenarios included sampling one random patch; one random cross section; three cross sections (first, second, and third cross sections located in the tail, middle, and crest of riffle); the entire riffle population and digitization; and sampling the entire riffle population and grid sampling. Tail, middle, and crest of the riffle are downstream, center, and upstream of the riffle, respectively. These scenarios were compared and contrasted with the rapid bioassessment method using a single factor ANOVA test with a 95% confidence interval. The statistical results, including required field time, laboratory time, and residual, are shown in Table 8.3.

In the first scenario, the required field time, laboratory time, and residual are less than the rapid bioassessment. However, residual is relatively high in comparison to other scenarios. In the second scenario, both residual and required time is less for the rapid bioassessment, whereas the required laboratory time is greater than the rapid bioassessment. The advantage of this scenario is that it can be beneficial as a quick and fast rule-of-thumb scenario for the site reconnaissance phase when an inventory of an unhealthy stream has been conducted.

Although in the third scenario the required field and laboratory times are greater than the rapid bioassessment, residual is approximately 20% of rapid bioassessment. This scenario can be used to approximate the results with less than 10% error, in comparison to riffle population with a third of the field and laboratory time requirement.

In both the fourth and fifth scenarios, the entire riffle population is sampled, and riffle with visual and digitization of components is measured. In both scenarios, the required field and laboratory times are increased substantially, whereas residual is decreased to 5% and 0%, respectively. These scenarios may be useful when a more accurate evaluation of streambed components is required.

Table 8.3

Comparison of the Field and Laboratory Time Requirements, Residual for Varying Scenarios of Sampling Methodology and the Rapid Bioassessment with Sampled Riffle Populations

Sampling Methodology Scenario	Field time (min)	Laboratory time (min)	Residual (%)
First scenario (one patch)	0.5	3	28
Second scenario (one CS)	<10	30	14
Third scenario(three CS)	22	90	7
Fourth scenario (riffle population with grid method)	120	480	5
Fifth scenario (riffle population with digitization)	120	960	0
Rapid bioassessment	**15**	**0**	**33**

CHAPTER IX

CONCLUSION AND RECOMMENDATIONS

Sampling results were greatly varied among the proposed method and the rapid bioassessment. Despite the extensive use of the rapid bioassessment in evaluation of streambed physical components, this approach reduced the streambed physical components survey into the two simple variables, including embeddedness and epifaunal substrate. Definitions, measurement, and sampling methodology of both variables in the rapid bioassessment method were vague and subjective. The definition was vague regarding the percentage of area of a pebble that should be covered or surrounded by fine materials to be considered embedded material.

Several important components of streambed characteristics are not included: free gravel, DO, and temperature. This study showed that, on average, half of the physical streambed components may be free gravel.

Measurement methodology in the rapid bioassessment method is visual and subjected to observer training and experience. The rapid bioassessment method includes sampling of 40% of sampling points in the waterline of the streambed, and 80% of the entire sampling population from the area close to the bank. This area stores more fine materials than other parts of the channel and causes an overestimation of the embeddedness in 80% of the sampled riffle in this study. The sampling size also can be insufficient. Sample sizes as small as 15 locations typically have a limitation in detecting the changes in the amount of the physical streambed components. These flaws alone justify revision to the rapid bioassessment approach.

This research defined several new streambed components that have a balance between simplicity and expensive in the field on one hand, and the importance in aquatic animal life and comprehensively in streambed components on the other hand. Physical components in the proposed classification system include free gravel, embedded gravel, free epifaunal substrate, embedded epifaunal substrate, LWD, CPOM, algae, and aquatic macrophytes. Shear stress calculation for 2 year channel discharge was used to separate the stable epifaunal substrate from the mobile gravel component.

A measurement method, which is a combination of photographic technique and grid sampling, was proposed to measure the streambed components in a direct and simple way in the field at the desired level of accuracy. The PPB device was utilized to record the image of physical streambed components under wadeable flow conditions. Recorded images were digitized manually, and the area of each streambed component in each grid cell was estimated to evaluate streambed components projected area. Manual picture digitization was a substitute for visual estimation of streambed components in the rapid bioassessment.

The PPB facilitated sampling of the riffle population with adequate picture quality in a short period of time. Therefore, the sample size and location were not effective in inventory of unhealthy streams. However, for a quick and simple inventory of impaired streams, scenarios were recommended for sampling methodology with varying accuracy and field and laboratory time requirements. Depending upon the scenario, residual was reduced from 33% in the rapid bioassessment to 5% in fourth scenario and 0% in the fifth scenario.

Measurement of the dissolved oxygen and temperature in 20 riffles indicated that temperatures, in the first layer of subsurface were similar to those in the water column. No evidence was found to support substrate measurement of temperature. However, the dissolved oxygen concentration varied significantly for embedded conditions. In contrast to the free gravel and epifaunal substrate, the DO content in fine material, embedded gravel, and embedded epifaunal substrate components was in anoxia and hypoxia conditions. Anoxia lasted for several days after flood events.

Findings from this research show that the proposed streambed components and the PPB provided a simple and direct method to more accurately assess streambed habitat than the rapid bioassessment. The PPB facilitated the recording of images of streambed components. However, it was limited to water depth above the streambed component due to reflection issues. In addition, manual digitization of the recorded images can be replaced by automatic digitization software, which this will avoid human error in digitization and reduce digitization time. The PPB can detect the materials as small as fine material components.

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Appendix I

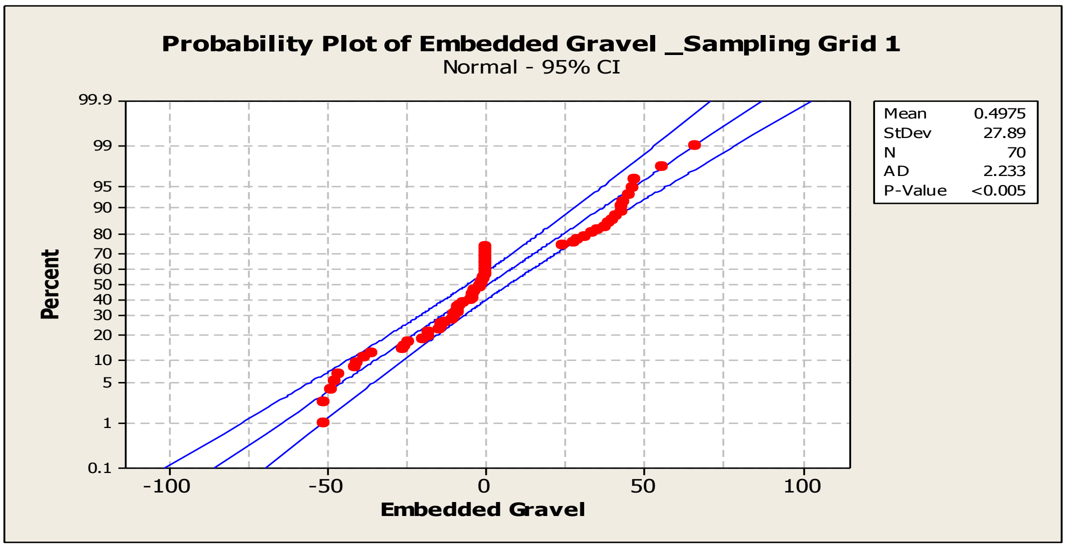

Figure 1. Normality plot for embedded gravel component for sampling grid 1 with cell size of 25 cm by 25 cm.

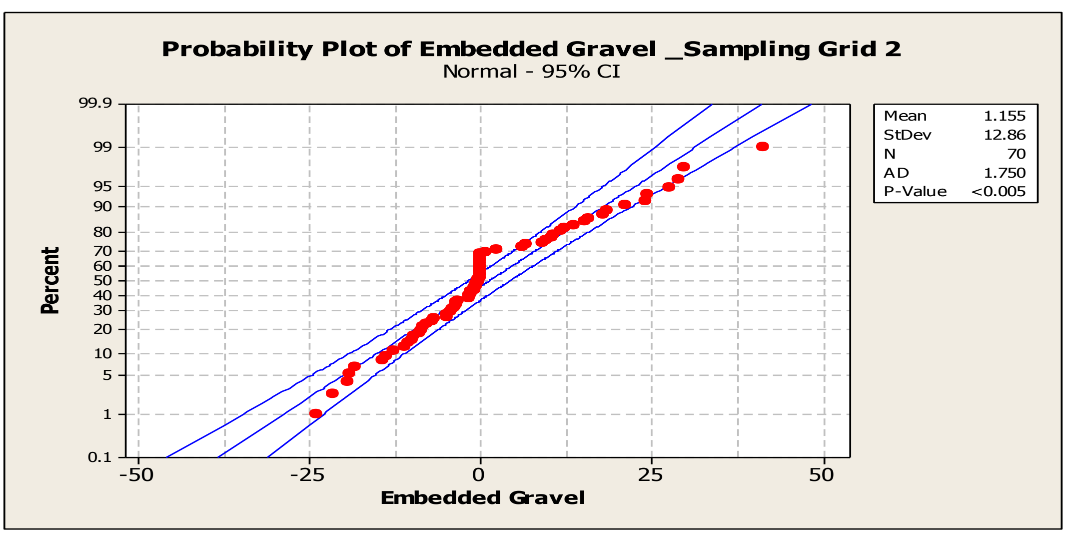

Figure 2. Normality plot for embedded gravel component for sampling grid 2 with cell size of 12.5 cm by 12.5 cm.

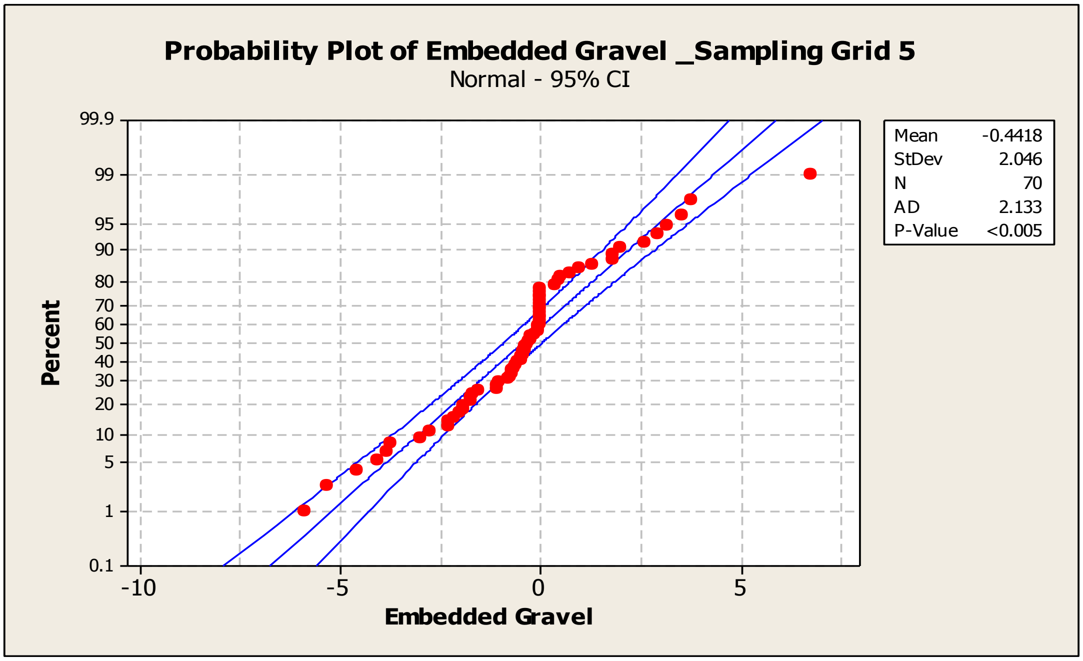

Figure 3. Normality plot for embedded gravel component for sampling grid 5 with cell size of 1.25 cm by 1.25 cm.

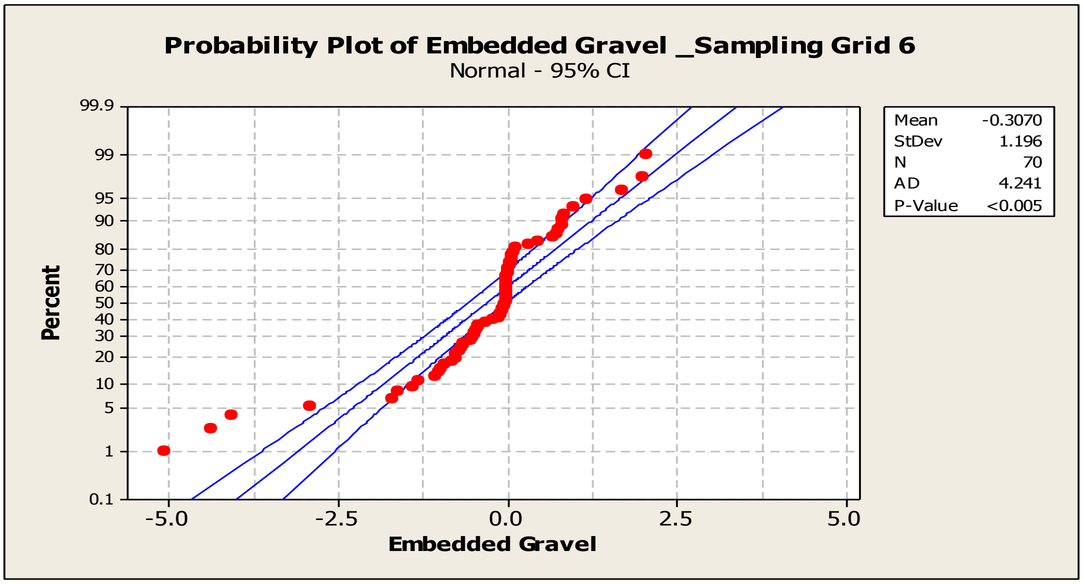

Figure 4. Normality plot for embedded gravel component for sampling grid 6 with cell size of 0.625 cm by 0.625 cm.

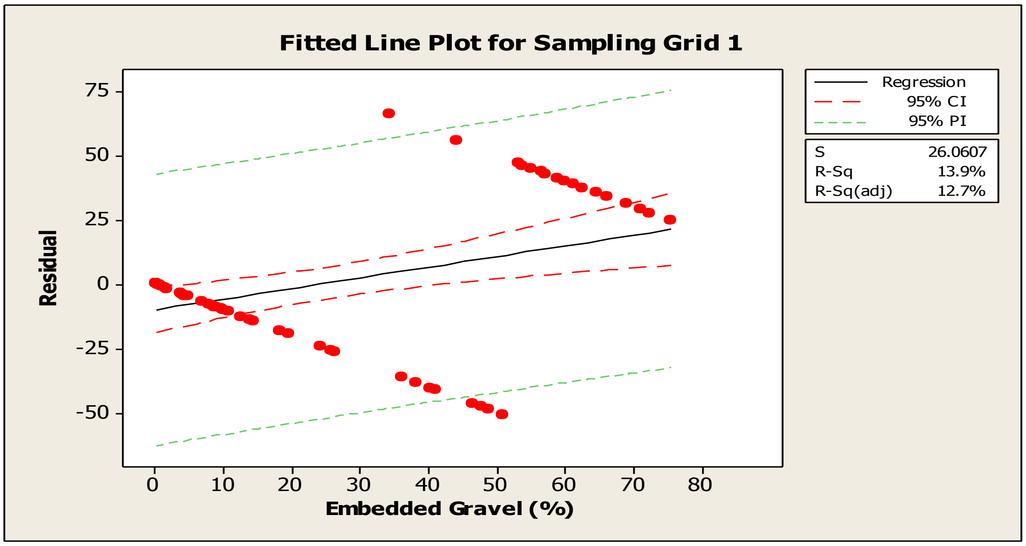

Figure 5. Residual plot for embedded gravel component for sampling grid 1 with cell size of 25 cm by 25 cm.

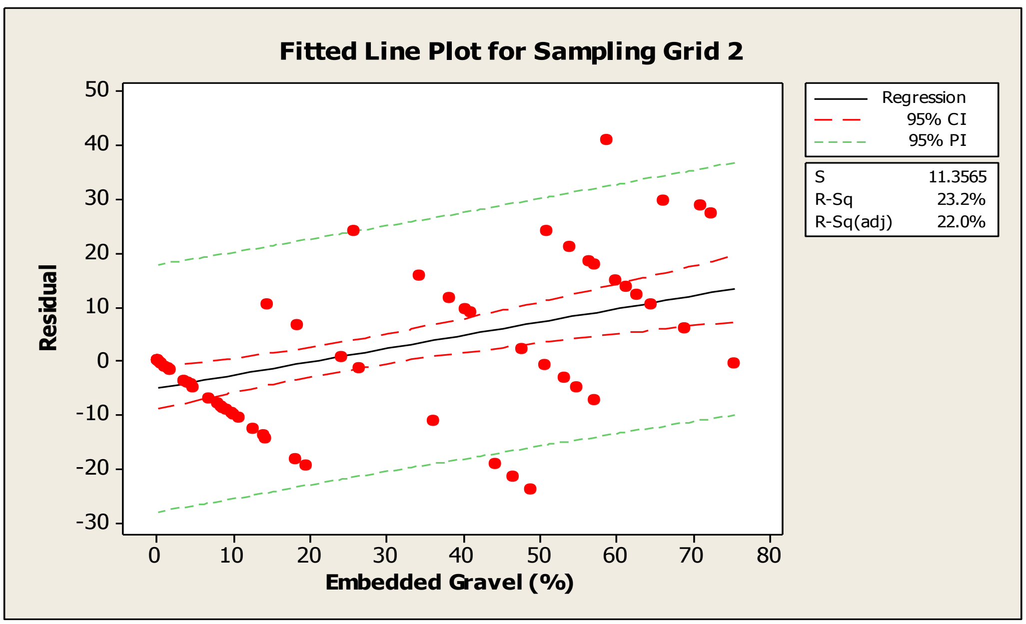

Figure 6. Residual plot for embedded gravel component for sampling grid 2 with cell size of 12.5 cm by 12.5 cm.

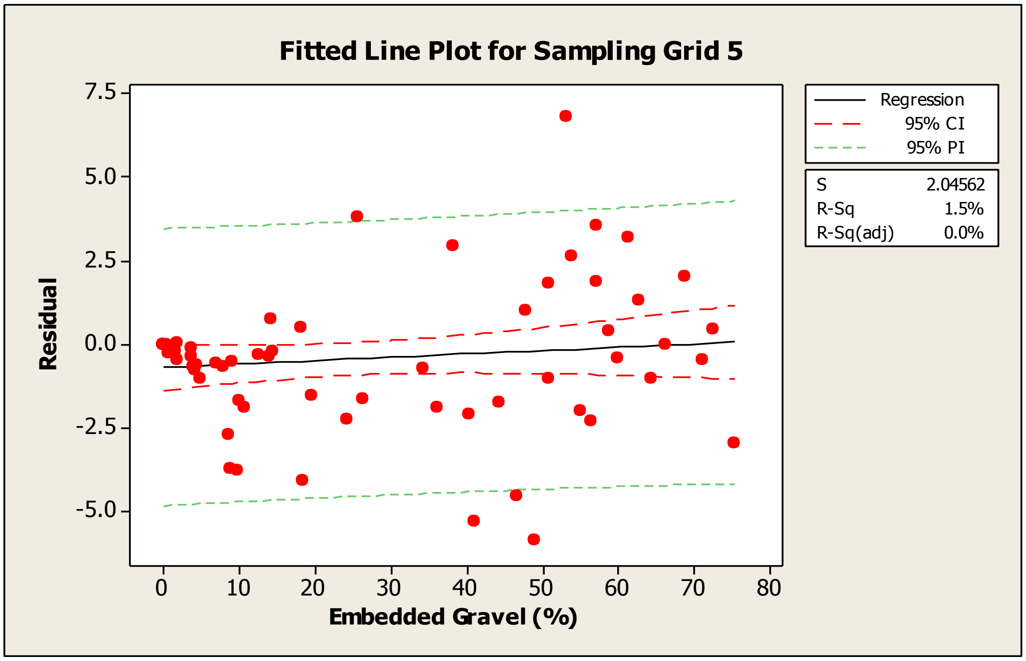

Figure 7. Residual plot for embedded gravel component for sampling grid 5 with cell size of 1.25 cm by 1.25 cm.

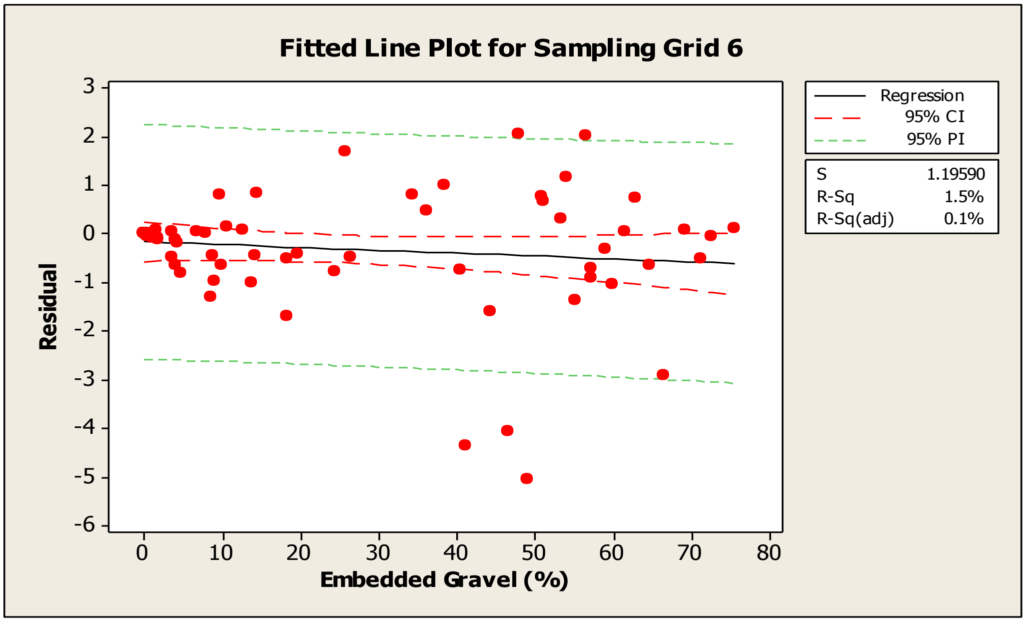

Figure 8. Residual plot for embedded gravel component for sampling grid 6 with cell size of 0.625 cm by 0.625 cm.

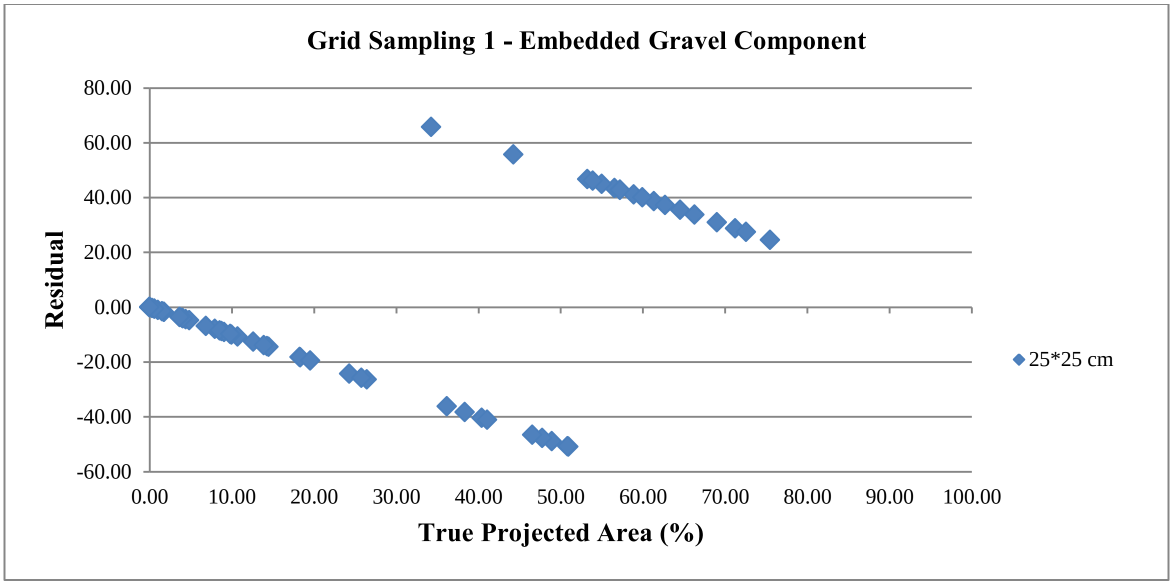

Figure 9. Projected areal error (%) for 70 populations - embedded gravel component in sampling grid 1 with cell size of 25 cm by 25 cm.

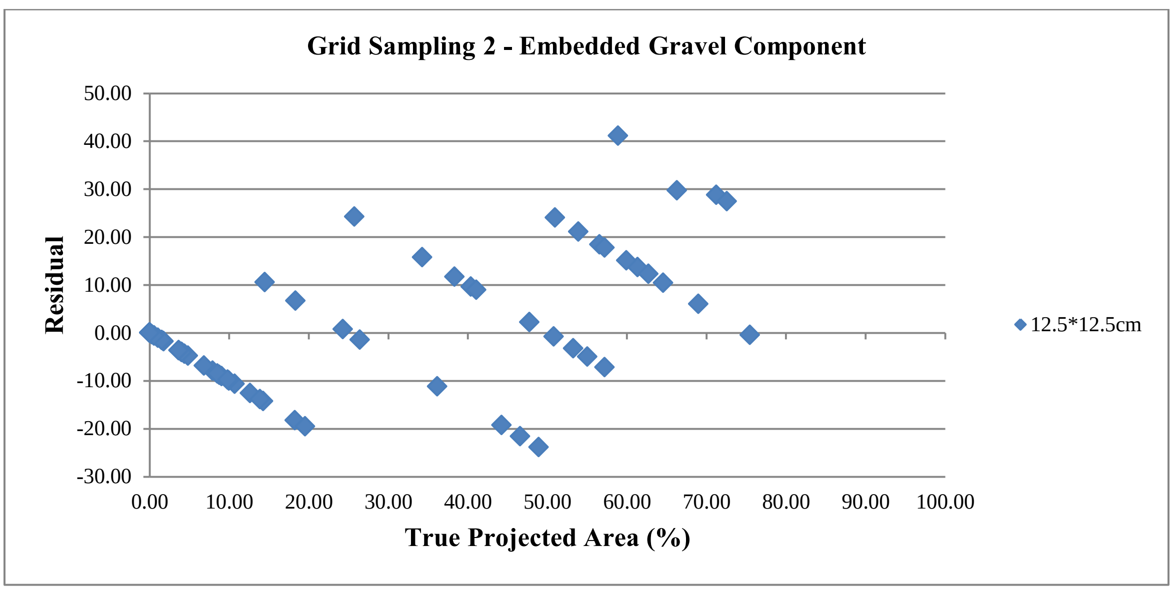

Figure 10. Projected areal error (%) for 70 populations - embedded gravel component in sampling grid 2 with cell size of 12.5 cm by 12.5 cm.

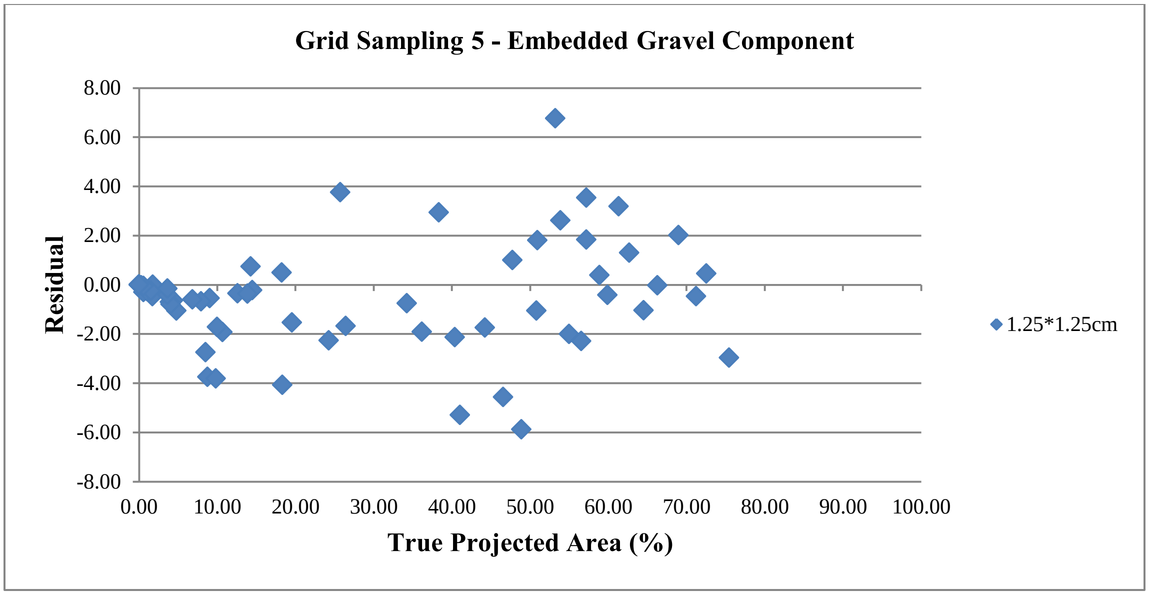

Figure 11. Projected areal error (%) for 70 populations - embedded gravel component in sampling grid 5 with cell size of 1.25 cm by 1.25 cm.

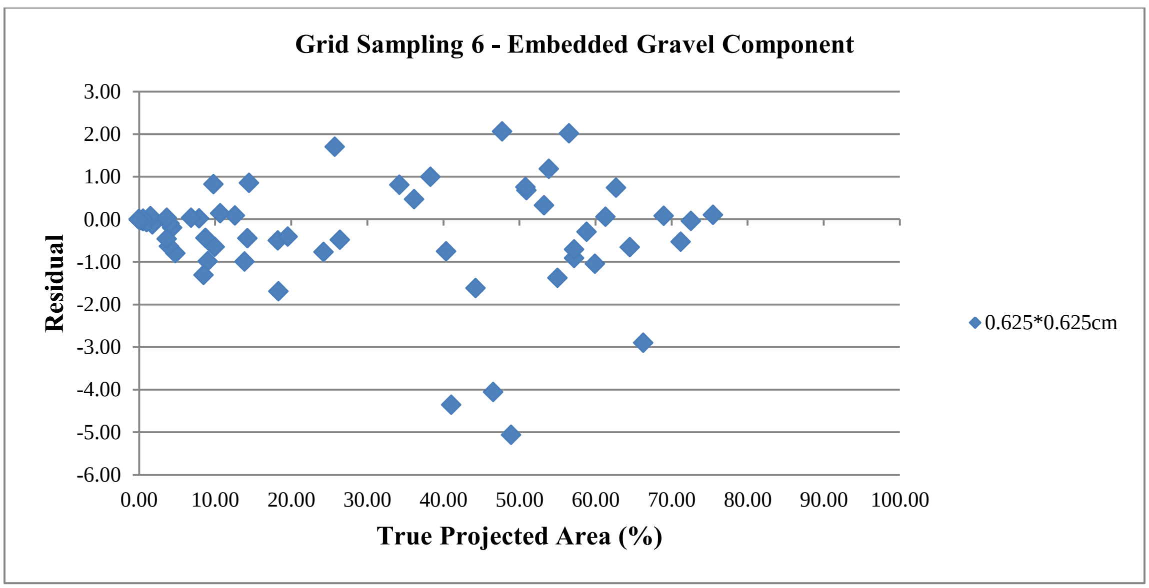

Figure 12. Projected areal error (%) for 70 populations - embedded gravel component in sampling grid 6 with cell size of 0.625 cm by 0.625 cm.

Appendix II

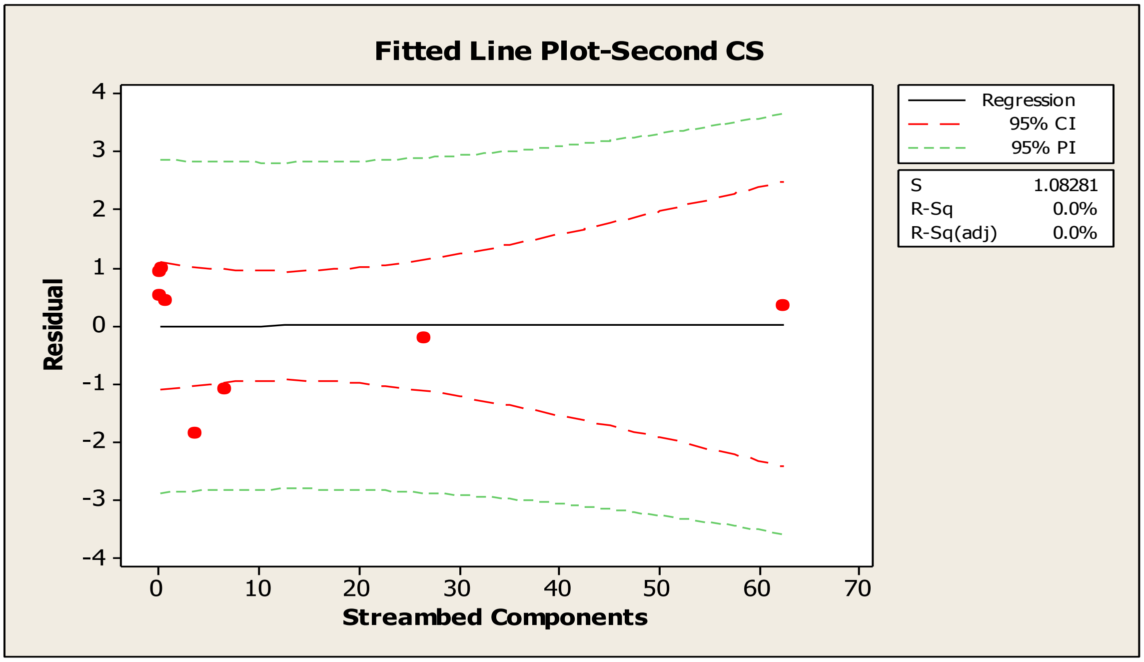

Figure 1. Residual plot for streambed components with 95% PI and CI for second CS riffle 1.

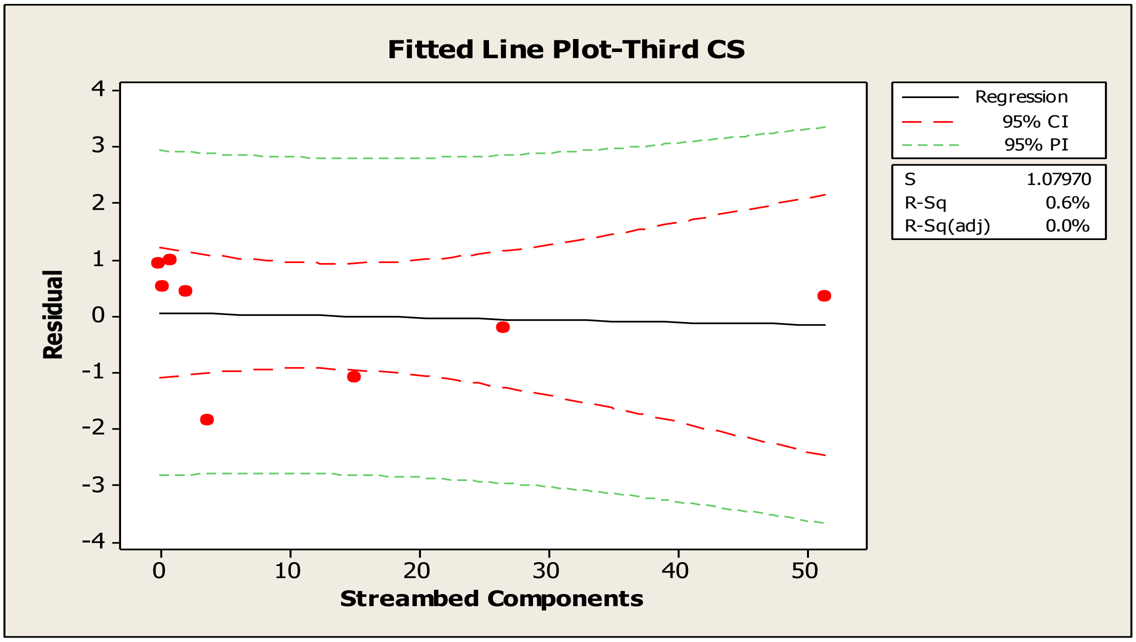

Figure 2. Residual plot for streambed components with 95% PI and CI for third CS riffle 1.

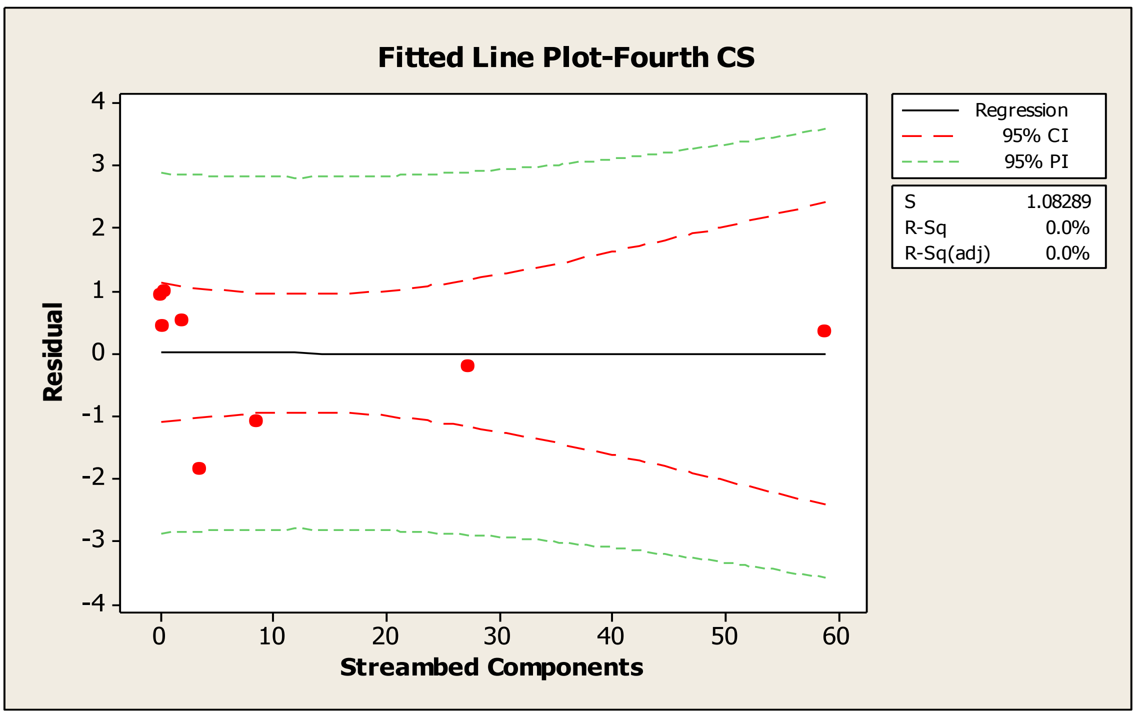

Figure 3. Residual plot for streambed components with 95% PI and CI for fourth CS riffle 1.

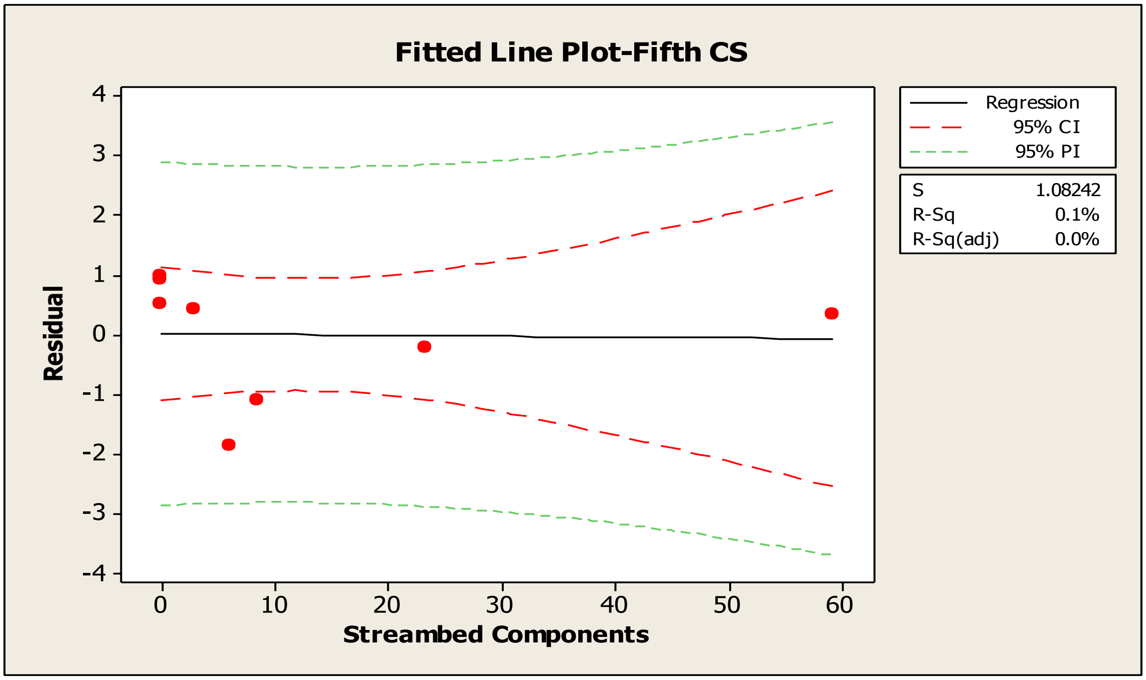

Figure 4. Residual plot for streambed components with 95% PI and CI for fifth CS riffle 1.

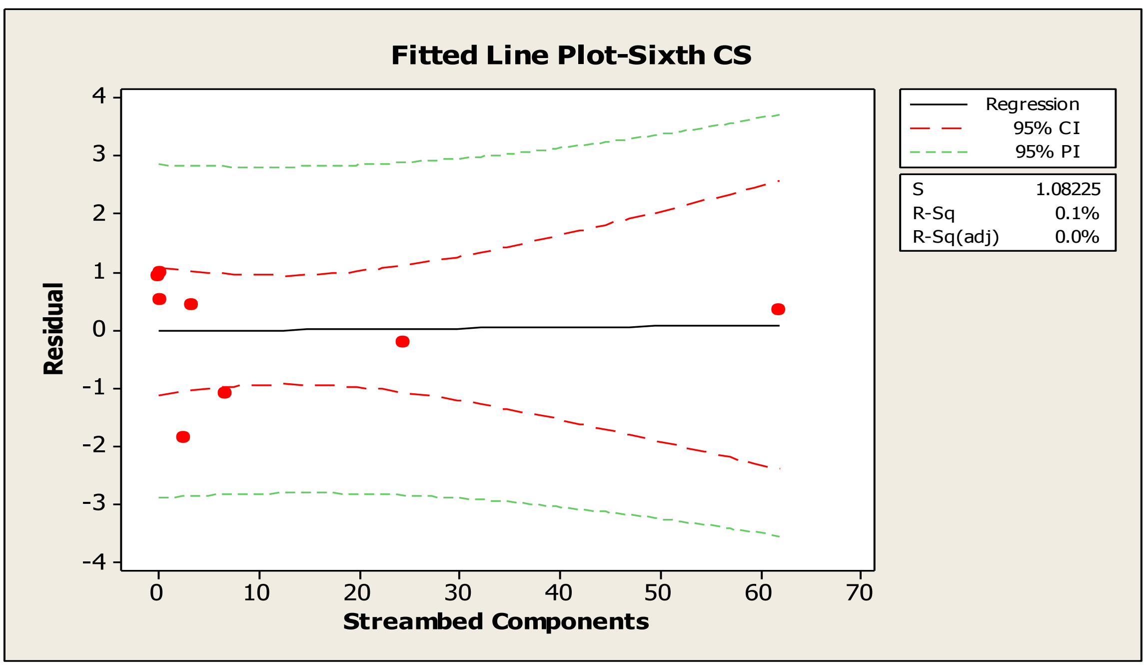

Figure 5. Residual plot for streambed components with 95% PI and CI for sixth CS riffle 1.

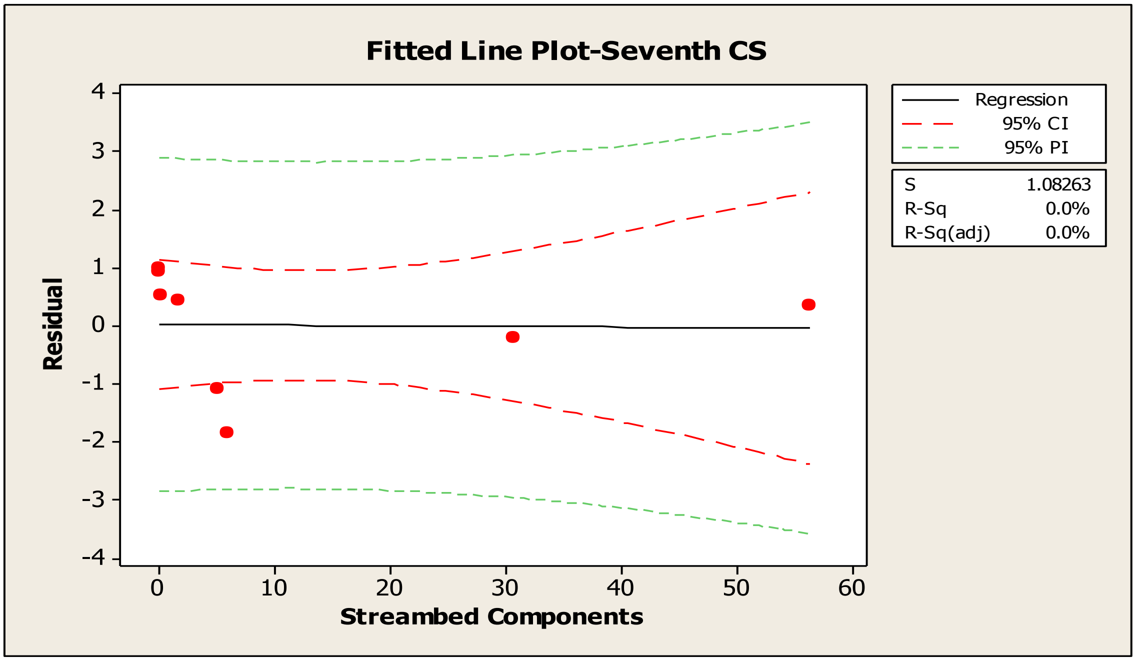

Figure 6. Residual plot for streambed components with 95% PI and CI for seventh CS riffle 1.

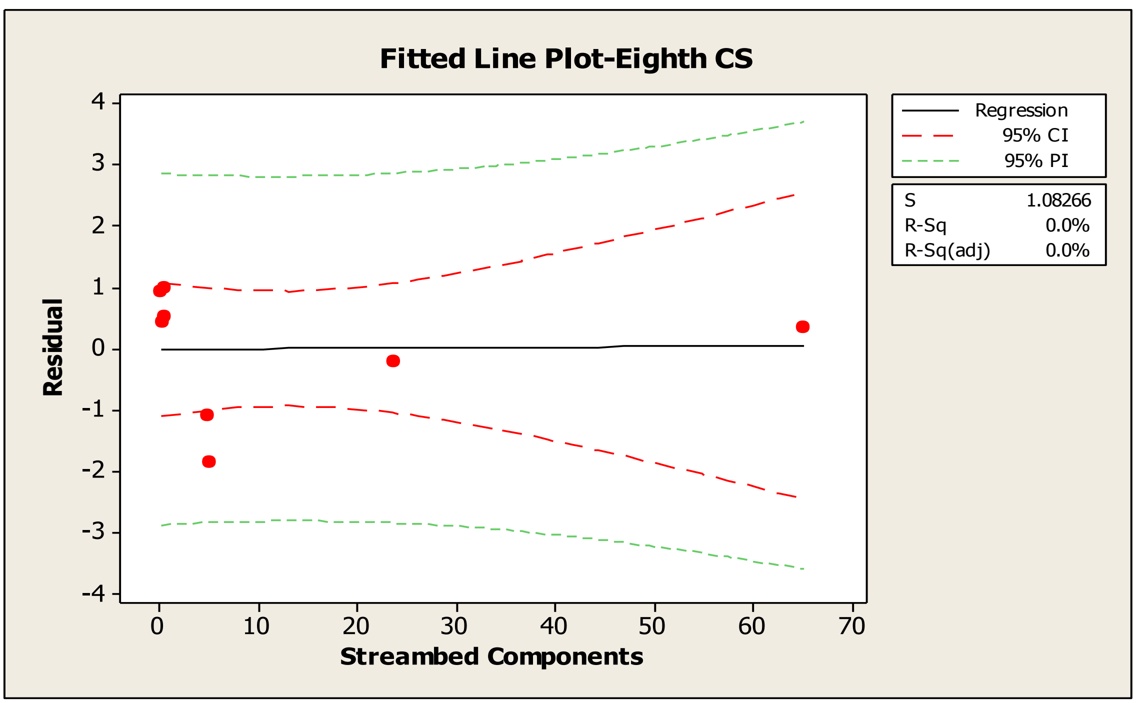

Figure 7. Residual plot for streambed components with 95% PI and CI for eighth CS riffle 1.

Statistical Analysis of the Second Riffle Data: The second riffle is also located in Wilson Creek with the drainage area of 5.73 ml^2. It is a restored riffle with the sign of bed and bank erosions. In addition to that, there is no sign of human activities in the watershed area. This riffle also has the layer of fine material.

Following Tables 1 and 2 summarize the projected aerial and residual for each component for riffle 2. Table 1 shows the average residual for each CS, while the variance of residual describes in Table 2. To cover the entire riffle, 154 images were recorded using the PPB. Based on the Table 1, free gravel and the free epifaunal substrate are the main substrate variables with the average of 54.82% and 33.42 %, respectively, whereas fine material, CPOM, and LWD components are absent in the streambed composition. The other components contain less than 12% of streambed compositions each. In riffle 2, 1.60% of area is covered by algae cover. Maximum residual is for embedded gravel component in seventh CS, which is 3.86 (Table 2).

Table 1

Projected Areal Percentage of Each Component in Riffle 2

CS Name	Free Gravel	Embed. Gravel	Free Epif. Subst.	Embedd. Epif. Subst.	Fine Material	CPOM	LWD	Algae Cover
First	58.33	8.22	29.61	2.78	0.00	0.00	0.00	1.06
Second	53.94	8.29	34.53	1.12	0.00	0.00	0.00	2.12
Third	51.50	5.78	36.61	2.56	0.06	0.00	0.00	3.50
Fourth	55.22	5.50	32.39	5.67	0.00	0.00	0.00	1.22
Fifth	54.84	5.21	34.63	2.89	0.05	0.00	0.00	2.37
Sixth	51.00	8.00	34.83	3.89	0.00	0.00	0.00	2.28
Seventh	56.61	11.22	31.50	0.56	0.00	0.00	0.00	0.11
Eighth	57.09	6.68	33.27	2.77	0.00	0.00	0.00	0.18
Average Riffle	54.82	7.36	33.42	2.78	0.01	0.00	0.00	1.60

Table 2

Residual of Each Component in Riffle 2

CS Name	Free Gravel	Embed. Gravel	Free Epif. Subst.	Embedd. Epif. Subst.	Fine Material	CPOM	LWD	Algae Cover
First	-3.52	-0.86	3.81	0.00	0.01	0.00	0.00	0.55
Second	0.88	-0.93	-1.11	1.66	0.01	0.00	0.00	-0.51
Third	3.32	1.59	-3.19	0.22	-0.04	0.00	0.00	-1.90
Fourth	-0.40	1.86	1.03	-2.89	0.01	0.00	0.00	0.38
Fifth	-0.02	2.15	-1.21	-0.12	-0.04	0.00	0.00	-0.76
Sixth	3.82	-0.64	-1.41	-1.11	0.01	0.00	0.00	-0.67
Seventh	-1.79	-3.86	1.92	2.22	0.01	0.00	0.00	1.49
Eighth	-2.27	0.68	0.15	0.01	0.01	0.00	0.00	1.42

A single factor ANOVA test shows the means of streambed bed CS components measured using sampling grids are not statistically different since F (=1.16) < Fcrit (=2.075). Similar to riffle 1, there is no significant difference between streambed components measured in riffle population and each CS for a 95% confidence interval since $p > 0.05$ (Table 3).

Table 3

p-value for α=0.05 for Each Row in Riffle 2

First CS	Second CS	Third CS	Fourth CS	Fifth CS	Sixth CS	Seven CS	Eighth CS
0.93	0.98	0.95	0.99	0.99	0.93	0.97	0.96

Figure 8 shows the prediction interval (PI) and confidence interval (CI) for streambed components measured in the first CS in riffle 2. Based on Figure 8, the observation is more likely to fall in a range of ± 7% difference from streambed components measured in riffle population with 95% probability. The residual shows in the x-axis and the amount of streambed components show in the y-axis.

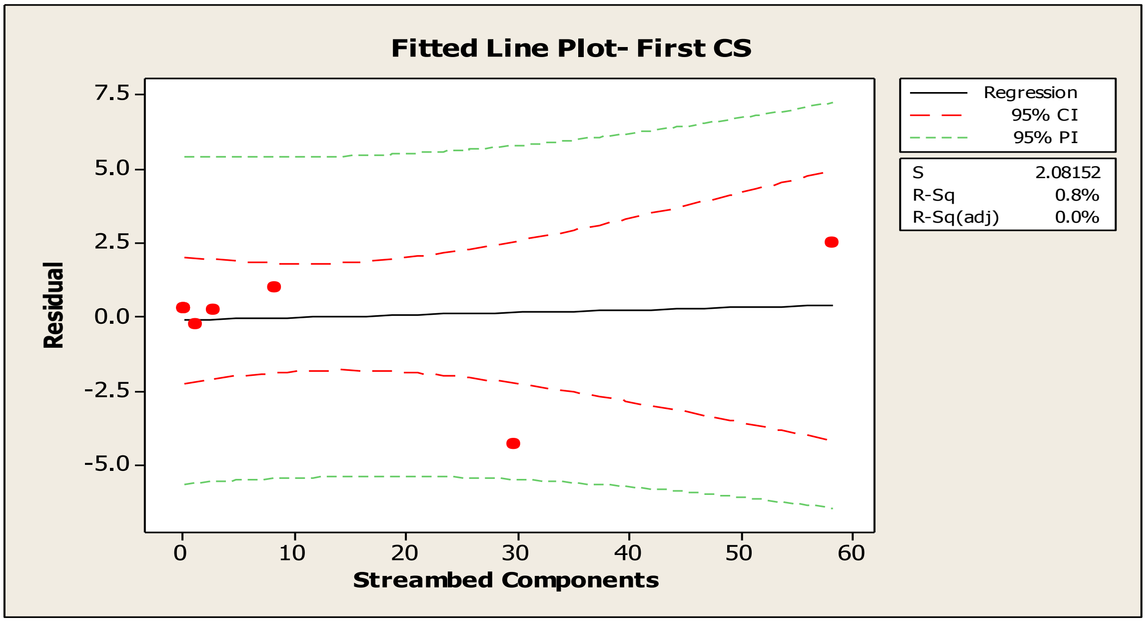

Figure 8. Residual plot for streambed components with 95% PI and CI for first CS riffle 2.

Statistical Analysis of the Third Riffle Data: The third riffle is located in Harrison Creek with the drainage area of 9.55 ml^2. It is an un-restored riffle with agricultural activities in the watershed close to the main channel. There is no sign of bed/bank or a fine layer of material in the channel. However, the bedrock outcrop was observed in few spots in the third riffle.

Following Tables 4 and 5 summarize the projected aerial and residual for each component for riffle 3. Table 4 shows the average residual for each CS, while the variance of residual describes in Table 5. To cover the entire riffle, 168 images were recorded using the PPB. Based on the Table 4, free and embedded gravel are the main substrate variables with the average of 56.37% and 21.63 %, respectively, whereas fine material, CPOM, and LWD components are absent in the streambed composition. The other components including embedded and free epifaunal substrate contain less than 5% of streambed compositions each. In riffle 3, a significant of surficial area, 14.14%, is covered by algae cover. Maximum residual is for free gravel component in second CS, which is 19.67 (Table 5).

Table 4

Projected Areal Percentage of Each Component in Riffle 3

CS Name	Free Gravel	Embed. Gravel	Free Epif. Subst.	Embedd. Epif. Subst.	Fine Material	CPOM	LWD	Algae Cover
First	38.58	37.11	3.84	4.42	0.00	0.00	0.00	16.05
Second	36.70	39.15	4.60	3.10	0.00	0.00	0.00	16.45
Third	49.05	21.05	5.55	4.95	0.65	0.00	0.00	18.75
Fourth	64.19	15.76	4.29	2.95	0.29	0.00	0.00	12.52
Fifth	75.45	6.05	5.86	1.14	0.14	0.00	0.00	11.36
Sixth	58.27	18.82	3.73	3.00	0.00	0.00	0.00	16.18
Seventh	68.80	11.75	4.10	2.10	0.20	0.00	0.00	13.05
Eighth	59.92	23.38	4.50	3.50	0.00	0.00	0.00	8.71
Average Riffle	56.37	21.63	4.56	3.14	0.16	0.00	0.00	14.14

Table 5

Residual of Each Component in Riffle 3

CS Name	Free Gravel	Embed. Gravel	Free Epif. Subst.	Embedd. Epif. Subst.	Fine Material	CPOM	LWD	Algae Cover
First	17.79	-15.47	0.72	-1.28	0.16	0.00	0.00	-1.92
Second	19.67	-17.52	-0.04	0.04	0.16	0.00	0.00	-2.31
Third	7.32	0.58	-0.99	-1.81	-0.49	0.00	0.00	-4.61
Fourth	-7.82	5.87	0.27	0.19	-0.13	0.00	0.00	1.61
Fifth	-19.08	15.59	-1.31	2.01	0.02	0.00	0.00	2.77
Sixth	-1.90	2.81	0.83	0.14	0.16	0.00	0.00	-2.05
Seventh	-12.43	9.88	0.46	1.04	-0.04	0.00	0.00	1.09
Eighth	-3.55	-1.74	0.06	-0.36	0.16	0.00	0.00	5.43

A single factor ANOVA test shows the means of streambed bed CS components measured using sampling grids are not statistically different since F (=2.067) < Fcrit (=4.087). Similar to previous riffles, there is no significant difference between streambed components measured in riffle population and each CS for a 95% confidence interval since $p > 0.05$ (Table 6).

Table 6

p-value for α=0.05 for Each Row in Riffle 3

First CS	Second CS	Third CS	Fourth CS	Fifth CS	Sixth CS	Seven CS	Eighth CS
0.68	0.67	0.82	0.78	0.47	0.95	0.65	0.91

Figure 9 shows the prediction intervals (PI) and confidence intervals (CI) for streambed components measured in the first CS in riffle 3. Based on Figure 9, the observation is more likely to fall in a range of ± 27% difference from streambed components measured in riffle population with 95% probability. The residual shows in the x-axis and the amount of streambed components show in the y-axis.

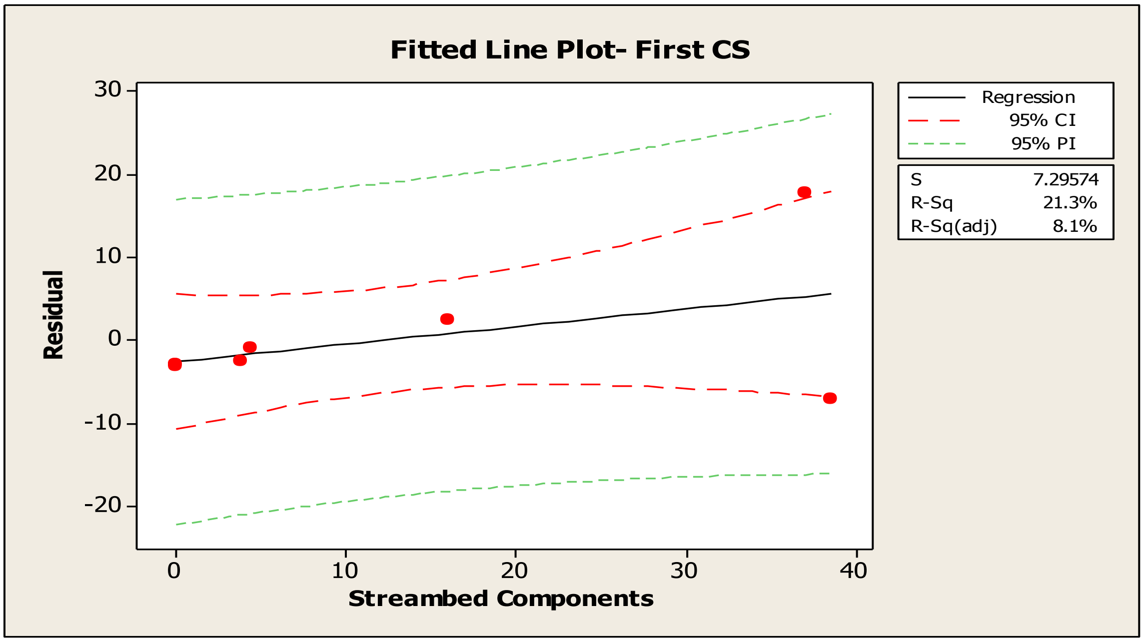

Figure 9. Residual plot for streambed components with 95% PI and CI for first CS riffle 3.

Statistical Analysis of the Fourth Riffle Data: The fourth riffle is located in Harrison Creek with the drainage area of 12.26 mil^2. This riffle has similar characteristics to the riffle 3. It is an un-restored riffle with agricultural activities in the watershed close to the main channel. There is limited sign of bed/bank or a fine layer of material in the channel with the bedrock outcrop in the main channel.

Following Tables 7 and 8 summarize the projected aerial and residual for each component for riffle 4. Table 7 shows the average residual for each CS, while the variance of residual describes in Table 8.

To cover the entire riffle, 107 images were recorded using the PPB. Based on the Table 7, the free gravel and free epifaunal substrate are the main substrate variables with the average of 57.46% and 16.75 %, respectively, whereas fine material, CPOM, and LWD components are absent in the streambed composition. In riffle 4, 5.87% of area is covered by algae cover. Maximum residual is for free gravel component in fourth CS, which is -9.71.

Table 7
Projected Areal Percentage of Each Component in Riffle 4

CS Name	Free Gravel	Embed. Gravel	Free Epif. Subst.	Embedd. Epif. Subst.	Fine Material	CPOM	LWD	Algae Cover
First	61.04	4.37	20.48	4.04	0.00	0.00	0.11	9.96
Second	49.00	9.64	29.86	5.64	0.00	0.14	0.00	5.71
Third	61.19	9.69	19.31	5.00	0.00	0.13	0.00	4.69
Fourth	47.75	20.88	12.25	11.31	0.00	0.00	0.00	7.81
Fifth	58.75	17.56	10.94	11.81	0.00	0.00	0.00	0.94
Sixth	67.06	10.72	7.67	7.89	0.00	0.56	0.00	6.11
Average Riffle	57.46	12.14	16.75	7.62	0.00	0.14	0.02	5.87

Table 8

Residual of Each Component in Riffle 4

CS Name	Free Gravel	Embed. Gravel	Free Epif. Subst.	Embedd. Epif. Subst.	Fine Material	CPOM	LWD	Algae Cover
First	-3.57	7.77	-3.73	3.58	0.00	0.14	-0.09	-4.09
Second	8.46	2.50	-13.11	1.97	0.00	-0.01	0.02	0.16
Third	-3.72	2.46	-2.56	2.62	0.00	0.01	0.02	1.18
Fourth	9.71	-8.73	4.50	-3.70	0.00	0.14	0.02	-1.94
Fifth	-1.29	-5.42	5.81	-4.20	0.00	0.14	0.02	4.93
Sixth	-9.59	1.42	9.08	-0.27	0.00	-0.42	0.02	-0.24

A single factor ANOVA test shows the means of streambed bed CS components measured using sampling grids are not statistically different since F (=2.30) < Fcrit (=2.59). Similar to previous riffles, there is no significant difference between streambed components measured in riffle population and each CS for a 95% confidence interval since p> 0.05 (Table 9).

Table 9

p-value for α=0.05 for Each Row in Riffle 4

First CS	Second CS	Third CS	Fourth CS	Fifth CS	Sixth CS
0.89	0.80	0.88	0.73	0.96	0.66

Figure 10 shows the prediction intervals (PI) and confidence intervals (CI) for streambed components measured in the first CS in riffle 4. Based on Figure10, the observation is more likely to fall in a range of ± 14% difference from streambed components measured in riffle population with 95% probability. The residual shows in the x-axis and the amount of streambed components show in the y-axis.

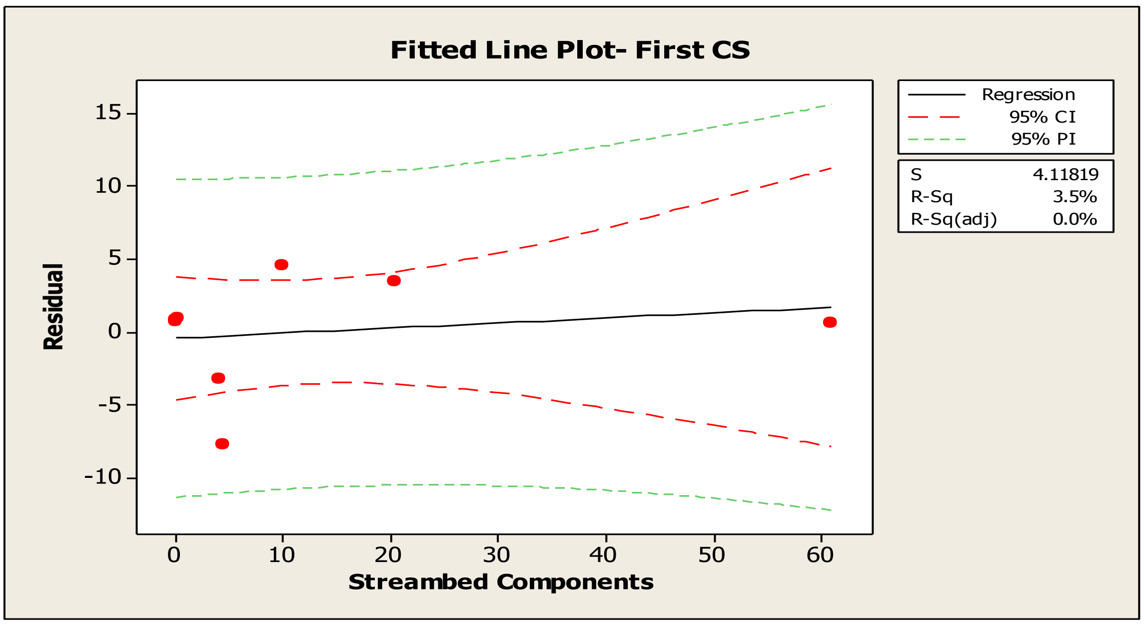

Figure 10. Residual plot for streambed components with 95% PI and CI for first CS riffle 4.

Statistical Analysis of the Fifth Riffle Data: The fifth riffle is located in Overalls Creek with the drainage area of 2.86 ml^2. There is a bedrock outcrop in the left bank, without limited sign of bed/bank erosion or fine layer of materials. It is an un-restored riffle without any substantial human activities in the watershed area.

The following Tables (10 and 11) summarize the projected aerial and residual for each component for riffle 5. The number of images recorded for this riffle is 191. Table 10 shows the average residual for each CS, while the variance of residual describes in Table 11. In this riffle, the free and the embedded gravel are the main substrate parameters with the average of 32.33% and 31.15 %, respectively, whereas CPOM and LWD components are absent in the streambed composition. Components including fine material and algae cover contain less than 2% of streambed compositions. In riffle 5, 0.51% of area is covered by algae cover. Maximum residual is for embedded gravel component in first CS, which is 10.52.

Table 10

Projected Areal Percentage of Each Component in Riffle 5

CS Name	Free Gravel	Embed. Gravel	Free Epif. Subst.	Embedd. Epif. Subst.	Fine Material	CPOM	LWD	Algae Cover
First	21.80	40.80	16.64	19.96	0.68	0.00	0.00	0.12
Second	24.00	39.07	18.86	14.57	1.21	0.00	0.00	2.29
Third	39.07	22.57	18.93	15.93	2.71	0.00	0.00	0.79
Fourth	35.11	33.00	19.74	10.26	1.89	0.00	0.00	0.00
Fifth	29.34	34.17	19.97	12.55	3.59	0.00	0.00	0.38
Sixth	38.22	25.11	23.15	12.93	0.22	0.00	0.00	0.37
Seventh	35.52	25.19	28.22	10.37	0.33	0.00	0.37	0.00
Eighth	35.46	29.29	20.21	13.93	0.79	0.00	0.18	0.14
Average Riffle	32.32	31.15	20.71	13.81	1.43	0.00	0.07	0.51

Table 11

Residual of Each Component in Riffle 5

CS Name	Free Gravel	Embed. Gravel	Free Epif. Subst.	Embedd. Epif. Subst.	Fine Material	CPOM	LWD	Algae Cover
First	10.52	-9.65	4.07	-6.15	0.75	0.00	0.07	0.39
Second	8.32	-7.92	1.86	-0.76	0.21	0.00	0.07	-1.78
Third	-6.75	8.58	1.79	-2.12	-1.29	0.00	0.07	-0.28
Fourth	-2.79	-1.85	0.97	3.55	-0.46	0.00	0.07	0.51
Fifth	2.97	-3.02	0.75	1.26	-2.16	0.00	0.07	0.13
Sixth	-5.91	6.04	-2.43	0.89	1.21	0.00	0.07	0.14
Seventh	-3.20	5.96	-7.51	3.44	1.09	0.00	-0.30	0.51
Eighth	-3.15	1.86	0.50	-0.12	0.64	0.00	-0.11	0.37

A single factor ANOVA test shows the means of streambed bed CS components measured using six sampling grids are not statistically different since F (=1.73) < Fcrit (=2.06). Similar to previous riffles, there is no significant difference between streambed components measured in riffle population and each CS for a 95% confidence interval since p> 0.05 (Table 12).

Table 12

p-value for α=0.05 for Each Row in Riffle 5

First CS	Second CS	Third CS	Fourth CS	Fifth CS	Sixth CS	Seven CS	Eighth CS
0.85	0.87	0.87	0.95	0.95	0.89	0.94	0.94

Figure 11 shows the prediction intervals (PI) and confidence intervals (CI) for streambed components measured in first the CS in riffle 5. Based on Figure 11, the observation is more likely to fall in a range of ± 15% difference from streambed components measured in riffle population with 95% probability. The residual shows in the x-axis and the amount of streambed components show in the y-axis.

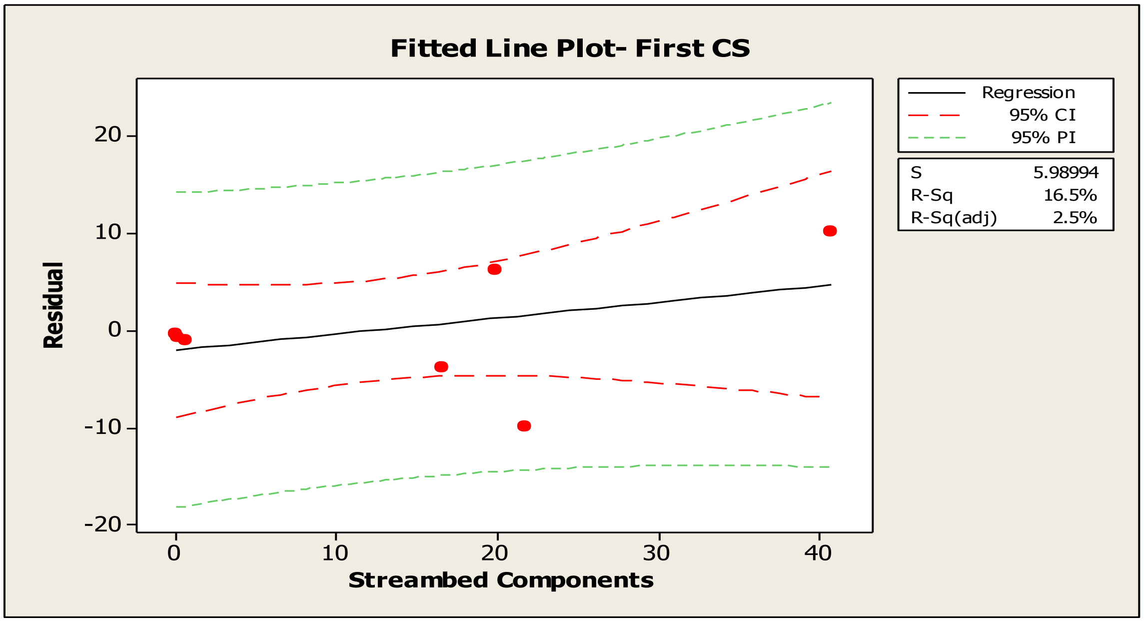

Figure 11. Residual plot for streambed components with 95% PI and CI for first CS riffle 5.

Statistical Analysis of the Sixth Riffle Data: The sixth riffle is located in Wilson Creek with the drainage area of 5.73 ml^2. It is a restored riffle with limited bed/bank erosion sign, fine layer of materials, bedrock outcrops, and human activities in its watershed area.

The Tables 13 and 14 summarize the projected aerial and residual for each component for riffle 6. The number of images recorded for this riffle is 147. Table 13 shows the average residual for each CS, while the variance of residual describes in Table 14. The free gravel is the main substrate parameters with the average of 73.71%, whereas fine material, CPOM, and LWD components are absent in the streambed composition (Table 13). Components including fine material and algae cover contain less than 2% of streambed compositions. In this riffle, 1.26% of area is covered by algae cover. Maximum residual is for free gravel component in second CS, which is 13.05.

Table 13
Projected Areal Percentage of Each Component in Riffle 6

CS Name	Free Gravel	Embed. Gravel	Free Epif. Subst.	Embedd. Epif. Subst.	Fine Material	CPOM	LWD	Algae Cover
First	69.58	9.67	16.92	0.08	0.17	0.00	0.00	3.58
Second	60.67	16.00	19.46	2.63	0.63	0.00	0.00	0.63
Third	63.79	5.21	25.29	0.86	0.86	0.00	0.00	4.00
Fourth	72.08	5.62	19.31	1.85	0.62	0.00	0.00	0.54
Fifth	68.50	12.10	16.90	1.20	0.00	0.00	0.00	1.30
Sixth	78.62	7.23	12.46	0.77	0.00	0.00	0.00	0.92
Seventh	72.45	8.27	17.82	1.27	0.18	0.00	0.00	0.00
Eighth	78.64	9.55	8.73	2.91	0.18	0.00	0.00	0.00
Ninth	78.64	8.09	6.00	5.55	0.00	0.00	0.00	1.73
Tenth	78.70	9.20	12.00	0.00	0.00	0.00	0.00	0.10
Eleventh	82.00	3.00	12.67	0.67	0.33	0.00	0.00	1.33
Twelfth	80.89	5.33	12.00	0.78	0.00	0.00	0.00	1.00
Average Riffle	73.71	8.27	14.96	1.55	0.25	0.00	0.00	1.26

Table 14

Residual of Each Component in Riffle 6

CS Name	Free Gravel	Embed. Gravel	Free Epif. Subst.	Embedd. Epif. Subst.	Fine Material	CPOM	LWD	Algae Cover
First	4.13	-1.39	-1.95	1.46	0.08	0.00	0.00	-2.32
Second	13.05	-7.73	-4.50	-1.08	-0.38	0.00	0.00	0.64
Third	9.93	3.06	-10.32	0.69	-0.61	0.00	0.00	-2.74
Fourth	1.64	2.66	-4.35	-0.30	-0.37	0.00	0.00	0.72
Fifth	5.21	-3.83	-1.94	0.35	0.25	0.00	0.00	-0.04
Sixth	-4.90	1.04	2.50	0.78	0.25	0.00	0.00	0.34
Seventh	1.26	0.00	-2.86	0.27	0.06	0.00	0.00	1.26
Eighth	-4.92	-1.27	6.23	-1.36	0.06	0.00	0.00	1.26
Ninth	-4.92	0.18	8.96	-4.00	0.25	0.00	0.00	-0.47
Tenth	-4.99	-0.93	2.96	1.55	0.25	0.00	0.00	1.16
Eleventh	-8.29	5.27	2.30	0.88	-0.09	0.00	0.00	-0.07
Twelfth	-7.18	2.94	2.96	0.77	0.25	0.00	0.00	0.26

A single factor ANOVA test shows the means of streambed bed CS components measured using sampling grids are not statistically different since F (=1.88) < Fcrit (=3.03). Similar to previous riffles, there is no significant difference between streambed components measured in riffle population and each CS for a 95% confidence interval since p> 0.05 (Table 15).

Table 15

p-value for α=0.05 for Each Row in Riffle 6

First CS	Second CS	Third CS	Fourth CS	Fifth CS	Sixth CS	Seven CS	Eighth CS	Ninth CS	Tenth CS	Eleventh CS	Twelfth CS
0.86	0.63	0.73	0.94	0.83	0.81	0.95	0.79	0.78	0.81	0.67	0.71

Figure 12 shows the prediction intervals (PI) and confidence intervals (CI) for streambed components measured in the first CS in riffle 6. Based on Figure 12, the observation is more likely to fall in a range of ± (3-5) % difference from streambed components measured in riffle population with 95% probability. The residual shows in the x-axis and the amount of streambed components show in the y-axis.

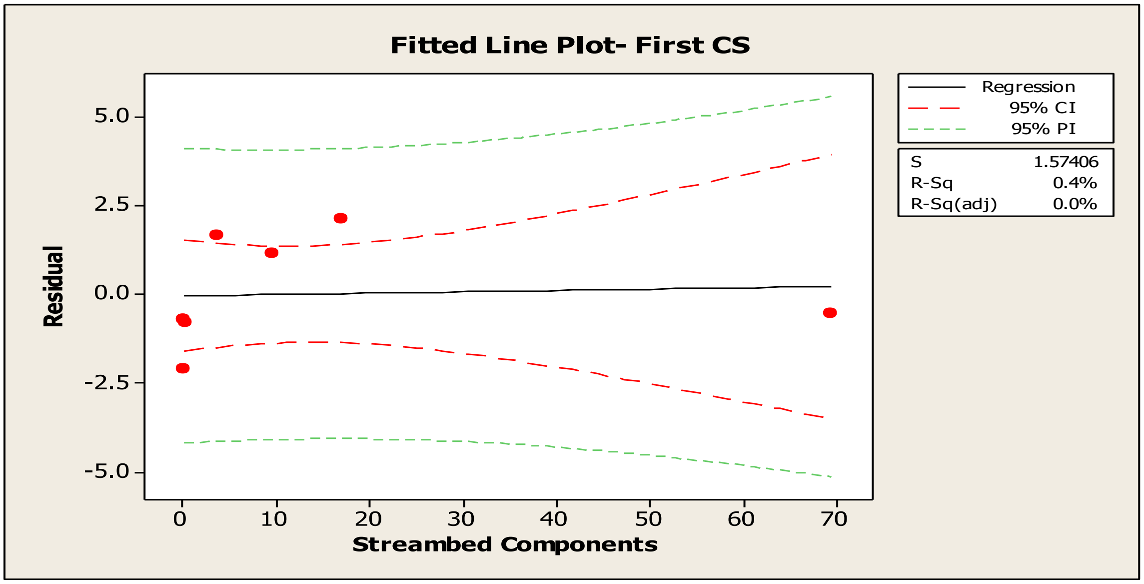

Figure 12. Residual plot for streambed components with 95% PI and CI for first CS riffle 6.

Statistical Analysis of the Seventh Riffle Data: The seventh riffle is similar to characteristics of the riffle sixth, which is mentioned in previous section. The Tables 16 and 17 summarize the projected aerial and residual for each component for riffle 7. The number of images recorded for this riffle is 172. Table 16 shows the average residual for each CS, while the variance of residual describes in Table 17. The free epifaunal substrate is the main substrate components with the average of 63.86%, whereas fine material, CPOM, and LWD components are absent in the streambed composition (Table 16). Components including embedded gravel, embedded epifaunal, and algae cover contain less than 13% of streambed compositions. In riffle 7, 0.52% of area is covered by algae cover. Maximum residual is for free gravel component in fifth CS, which is -9.56.

Table 16

Projected Areal Percentage of Each Component in Riffle 7

CS Name	Free Gravel	Embed. Gravel	Free Epif. Subst.	Embedd. Epif. Subst.	Fine Material	CPOM	LWD	Algae Cover
First	21.35	4.88	61.59	10.65	0.00	0.00	0.00	1.53
Second	26.18	4.76	61.29	7.76	0.00	0.00	0.00	0.00
Third	29.00	7.11	56.44	7.39	0.00	0.00	0.00	0.06
Fourth	33.11	6.72	48.28	11.44	0.00	0.00	0.00	0.44
Fifth	22.65	4.15	67.85	5.15	0.00	0.00	0.00	0.20
Sixth	21.25	4.20	69.95	4.25	0.00	0.00	0.00	0.35
Seventh	15.47	5.42	70.84	8.16	0.00	0.00	0.00	0.11
Eighth	25.73	3.73	65.67	4.07	0.27	0.00	0.00	0.53
Ninth	21.33	2.93	70.33	4.53	0.00	0.00	0.00	0.87
Tenth	19.46	7.23	66.69	5.46	0.00	0.00	0.00	1.15
Average Riffle	23.55	5.11	63.89	6.89	0.03	0.00	0.00	0.52

Table 17

Residual of Each Component in Riffle 7

CS Name	Free Gravel	Embed. Gravel	Free Epif. Subst.	Embedd. Epif. Subst.	Fine Material	CPOM	LWD	Algae Cover
First	2.20	0.23	2.31	-3.76	0.03	0.00	0.00	-1.01
Second	-2.62	0.35	2.60	-0.88	0.03	0.00	0.00	0.52
Third	-5.45	-2.00	7.45	-0.50	0.03	0.00	0.00	0.47
Fourth	-9.56	-1.61	15.62	-4.56	0.03	0.00	0.00	0.08
Fifth	0.90	0.96	-3.96	1.74	0.03	0.00	0.00	0.32
Sixth	2.30	0.91	-6.06	2.64	0.03	0.00	0.00	0.17
Seventh	8.08	-0.31	-6.95	-1.27	0.03	0.00	0.00	0.42
Eighth	-2.18	1.38	-1.77	2.82	-0.24	0.00	0.00	-0.01
Ninth	2.22	2.18	-6.44	2.35	0.03	0.00	0.00	-0.34
Tenth	4.09	-2.12	-2.80	1.42	0.03	0.00	0.00	-0.63

A single factor ANOVA test shows the means of streambed bed CS components measured using sampling grids are not statistically different since F (=1.60) < Fcrit (=1.94). Similar to previous riffles, there is no significant difference between streambed components measured in riffle population and each CS for a 95% confidence interval since p> 0.05 (Table 18).

Table 18

p-value for α=0.05 for Each Row in Riffle 7

First CS	Second CS	Third CS	Fourth CS	Fifth CS	Sixth CS	Seven CS	Eighth CS	Ninth CS	Tenth CS
0.98	0.98	0.95	0.90	0.99	0.98	0.93	0.98	0.98	0.96

Figure 13 shows the prediction intervals (PI) and confidence intervals (CI) for streambed components measured in the first CS in riffle 7. Based on Figure 13, the observation is more likely to fall in a range of ± (4-6) % difference from streambed components measured in riffle population with 95% probability. The residual shows in the x-axis and the amount of streambed components show in the y-axis.

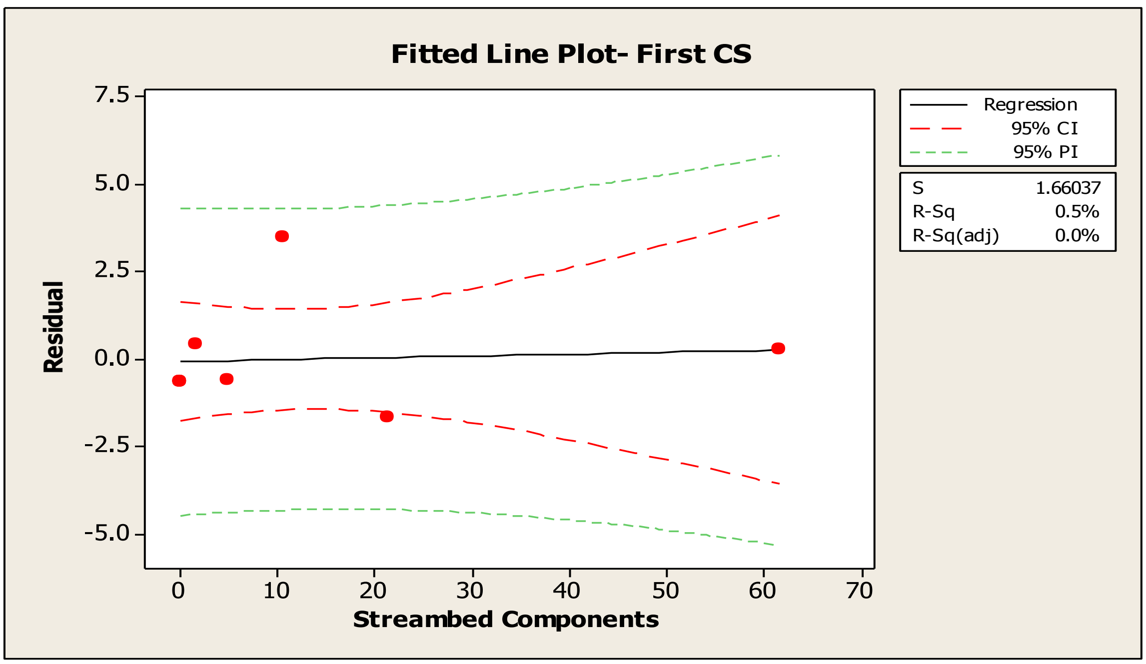

Figure 13. Residual plot for streambed components with 95% PI and CI for first CS riffle 7.

Statistical Analysis of the Eighth Riffle Data: The eighth riffle is similar to characteristics of the riffle fifth. The Tables 19 and 20 summarize the projected aerial and residual for each component for riffle 8. The number of images recorded for this riffle is 113. Table 19 shows the average residual for each CS, while the variance of residual describes in Table 20. The free gravel is the main substrate components with the average of 67.75%, whereas fine material, CPOM, and LWD components are absent in the streambed composition (Table 19). Components including embedded epifaunal and algae cover contain less than 5% of streambed compositions. In riffle 8, 0.03% of area is covered by algae cover. Maximum residual is for free gravel component in tenth CS, which is 17.52.

Table 19
Projected Areal Percentage of Each Component in Riffle 8

CS Name	Free Gravel	Embed. Gravel	Free Epif. Subst.	Embedd. Epif. Subst.	Fine Material	CPOM	LWD	Algae Cover
First	79.56	5.11	11.22	2.78	0.00	0.89	0.00	0.44
Second	76.29	5.00	14.71	2.86	0.00	1.14	0.00	0.00
Third	70.00	6.33	17.17	1.83	0.00	2.83	1.83	0.00
Fourth	68.63	8.13	16.25	4.50	0.00	2.50	0.00	0.00
Fifth	68.71	13.43	9.00	5.14	0.00	3.71	0.00	0.00
Sixth	68.25	6.75	19.13	4.50	0.00	1.38	0.00	0.00
Seventh	77.14	5.71	14.29	1.86	0.00	1.00	0.00	0.00
Eighth	73.63	7.88	15.13	2.88	0.00	0.50	0.00	0.00
Ninth	64.00	13.63	15.75	6.63	0.00	0.00	0.00	0.00
Tenth	50.22	32.22	12.67	4.89	0.00	0.00	0.00	0.00
Eleventh	69.29	4.71	24.71	0.71	0.00	0.57	0.00	0.00
Twelfth	67.10	12.10	15.10	5.70	0.00	0.00	0.00	0.00
Thirteenth	63.00	13.88	15.63	7.25	0.00	0.25	0.00	0.00
Fourteenth	52.64	30.18	12.36	4.73	0.00	0.09	0.00	0.00
Average Riffle	67.75	11.79	15.22	4.02	0.00	1.06	0.13	0.03

Table 20

Residual of Each Component in Riffle 8

CS Name	Free Gravel	Embed. Gravel	Free Epif. Subst.	Embedd. Epif. Subst.	Fine Material	CPOM	LWD	Algae Cover
First	-11.81	6.68	4.00	1.24	0.00	0.17	0.13	-0.41
Second	-8.54	6.79	0.51	1.16	0.00	-0.08	0.13	0.03
Third	-2.25	5.46	-1.94	2.18	0.00	-1.77	-1.70	0.03
Fourth	-0.88	3.66	-1.03	-0.48	0.00	-1.44	0.13	0.03
Fifth	-0.97	-1.64	6.22	-1.13	0.00	-2.65	0.13	0.03
Sixth	-0.50	5.04	-3.90	-0.48	0.00	-0.31	0.13	0.03
Seventh	-9.40	6.08	0.94	2.16	0.00	0.06	0.13	0.03
Eighth	-5.88	3.91	0.10	1.14	0.00	0.56	0.13	0.03
Ninth	3.75	-1.84	-0.53	-2.61	0.00	1.06	0.13	0.03
Tenth	17.52	-20.43	2.56	-0.87	0.00	1.06	0.13	0.03
Eleventh	-1.54	7.08	-9.49	3.30	0.00	0.49	0.13	0.03
Twelfth	0.65	-0.31	0.12	-1.68	0.00	1.06	0.13	0.03
Thirteenth	4.75	-2.09	-0.40	-3.23	0.00	0.81	0.13	0.03
Fourteenth	15.11	-18.39	2.86	-0.71	0.00	0.97	0.13	0.03

A single factor ANOVA test shows the means of streambed bed CS components measured using sampling grids are not statistically different since F (=1.82) < Fcrit (=2.15). Similar to previous riffles, there is no significant difference between streambed components measured in riffle population and each CS for a 95% confidence interval since $p > 0.05$ (Table 21).

Table 21

p-value for α=0.05 for Each Row in Riffle 8

First CS	Second CS	Third CS	Fourth CS	Fifth CS	Sixth CS	Seven CS
0.57	0.70	0.92	0.97	0.97	0.98	0.67
Eighth CS	Ninth CS	Tenth CS	Eleventh CS	Twelfth CS	Thirteenth CS	Fourteenth CS
0.80	0.88	0.64	0.96	0.98	0.85	0.67

Figure 14 shows the prediction interval (PI) and confidence interval (CI) for streambed components measured in the first CS in riffle 8. Based on Figure 14, the observation is more likely to fall in a range of ± (10-15) % difference from streambed components measured in riffle population with 95% probability. The residual shows in the x-axis and the amount of streambed components show in the y-axis.

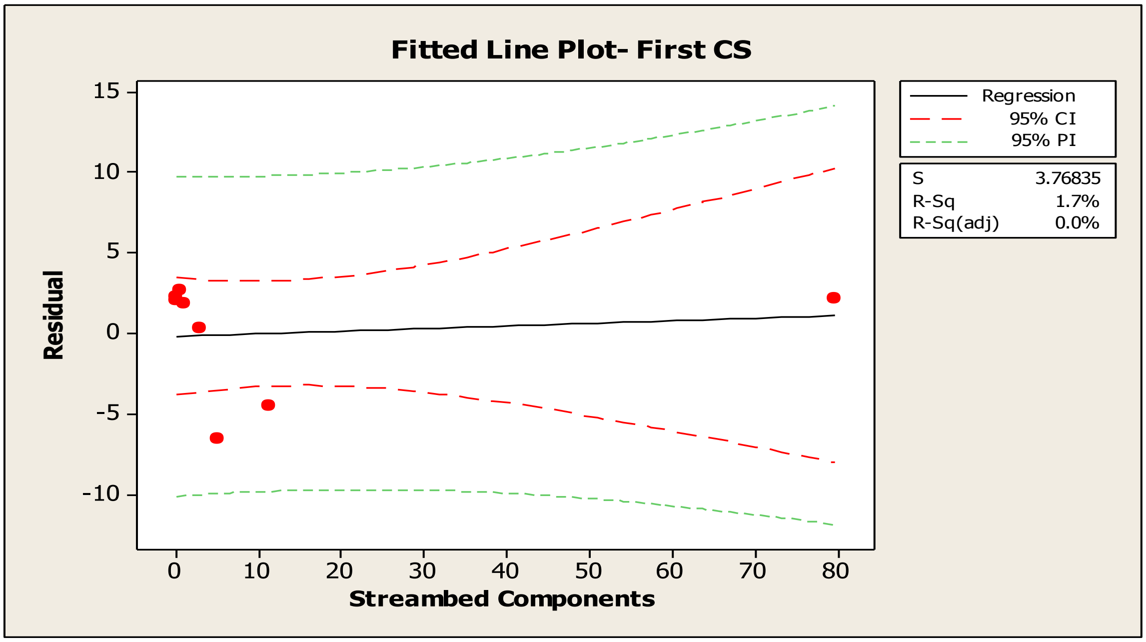

Figure 14. Residual plot for streambed components with 95% PI and CI for first CS riffle 8.

Statistical Analysis of the Ninth Riffle Data: The ninth riffle is similar to characteristics of the riffle sixth. The Tables 22 and 23 summarize the projected aerial and residual for each component for riffle 9. The number of images recorded for this riffle is 106. Table 22 shows the average residual for each CS, while the variance of residual describes in Table 23. The free gravel and the free epifaunal substrate are the main substrate components with the average of 44.82 and 47.56%, respectively whereas fine material, CPOM, and LWD components are absent in the streambed composition (Table 22). Components including embedded gravel, embedded epifaunal, and algae cover contain less than 7% of streambed compositions. In riffle 9, 0.21% of area is covered by algae cover. Maximum residual is for free epifaunal substrate component in tenth CS, which is -15.44.

Table 22

Projected Areal Percentage of Each Component in Riffle 9

CS Name	Free Gravel	Embed. Gravel	Free Epif. Subst.	Embedd. Epif. Subst.	Fine Material	CPOM	LWD	Algae Cover
First	49.07	3.67	41.13	5.60	0.00	0.00	0.00	0.53
Second	56.75	3.63	35.50	4.13	0.00	0.00	0.00	0.00
Third	47.47	3.73	43.27	4.87	0.00	0.00	0.00	0.67
Fourth	31.13	2.73	63.00	2.47	0.67	0.00	0.00	0.00
Fifth	38.07	4.64	56.07	1.21	0.00	0.00	0.00	0.00
Sixth	47.73	3.00	46.80	1.73	0.60	0.00	0.00	0.13
Seventh	43.50	4.06	47.13	5.19	0.00	0.00	0.00	0.13
Average Riffle	44.82	3.64	47.56	3.60	0.18	0.00	0.00	0.21

Table 23

Residual of Each Component in Riffle 9

CS Name	Free Gravel	Embed. Gravel	Free Epif. Subst.	Embedd. Epif. Subst.	Fine Material	CPOM	LWD	Algae Cover
First	-4.25	-0.03	6.42	-2.00	0.18	0.00	0.00	-0.33
Second	-11.93	0.01	12.06	-0.53	0.18	0.00	0.00	0.21
Third	-2.65	-0.10	4.29	-1.27	0.18	0.00	0.00	-0.46
Fourth	13.68	0.90	-15.44	1.13	-0.49	0.00	0.00	0.21
Fifth	6.75	-1.01	-8.51	2.38	0.18	0.00	0.00	0.21
Sixth	-2.92	0.64	0.76	1.87	-0.42	0.00	0.00	0.08
Seventh	1.32	-0.42	0.43	-1.59	0.18	0.00	0.00	0.08

A single factor ANOVA test shows the means of streambed bed CS components measured using sampling grids are not statistically different since F (=2.19) < Fcrit (=2.95). Similar to previous riffles, there is no significant difference between streambed components measured in riffle population and each CS for a 95% confidence interval since $p > 0.05$ (Table 24).

Table 24

p-value for α=0.05 for Each Row in Riffle 9

First CS	Second CS	Third CS	Fourth CS	Fifth CS	Sixth CS	Seven CS
0.95	0.84	0.97	0.86	0.93	0.97	0.98

Figure 15 shows the prediction intervals (PI) and confidence intervals (CI) for streambed components measured in first CS in the riffle 9. Based on Figure 15, the observation is more likely to fall in a range of ± (8-10) % difference from streambed components measured in riffle population with 95% probability. The residual shows in the x-axis and the amount of streambed components show in the y-axis.

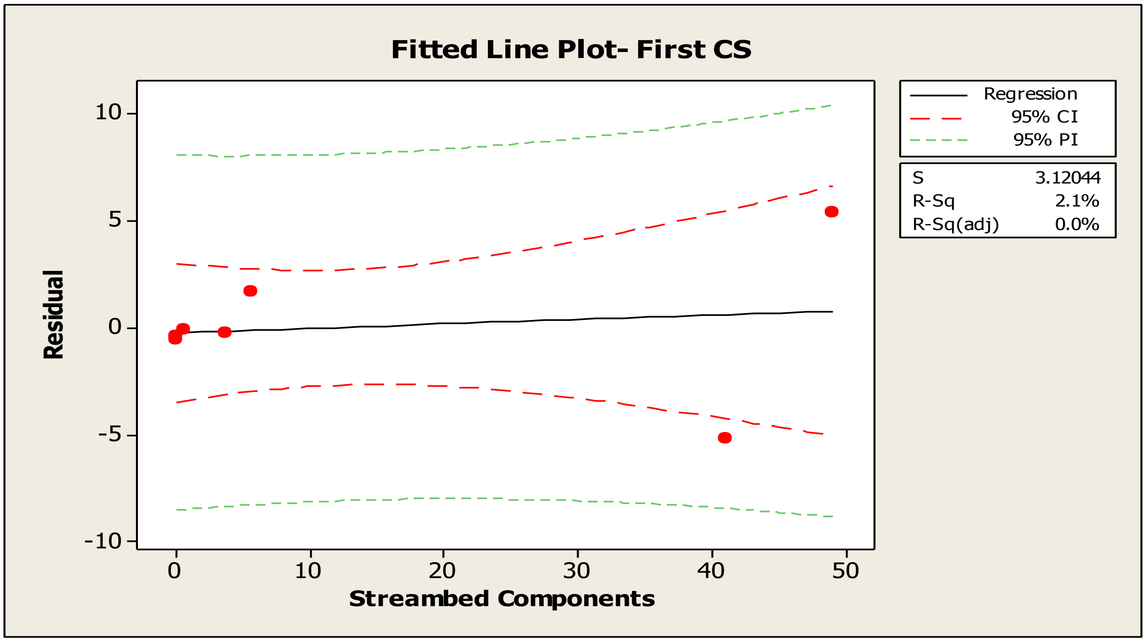

Figure 15. Residual plot for streambed components with 95% PI and CI for first CS riffle 9.

Statistical Analysis of the Tenth Riffle Data: The tenth riffle is similar to characteristics of riffle sixth. The Tables 25 and 26 summarize the projected aerial and residual for each component for riffle 10. The number of images recorded for this riffle is 119. Table 25 shows the average residual for each CS, while the variance of residual describes in Table 26. The free gravel and the free epifaunal substrate are the main substrate components with the average of 56.41 and 35.50%, respectively whereas fine material, CPOM, and LWD components are absent in the streambed composition (Table 25). Components including embedded gravel, embedded epifaunal, and algae cover contain less than 7% of streambed compositions. In riffle 10, 0.76% of area is covered by algae cover. Maximum residual is for free gravel component in first CS, which is 14.86.

Table 25

Projected Areal Percentage of Each Component in Riffle 10

CS Name	Free Gravel	Embed. Gravel	Free Epif. Subst.	Embedd. Epif. Subst.	Fine Material	CPOM	LWD	Algae Cover
First	41.55	2.82	46.91	2.82	0.00	0.00	0.00	5.91
Second	51.17	7.33	35.08	5.33	0.00	0.00	0.00	1.08
Third	44.92	7.67	38.92	8.25	0.00	0.00	0.00	0.25
Fourth	53.29	1.00	42.93	2.79	0.00	0.00	0.00	0.00
Fifth	61.90	0.80	31.90	4.10	0.00	1.30	0.00	0.00
Sixth	69.00	1.67	24.67	4.67	0.00	0.00	0.00	0.00
Seventh	61.63	3.63	30.63	4.13	0.00	0.00	0.00	0.00
Eighth	64.00	5.00	27.30	3.70	0.00	0.00	0.00	0.00
Ninth	56.40	3.10	39.10	1.40	0.00	0.00	0.00	0.00
Tenth	60.26	0.57	37.57	1.26	0.00	0.00	0.00	0.35
Average Riffle	56.41	3.36	35.50	3.84	0.00	0.13	0.00	0.76

Table 26

Residual of Each Component in Riffle 10

CS Name	Free Gravel	Embed. Gravel	Free Epif. Subst.	Embedd. Epif. Subst.	Fine Material	CPOM	LWD	Algae Cover
First	14.86	0.54	-11.41	1.03	0.00	0.13	0.00	-5.15
Second	5.24	-3.98	0.42	-1.49	0.00	0.13	0.00	-0.32
Third	11.49	-4.31	-3.42	-4.41	0.00	0.13	0.00	0.51
Fourth	3.12	2.36	-7.43	1.06	0.00	0.13	0.00	0.76
Fifth	-5.49	2.56	3.60	-0.26	0.00	-1.17	0.00	0.76
Sixth	-12.59	1.69	10.83	-0.82	0.00	0.13	0.00	0.76
Seventh	-5.21	-0.27	4.87	-0.28	0.00	0.13	0.00	0.76
Eighth	-7.59	-1.64	8.20	0.14	0.00	0.13	0.00	0.76
Ninth	0.01	0.26	-3.60	2.44	0.00	0.13	0.00	0.76
Tenth	-3.85	2.79	-2.07	2.58	0.00	0.13	0.00	0.41

A single factor ANOVA test shows the means of streambed bed CS components measured using sampling grids are not statistically different since F (=1.96) < Fcrit (=2.81). Similar to previous riffles, there is no significant difference between streambed components measured in riffle population and each CS for a 95% confidence interval since p> 0.05 (Table 27).

Table 27

p-value for α=0.05 for Each Row in Riffle 10

First CS	Second CS	Third CS	Fourth CS	Fifth CS	Sixth CS	Seven CS	Eighth CS	Ninth CS	Tenth CS
0.80	0.92	0.83	0.96	0.91	0.77	0.91	0.86	1.00	0.94

Figure 16 shows the prediction interval (PI) and confidence interval (CI) for streambed components measured in first CS in the riffle 10. Based on Figure 16, the observation is more likely to fall in a range of ± (18-25) % difference from streambed components measured in riffle population with 95% probability. The residual shows in the x-axis and the amount of streambed components show in the y-axis.

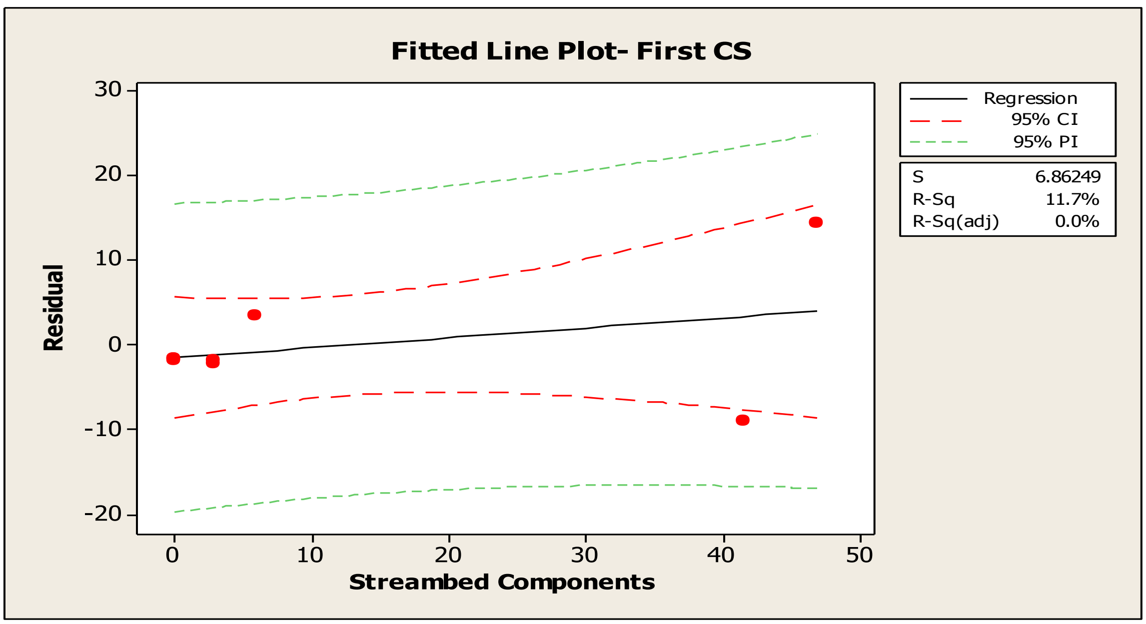

Figure 16. Residual plot for streambed components with 95% PI and CI for first CS riffle 10.

Appendix III

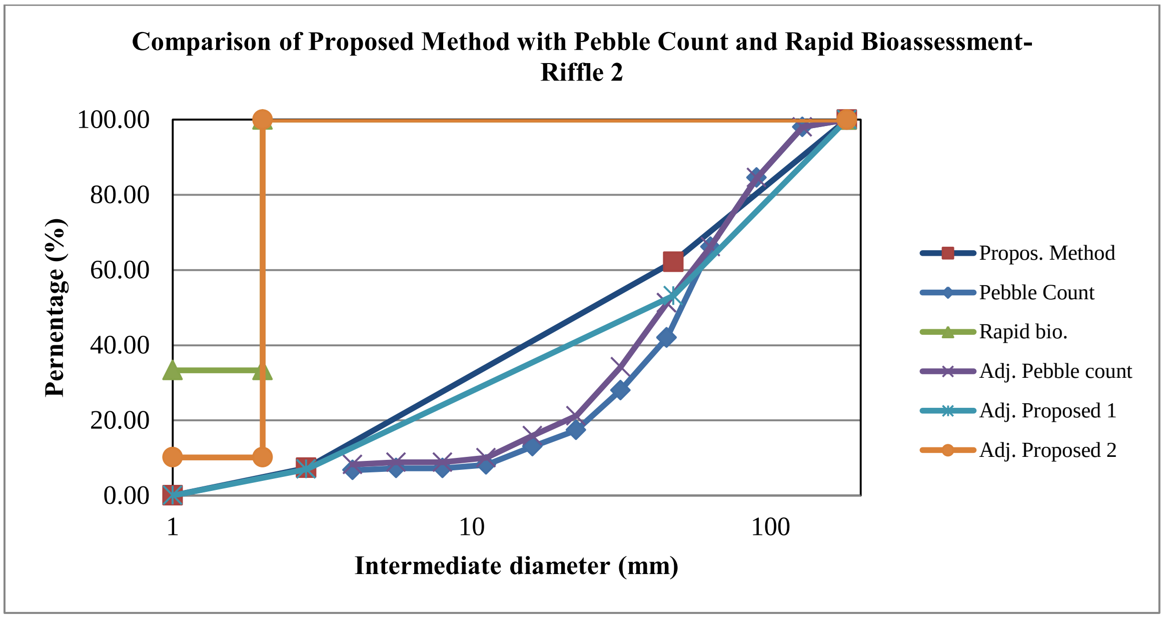

Figure 1. Comparison of sampling methods in riffle 2.

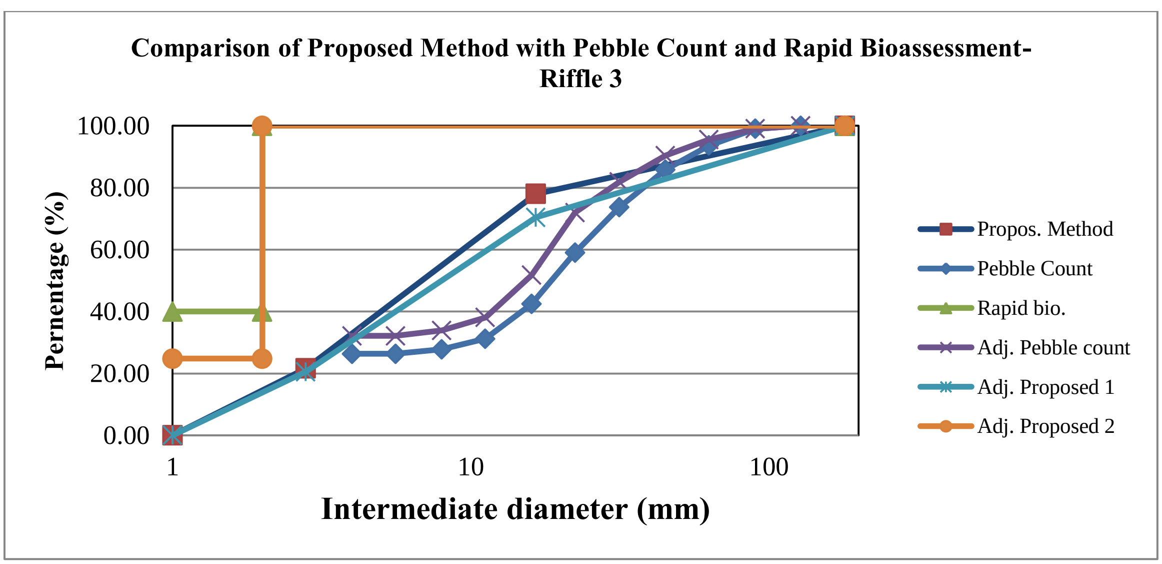

Figure 2. Comparison of sampling methods in riffle 3.

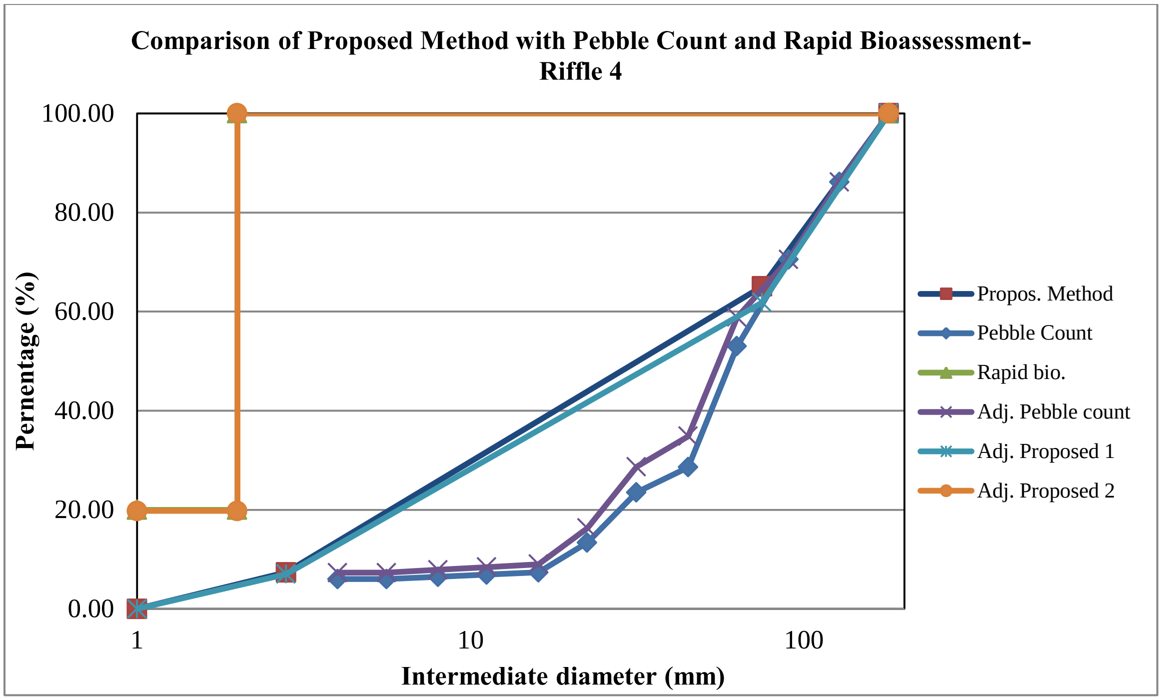

Figure 3. Comparison of sampling methods in riffle 4.

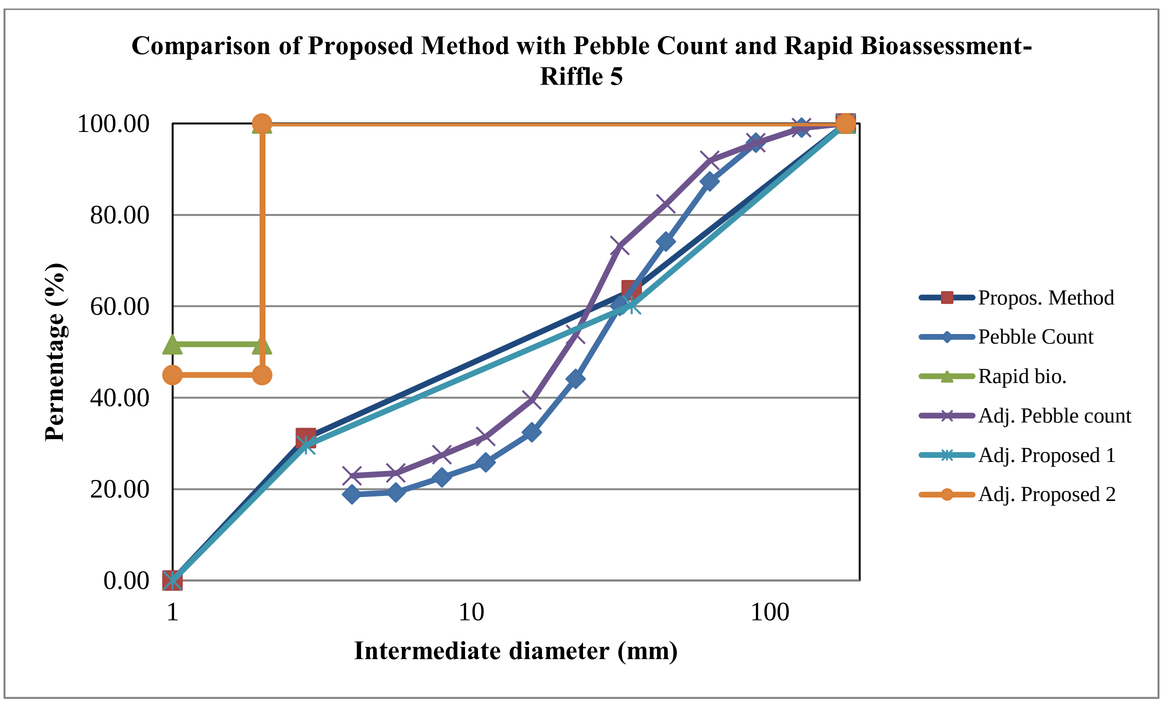

Figure 4. Comparison of sampling methods in riffle 5.

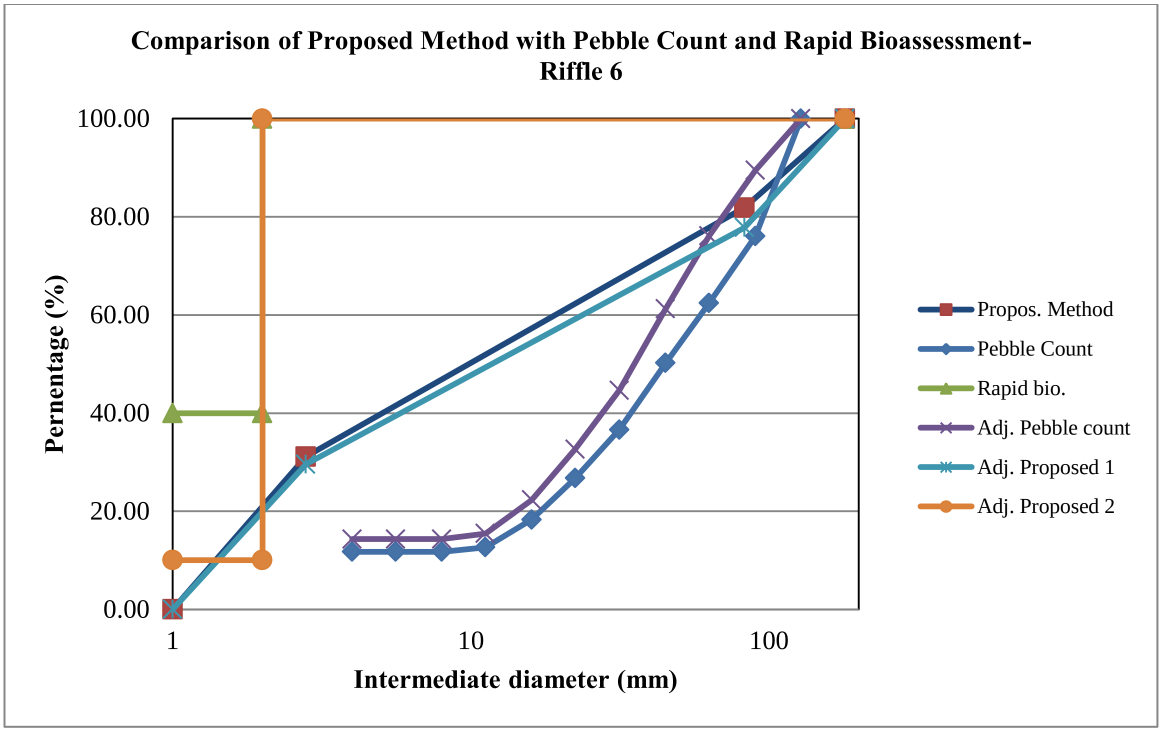

Figure 5. Comparison of sampling methods in riffle 6.

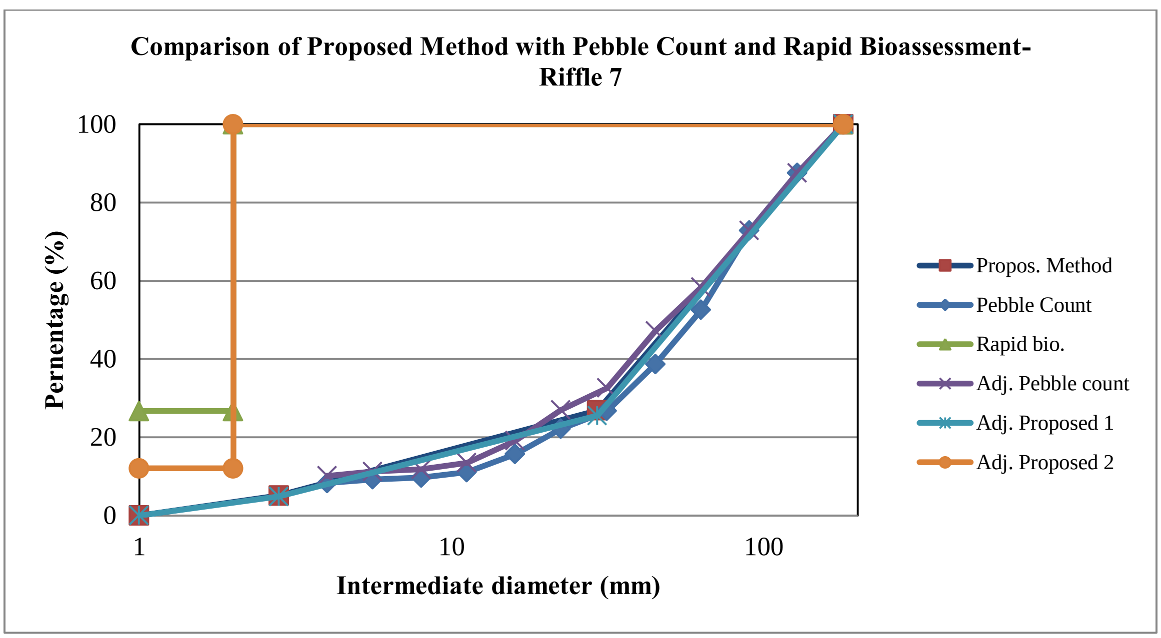

Figure 6. Comparison of sampling methods in riffle 7.

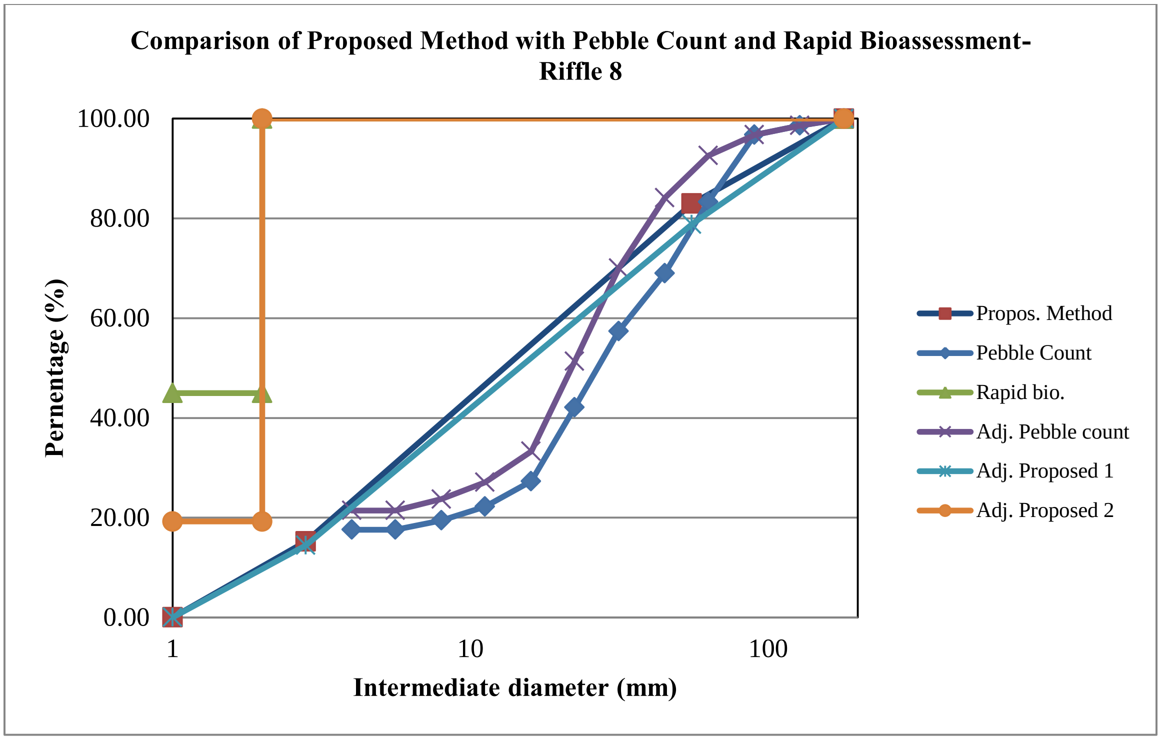

Figure 7. Comparison of sampling methods in riffle 8.

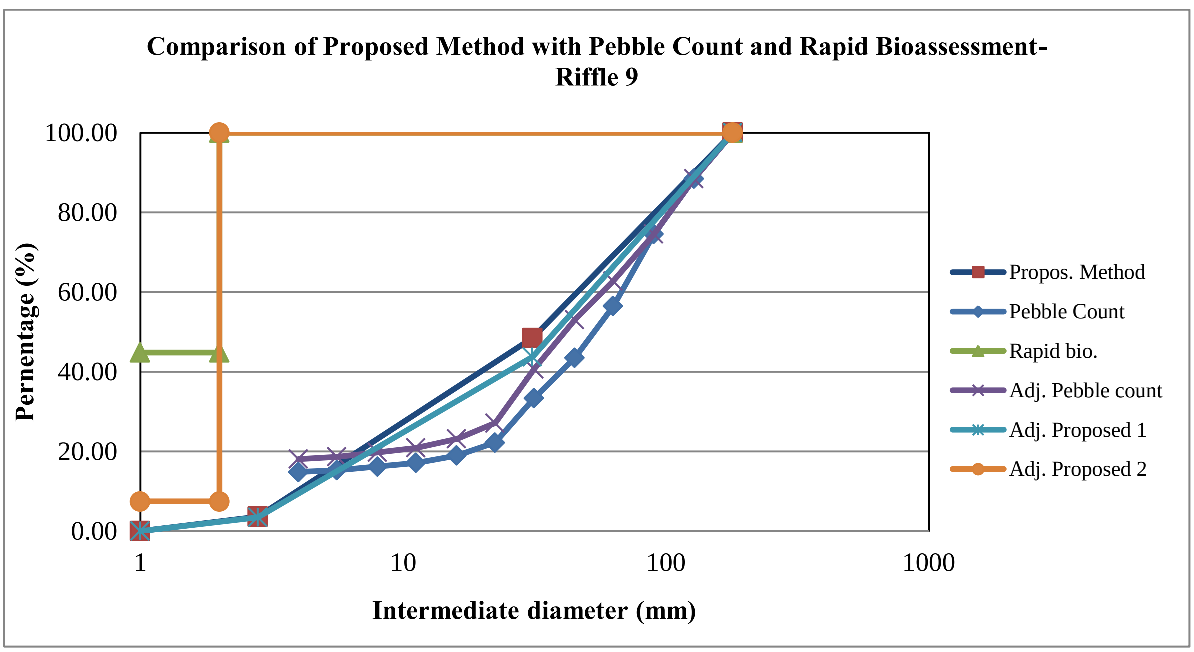

Figure 8. Comparison of sampling methods in riffle 9.

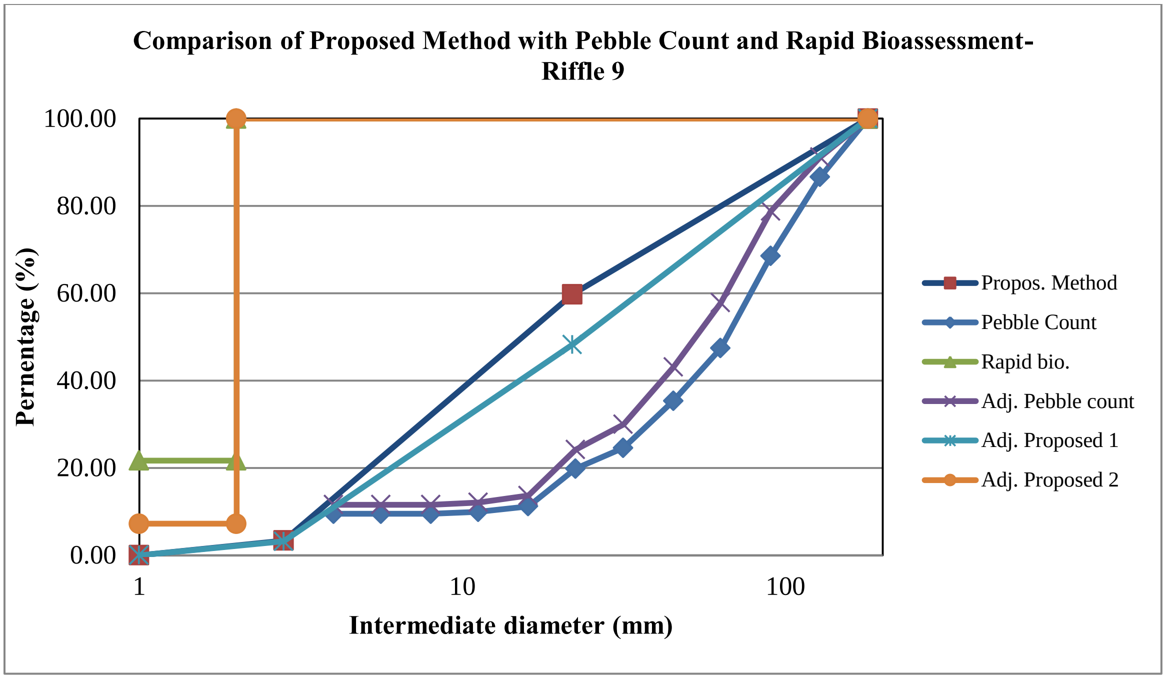

Figure 9. Comparison of sampling methods in riffle 10.

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