USING TERRESTRIAL PHOTOGRAPHY TO MEASURE STREAM MORPHOLOGY

by

DUSTIN ALAN MENHART

(Under the Direction of DAVID S. LEIGH)

ABSTRACT

The ability to properly identify stream channel morphology is an essential tool for all fluvial geomorphologists and river scientists. Research compared measurements from traditional stream channel survey to a terrestrial photography technique that evaluated variables from stream channels. Statistical results show that a photographic methodology accurately measures and describes morphological parameters considered in this study. Classification systems were created to identify dominant bed material and physical habitat for the ten vegetative (5 forested/ 5 pastured) streams surveyed. This scientific technique was performed on streams in the southern Blue Ridge Mountains near Coweeta Long Term Ecological Research Center.

INDEX WORDS: STREAM MORPHOLOGY, TERRESTRIAL PHOTOGRAPHY, TECHNIQUES IN FLUVIIAL GEOMORPHOLOGY, CHANNEL MONITORING, PHOTO DOCUMENTATION

USING TERRESTRIAL PHOTOGRAPHY TO MEASURE STREAM MORPHOLOGY

by

DUSTIN ALAN MENHART

B.A., CALIFORNIA UNIVERSITY OF PA, 1996

M.A., CALIFORNIA UNIVERSITY OF PA, 1997

A Thesis Submitted to the Graduate Faculty of The University of Georgia in Partial Fulfillment of the Requirements for the Degree

MASTER OF SCIENCE

ATHENS, GEORGIA

2011

USING TERRESTRIAL PHOTOGRAPHY TO MEASURE STREAM MORPHOLOGY

by

DUSTIN ALAN MENHART

Major Professor: DAVID S. LEIGH

Committee: C. RHETT JACKSON
THOMAS R. JORDAN

Electronic Version Approved:

Maureen Grasso
Dean of the Graduate School
The University of Georgia
AUGUST 2011

DEDICATION

This Thesis is dedicated to my wife Jolene and my children Dalton and Gavin. They have sacrificed many months of their lives to ensure I was successful. I only wish that I can resolve all of their vanished time.

ACKNOWLEDGEMENTS

I would like to particularly thank my major professor Dr. David Leigh, as well as my committee members Dr. Rhett Jackson and Dr. Tommy Jordan, for their complete guidance, direction, and support in the research process.

My colleagues at the United States Military Academy (USMA) at West Point, NY were invaluable for their support and friendship. Thanks to the Coweeta Long Term Ecological Research Center and all of the UGA Geomorphology crew including, Jake McDonald, Brad Suthers, and Seth Yonger.

Most importantly I would like to thank my wife Jolene and my boys Dalton and Gavin for their complete support throughout this extensive and very rewarding experience.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

As you visit a river or stream your intuition of that watershed is supported by visual signs of the immediate scenery and how it appears. These perceptions are evaluations of the physical habitat of that stream. One way to capture these impressions and to characterize the landscape is to use photography to permanently and consistently document these assessments, hence the rationale fueling this study.

The objective of this research was to evaluate the effectiveness and accuracy of photographic documentation of stream morphology and to provide guidance for geomorphologists, hydrologists, ecologists, and others who work with stream channel survey techniques. The intent was to provide an accurate and quantitative field method that uses photographs to determine measurements of stream channel morphology. Photographic sequences were used to document specific characteristics within stream channels, while providing statistical and comparative analyses for a permanent stream channel survey method and technique. The study examined two methods of stream channel survey (ground survey and photo documentation) and compared data from several morphological variables selected for examination. Ultimately, this research sought to determine if terrestrial photographs provided channel information comparable to traditional field methods for characterizing stream channel morphology.

Data were collected from streams with pasture and forested riparian conditions. Five open deciduous forest and five open pasture riparian areas of streams with comparable drainage areas constituted the sample database. The photographic documentation took place during the leaf-off season to increase the visibility of stream morphology. Empirical data, including wetted width, active channel-bed width, bankfull width, left and right bank height, thalweg depth, dominant habitat of cross section, and dominant bed material of cross sections recorded in association with the Coweeta Long Term Ecological Research (Coweeta LTER) project data were used to statistically compare photographic measures of stream morphology.

Scope and Objectives of the Study

The working hypothesis is that photographic documentation of streams can provide accurate and reliable measurements of channel width and other aspects of morphology. The ultimate goal is to provide a convenient and efficient procedure that uses photographs to provide accurate measurements of fluvial channels. Through a method of measurements and documentation with terrestrial photographs, this study provided geomorphic assessment of stream morphology and physical habitats (riffles, runs, pools) of fluvial environments. The general objective was to determine whether photographic documentation of stream channel morphology is a valid and accurate methodology compared to traditional stream surveying techniques. This project addressed the following research questions:

1. Will terrestrial photography be able to measure active channel bed width, wetted width, bank height, thalweg depth and position, bankfull width, and the presence of specific habitat units accurately?
2. What are the strengths and weaknesses of using terrestrial photography with respect to accuracy, scale, and time?
3. Can photography create an effective and efficient method of documentation to characterize, measure, and quantify stream channel morphology?

CHAPTER 2

LITERATURE REVIEW

Stream channel analysis has been a way for scientists to monitor and evaluate how fluvial systems change over time and space (Johnson, 1932; Leopold and Maddox, 1953; Schumm, 1973; Leopold, 1994; Fitzpatrick et al., 2002). For many years conservationists, ecologists, geomorphologists and hydrologists have used stream survey as a tool. Indeed, photography has been used to monitor natural resources and stream channels over multiple generations (Barnes, 1967; Graf, 1979; Brewer and Berrier, 1984; Trimble, 1998, 2008). Barnes (1967) was able to illustrate varying levels of the roughness of channels, Manning's n, with photographs. Many federal and state agencies have generated photographic protocols for documenting change of stream restoration projects (Crowley, 1992; Biedenharn et al., 1997; Hall, 2002; Doll et al., 2003; Gerstein and Kocher, 2005). However, apparently there has not been a photographic technique created to describe and measure stream morphology. Photography has had a long and lasting effect when comparing and contrasting temporal and spatial variations, especially in natural environments and stream channels (Barnes, 1967; Lane, 2000). Photographic documentation has, and will, continue to be a useful tool for scientist (Biedenharn et al., 1997; Gerstein and Kocher, 2005; Trimble, 2008). Repeat terrestrial photography has been used for evaluating temporal change in various geomorphic parameters (Barnes, 1967; Graf, 1979). Graf (1979) looked at historical photos to determine geomorphic changes over time and space. Trimble (1998, 2008) explored the significance that historical photographs have for dating fluvial regimes. Hall (2002) and the United States Department of Agriculture (USDA), Forest Service, published a technical report that allows users of photographic techniques to better understand the methods for evaluating and collecting photographic points of interest, particularly points that are related to stream channel change and morphology. Additionally, these guidebooks and photographic monitoring protocols are used to explore particle size, riparian buffers, and document change (repeat photography). However, despite this rich history of using photography in fluvial geomorphology there is virtually no literature on protocols and statistical evaluation of morphological data derived from terrestrial photographs. This study focuses on the cross-sectional channel form and composition of the channel bed (particle size and habitat unit).

STREAM CHANNEL MORPHOLOGY

Stream channel morphology is significantly influenced by the local geologic material of stream banks and valley walls as well as the degree of confinement of valley walls (Montgomery and Buffington, 1993). The channel confinement can be expressed as a ratio between the width of the valley floor and width of the bankfull channel. As noted above, channel morphology has a direct correlation to local conditions of the geomorphic setting, along with the variability of downstream hydraulic parameters (Montgomery and Buffington, 1993). Some of these channel hydraulic variables will be the basis for the photographic and traditional surveying methods used. Thus they will be given more attention and analysis in upcoming sections.

In order to evaluate stream channel morphology one must be able to distinguish the three elements of channel form discussed by Charlton (2008), including planform, longitudinal profile, and cross-section. The planform of a channel is the map view depicting the pattern, whether meandering or straight, of the stream channel. The longitudinal profile is the channel slope that describes the gradient of the channel. The cross section pertains to a topographical transect perpendicular to the stream channel from one bank to the other.

STREAM CHANNEL SURVEYING TECHNIQUES

Literature concerned with channel parameters illustrates proper procedures for field methods and techniques within fluvial systems (Fitzpatrick et al., 1998; Kaufman et al., 1999, 1994; Harrelson et al., 1994). Also this research displays how other geomorphologists (Barnes, 1967; Graf, 1979; Trimble, 2008) have used ground photographs to analyze and characterize channel physical habitats of streams.

By using prescribed stream survey techniques one can accurately document major features of the stream channel (Platts et al., 1987; Harrelson et al., 1994; Fitzpatrick et al., 1998; Hardy et al., 2005). Some of the major features observed are the bankfull dimensions. For example, floodplain surfaces, the top of point-bars, changes in vegetation, and bank materials are all relevant signs of bankfull stage (Harrelson et al., 1994; Fitzpatrick et al., 1998). According to Fitzpatrick et al., (1998) and Harrelson et al., (1994) these common signs are relatively easy to measure in the field. There are many hydrologic variations discussed in the literature involving the application of bankfull indicators. One of the most popular techniques was presented by Dunne and Leopold (1978) when they looked at bankfull discharge as it relates to drainage area. They found average values of bankfull channel dimensions have direct correlation to drainage areas. Within the study area for this project Leigh (2010) developed hydraulic geometry relations for streams in western North Carolina. Another important criterion when surveying a stream channel is to incorporate the measurement of bank characteristics into the sampling design. Bank stability or instability can indicate valuable information about the stream in terms of its water quality and health. Kaufman et al, (1999; 2006) displays in detail, how to properly conduct measurements of channel banks by providing a detailed explanation of banks as they relate to bankfull flows and dimensions. Kaufman et al, (1999; 2006) gives excellent examples of the different types of bank angles under the different types of bank conditions (incised, undercut, or overhanging banks).

TERRESTRIAL PHOTOGRAPHY

For multiple decades, photographic documentation has been used to capture physical features in and around stream channels, including the riparian buffer (Barnes, 1967; Graf, 1979; Rhoads, 2003; Trimble, 2008), canopy, and for characterizing channel change (Lawler, 1993). Site reconnaissance is another area that lends itself to photographic assessment (Hall, 2002; Shaff et al., 2007). Ground based terrestrial photographs are particularly useful when assessing and monitoring changes in channel geometry change (Rhoads, 2003). According to Trimble (2008), ground based photography offers more accurate scale and measurements than aerial photography. This is also suggested by Graf (1979) who claims that repeat photography from the same point will provide much geomorphic information. Ground terrestrial photographs also play an important role as a long lasting record for geomorphologists, river scientists, and stream enthusiasts to learn from.

STREAM RESTORATION AND RECOVERY

Natural channel design and stream restoration professionals rely on photography and its ability to illustrate change over extended periods of time (Biedenharn et al., 1997; Doll et al., 2003; Gerstein and Kocher, 2005). Proper photo documentation of stream channels has allowed river restoration experts to make critical evaluations on stream bank erosion rates (Doll et al., 2003).

STREAM HABITAT MONITORING

Physical habitat unit classification can be a practical geomorphic instrument for describing a stream hierarchical system. Leopold et al. (1964) states that streams maintain unbroken flowing water that are separated naturally into diverse habitat units, for instance, pools, riffles, and runs with fluctuating depths, substrate, and velocities. Developing such monitoring techniques for better understanding of stream conditions is very important to geomorphologists and river scientists (Poole et al., 1997). This can be seen through the numerous strategies and procedures in place for field measurements of physical habitat (Harrelson et al., 1994; Fitzpatrick et al., 1998; Kaufman et al., 1999; 2000).

CHAPTER 3

METHODOLOGY

The methods applied in this study can be classified into data collection, data analysis, and statistical analysis. A sampling structure of surveyed data was established for these streams in association with the Coweeta Long-Term Ecological Research (Coweeta LTER) project. This project developed a sampling strategy with sixteen cross-sections spaced at intervals of two times the wetted channel width (Price and Leigh, 2006) over a channel reach that is 30 times as long as it is wide (surveyed reach of 30 times the average channel bed width). Surveys incorporate specific cross-sectional and morphological data (bankfull height, active channel width, bankfull width, wetted width, thalweg position and depth, habitat of cross-section, and dominant particle size of bed material in the cross-section). This sampling strategy and existing data (Leigh and Jackson, personal communication) provide the raw data used to compare against measurements taken from stream channel photographs in the exact localities. From an applied geomorphic standpoint, this study is a fundamental step in developing photographic stream channel survey techniques.

STUDY AREA

Nine tributaries to the upper Little Tennessee River near Franklin, NC provide the field sites for the comparative analysis of photographic versus traditional methods of cross-sectional stream survey (Figure 1). These include ten stream reaches that have been surveyed by traditional field methods as part of the Coweeta Long Term Ecological Research (LTER) program (Leigh, D.S. and Jackson, C.R., personal communication). Figures 2-11 provide a brief photographic snapshot of each of the ten streams surveyed, which include five in forested reaches and five in pastured reaches.

All ten streams surveyed for this project were located in Macon County, North Carolina. This particular county is found in the southwestern part of North Carolina that borders the state of Georgia. These streams all lie within the Blue Ridge Mountains which is a physiographic province of this area (Robinson et al. 1992).

DATA COLLECTION

To limit the range of streams, only streams that can be waded or are "wadable" and do not require a boat have been analyzed. Specifically, this includes wadeable streams with an active basal channel width between one and ten meters. The field data were completed by incorporating two different stream channel survey techniques, including: (1) terrestrial photography (Hall, 2002; Rhoads, 2003; Shaff and Campbell, 2007) and (2) traditional ground surveys using field methods that have been established through the United States Geological Survey (USGS) and United States Department of Agriculture (USDA) (Kaufman et al., 1999, 2006; Fitzpatrick et al., 1998; Harrelson et al., 1994) as provided by D.S. Leigh as unpublished raw data.

The research took place in two distinct vegetative covers within the upper Little Tennessee watershed, including open deciduous forest and pasture land. Five streams in each one of these riparian vegetative covers were used yielding a total of ten study sites that span the order-of- magnitude size range of one to ten meters wide. There were a total of 18 photo-point set-ups within the designated 30x sample reach (Figure 12) for each of the ten streams surveyed. Photos were taken both upstream and downstream at each point, except for the endpoints of the reach (-2x upstream only and 32x downstream only). Empirical data from earlier field cross-sectional surveys have been obtained through the use of the LTER project and have been approved for use in this master's research (D.S. Leigh and C.R. Jackson, personal communication).

Time Analysis of photographic survey method:

The time investment for this photographic survey method is not much different than the time involved with traditional stream channel survey techniques. It all depends on the research objectives and overall intent of the study. Each study will have variation in the morphological variables needed for survey based off of these research goals.

This particular study looked at eight different stream parameters (wetted width, active channel bed width, bankfull width, photo-test measurement scale bars, thalweg depth and position, and left and right bank height) as well as dominant bed material and physical habitat. When the study was completed, the log sheets were calculated for both traditional and photographic survey results of the amount of time it took to conduct the assessment. The photographic method averaged less than 3 hours per stream reach whereas the traditional method averaged approximately 3.5 hours per stream reach. This includes the set-up for and documentation of each cross-section photograph in the upstream and downstream direction (realistically, only one direction of photographic analysis is needed). As one can see, this method of terrestrial photography for stream channel survey can provide timely support and accurate measurements of stream channel morphology. This technique benefits river scientists with the permanent record and its use for repeat measurement. It also allows professionally licensed scientists to investigate areas that they may not have had an opportunity to research for better understanding of the geomorphic pattern to that particular landscape.

Figure 13 depicts the photo test-measurement scale bars. The photo test-measurement scale bars provide a reliable correction factor for photographic error that should be applied to morphological variables photographically measured prior to a study. These correction values are essential when comparing traditional techniques of stream channel survey to photographic methodologies, such as this study. The 0.5 meter horizontal scale bar illustrated (Figure 13) was used for photographic data analysis and depiction. The horizontal photo test-measurement scale bar provided accurate accounts to each photographic cross-section surveyed. Essentially the horizontal 0.5 meter bar supplied the scale to establish the exact parameters for all variables being calculated.

The following variables were measured from photographs at each transect spaced at 2x where the Coweeta LTER project had previously recorded the same measurements by tape measure surveys and visual observation. A brief description of each morphological variable measured is documented below as sketched in Figures 14 (width), 15 (height/depth), 16 (physical habitat), and 17 (particle size).

Wetted Width: The distance across the stream that is submerged by water on the day of survey.

Bankfull Width: The maximum width the stream attains before it achieves the level of the active geomorphic floodplain. This morphological feature is often marked by a change in vegetation and/or topography.

Active Channel Bed Width: The horizontal measurement of the active channel bed, which is the most accurate of all width variables. It corresponds to the channel bed material that is actively mobile and totally lacks vegetation.

Photo Test-Measurement Scale Bars: A measurement taken from top of left bank scale bars to the top of right bank scale bars that provide accuracy and error analysis for terrestrial photographs.

Thalweg Depth: The deepest portion of the channel bed measured across the stream.

Thalweg Position: The location of the thalweg measured as a percentage of active channel bed width from the left bank toward right bank as the water is flowing downstream.

Left Bank Height: The vertical height of the left bank measured between the highest point and the base of the left bank water surface.

Right Bank Height: The vertical height of the right bank measured between the highest point and the base of the right bank water surface.

Dominant Physical Habitat of Cross-Section: The physical habitat is a classification system of pools, runs, glides, riffles, rapids, cascades, and steps (Kaufmann, 1999) that is determined by the dominant habitat of a cross-section (Figure 16). These classes were reduced to three classes of runs (glides and runs), riffles (riffles, steps, cascades and, rapids) and pools for the purpose of this study.

Dominant Bed Material of Cross-Section: Is the dominant particle size class of a measured cross-section that consists of the classes of boulders (>256mm), cobbles (64mm-256mm), gravels (2mm-64mm), and sands (<2mm) (Figure 16).

Photographic Methodology

A total of 18 camera set-up points were located at spacings of two-times the channel bed width to thoroughly document the 30x reach of stream (Figure 12). At each photo site, two one meter scale bars were placed at the left and right bank of each cross section, including two cross-sections downstream and two cross-sections upstream, along with a T-shaped one-half meter wide by one meter tall scale bar placed in the thalweg of each cross-section (two cross-sections downstream and two cross-sections upstream), for a total of twelve scales in each photo. The first photo point set-up is at the negative -2x cross-section transect only shooting upstream and then on every 2x transect up to the thirty-second (32x) cross-section (32x only shooting downstream) (Figure 12). There was a sequence of one photograph taken at each of the even cross-sectional photo points, always beginning upstream. The camera was then rotated to face downstream to collect the other photograph in the sequence. In addition, one photograph was taken from the left or the right bank to capture the physical habitat and dominant bed material for each cross-section. Also, a photo log data sheet (Table 1) was completed at each of the photo set up points. The exact distance between the tops of the two bank scale bars (calibration scale bars) was measured in the field to precisely evaluate the accuracy of width measurements wider than the 1 m scale bars. The variables measured were based on calibrations with the one meter scale bars created for this study. The camera height was set as a function of width of the channel (Table 2) so that progressively wider channels have higher camera heights in accord with higher banks. The focal length of the digital camera lens was held constant at 18mm, regardless of the distance between cross sections. At each one of the photo points a global positioning system (GPS) reference point was obtained to ensure the location is permanently documented and referenced for future relocation.

Each of the scale bars have been divided at ten centimeter (10 cm) intervals using black tape to accurately calibrate measurements in the photograph. The thalweg scale was T-shaped to help determine horizontal scale and measurements of water depth. A photo board was placed at every cross section to capture crucial information on stream location (left bank/right bank, cross-section number, etc.). This ensured the accuracy for ground photographs and for the filing of the photographic records. A Canon Rebel EOS digital camera was mounted on a standard camera tripod with a bubble-level built-in for consistency of set-up. Once the tripod was properly leveled and the camera was prepared for shooting, then the documentation of ground photography began in series with the steps discussed earlier.

The terrestrial photographs gathered for this project were corrected for lens distortion by the PT Lens™ program. These photographs have been archived and can be accessed through the Coweeta Long-Term Ecological Research program website.

Physical Habitat

A hierarchical system was designed to identify and classify three distinct physical habitats for determining the dominant form of terrestrial photographs at cross-sections. These three habitats represent a generalization of more elaborate classification schemes to facilitate recognition of habitats on the photos. These three geomorphic units are briefly describe below and will be discussed throughout the results and discussion. The table will integrate certain categories of classification(rapids, glides, steps, cascades) identified from the Coweeta LTER program into the three basic classes provided below for comparison (Figure 16).

Riffle: An area of the stream where the water breaks over cobbles, boulders and gravel or where the water surface is visibly broken (includes riffles, rapids, and cascades from Kaufman, 1999).

Run: Runs refer to an area where the water is flowing more gently than riffles and are generally located downstream from riffles (includes runs and glides from Kaufman, 1999).

Pool: An area of the stream that has greater depths and slower currents than riffles and runs (same as Kaufman, 1999).

Bed Material (Particle Size)

Terrestrial photographs were obtained at each of the sixteen cross-sections to help define the dominant bed material for each stream surveyed. A classification table was developed to compare the dominant particle size at each cross-section photographed against the visual observation. The table identified the dominant particle size (boulder, cobble, gravel, or sand) of that particular cross-section (Figure 12 and Figure 17) from photographs and compared results against data gathered from the Coweeta LTER program (D.S. Leigh and C.R. Jackson, personal communication).

Examination and Comparison of Field and Photographic Data

An arbitrary spacing of two times the channel width standardizes the geometric relationships with the photographs focusing on the stream channel. Every ground photograph taken was corrected using PT Lens Software™, which corrects lens distortion and error in the photograph. Once the distortion was corrected, measurements from the ground photographs were gathered for a comparative statistical analysis. Each of the eight morphological variables (calibration of scale bars, wetted width, active channel bed width, bankfull width, thalweg position, thalweg depth, right bank height, and left bank height) was measured by incorporating the corrected photograph into ArcGIS 9.3™ (Table 3). This method also was used for evaluating the accuracy between physical habitat (pool, riffle, and run) as well as determining dominant bed material (boulder, cobble, gravel, and sand). An equation was created for the measuring tool device (ArcMap) that precisely evaluated the morphological parameters based off of the number of pixels generated from the picture and scaled to the one-half meter calibration scale bar. The various scales in the photograph and the actual measured distance between the bank scales were used to evaluate accuracy and effectiveness of the terrestrial photograph measurements. Stream channel measurement error is always an issue when monitoring rivers. An error estimation term was created for the comparison of terrestrial photographs (upstream and downstream photos), as well as the traditional survey measurements (data collected from the Coweeta LTER project). When evaluating the data from upstream photographs against downstream measurements, I used a percentage difference equation to estimate the difference then compare it to the measurement error analysis. The equation is as follows:

Equation 1: Percentage Difference = (upstream measurement-downstream measurement)/ ((upstream +downstream)/2)*100

The equation for percentage error which is the difference between the upstream or downstream measurement when compared to the actual value is:

Equation 2: Percentage Error = ((upstream or downstream measurement -actual measurement)/ actual measurement)*100

Both of these difference values provide justification for error analysis and assist with the findings.

A geomorphic protocol was created for the collection of cross sectional data and physical habitats for the Coweeta LTER project (D.S. Leigh and C.R. Jackson, personal communication). Information collected from the nine variables selected above was utilized in a comparative statistical analysis. These data were compared by using t-tests to compare the mean values obtained from the photographs with the mean values obtained by previous field observations within each 30x reach of 16 transect observations. Linear regression was incorporated to compare all of the measured cross-sections (30) from the 10 sites to determine if any stream size bias existed in the one-to-one comparison between photographic and field observations.

STATISTICAL ANALYSIS

Basic summary statistics along with matched paired t-tests of the data were computed using in Microsoft Excel 2007®. Parametric tests were conducted on the five pasture and five forested reaches to determine if there were any significant differences between the upstream/downstream measurements, upstream/actual measurements, and the downstream/actual measurements. Descriptive summary statistics also provide the mean, standard deviation, and the range (Burt et al., 2009) of all eight variables measured within the ten stream reaches. A Mann-Whitney test was conducted to verify the difference of means in samples that did not pass normality tests. The parametric test for statistical comparison of means was the paired sample t-tests. A paired t-test was determined applicable because only two variables were considered (upstream/downstream, upstream/actual, downstream/actual) at each sample location and this is considered the classic normality test for statistical null hypothesis testing. Because paired t-tests value the difference between each variable measured, the larger the difference, the more unequal are the outcomes. All samples will have statistical analysis of one to one (photograph of upstream and downstream vs. traditional (actual) measurements). Ten streams and 16 cross-sectional reaches will provide a net sample size of 32 per reach or stream. Further analysis was conducted on the stream morphological measurements for traditional and the ground terrestrial photograph methods (Lawler, 1993; Hall et al., 2009). The results were then placed into tables for comparative analysis. The data collected also looked at range and variance of forest and pasture sums over the stream reach. This information proved to be helpful in the determination and final outcomes of the functionality and usefulness of ground terrestrial photography for stream channel measurements and survey method capabilities. All statistical tests used a threshold of $p < 0.05$, to define statistical significance. The null hypothesis can be defined as describing a case in which *"the variances of two data are equal."* If the t value is smaller than the t *crit* and a p value is greater than the level of significance, then we fail to reject the null hypothesis. Therefore, the t-ratio indicates that the newly estimated (photographic) values are similar to the actual (traditional survey) values. Otherwise, we reject the null hypothesis by saying that there is a significant inconsistency between their variances. During this research, I tested to see if the estimated values of photographic measurements of stream channel data differ significantly from the actual values of traditional surveying data. All statistical analyses were performed using Microsoft Excel 2007® data analysis package.

CHAPTER 4

RESULTS

Five forested streams and five pastured streams were identified for measurement. These ten streams range from 1 to 7 meters wide. Quantifying differences of width and height variables proved significant (Table 4 thru Table 11). Data collection and analysis of terrestrial photographs took place in the upstream and downstream direction of channel flow, as well as the cross-section banks to provide information and analysis for determining the dominant physical habitat (Table 12) and particle size (Table 13).

The physical distinction between forest and pasture vegetated sites are obvious from the ten streams surveyed. Forest streams and pastured streams both had their strengths and weaknesses dealing with factors of vegetation, operator and observation error, and topography when using the photographic methodology.

Before proceeding with statistical results, the ten streams identified (5 forest and 5 pasture) were examined by the traditional survey techniques discussed earlier. Paired sample t-tests were then performed to confirm the differences between the upstream photographic measurement, downstream photographic measurement, and the actual (traditional) measurement on all ten surveyed stream reaches and the eight morphological variables (Table 4 thru Table 11) Additionally dominant physical habitat and bed material were analyzed from photographs and compared to the data collected from visual observation surveys of the ten stream reaches. Paired sample t-tests for all ten streams demonstrated significant accuracy and precision from the terrestrial photographic technique. Moreover, a numerical correction factor was identified from the average difference of all measurements (upstream vs. downstream, upstream vs. actual, and downstream vs. actual) taken from the calibration scale bars. This correction factor could be applied to the other morphological variables measured however, in this study we choose not to use the numerical factor. Another note of interest is the positive and negative signs of the statistical results, which determine the positive or negative direction of the error.

Width Measurements

Morphological parameters of stream channel width (calibration scale bar width, bankfull width, active channel bed width, and wetted width) have been evaluated to determine the variability of difference between terrestrial photographic measurements and traditional stream survey computations (Table 4- Table 7 and Table 14). A categorical summary of how each variable (photographically) matched up to actual data acquired through the Coweeta Long Term Ecological Research stream survey team.

Photo test-Measurement Scale Bars

The photo test-measurement scale bars provide modest variability when comparing the photographic measurements involving the upstream and downstream views (Table 4). The average difference of means and average difference of percentage between means for this upstream and downstream measurement is 0.1 meters ; 3.4% (forest) and 0 .2 meters; 4.3% (pasture) respectively. Also the calibration bars demonstrate a numerical correction factor that can be practical when estimating the other variables of measurement within the forested and pastured streams using either the average difference between means or the average difference of percentage between means (upstream vs. actual (forest) 0.2 meters; 3.4% / (pasture) 0.6 meters; 8.9% and downstream vs. actual (forest) 0.3 meters; 7.3% / (pasture) 0.4 meters; 8%). These correction factors although not applied to this study will be referenced often throughout the results and discussion sections of this project. Additionally, the calibration scale bars illustrate the smallest amount of inconsistency when compared to other aspects of width, regardless of measuring pastured or forested reaches (Table 4- Table 7). When comparing the mean values from Table 4, one can see a systematic trend of under estimating the actual value measured. This pattern is consistent with the *p* value, *t* statistic, and the percentage of difference between the means.

Wetted Width

When examining wetted width measurements from pastured and forested reaches, there was a significant dissimilarity. The forested reaches validate a systematic deviation in average width of the reaches, meaning that as the surveyed streams widen the underestimation of measurements become more consistent, although this does not apply to the measurements among the upstream and downstream comparisons, which hypothetically, should be more reliable. Whereas pastured stream reaches also provide quality measurement amongst the smaller streams, they display a tendency of dissimilarity as reaches become wider (Table 5). There are only two forested reaches that overestimate the difference from terrestrial photographs when compared to actual field measurements. All other measurements of wetted width (photographically) underestimate the actual wetted width of these streams surveyed. The test statistic (*t)* also displays a significance of underestimation when measuring wetted width on most of the forested streams.

The forested reaches had a range of difference from 0.9% (upstream vs. downstream measurement) to 47.2% (down vs. actual measurement) however despite the large diversity, the majority of comparisons remained under 23% difference of means. The pastured reaches range of error was from 0% (upstream vs. downstream measurement) to 20.8% (downstream vs. actual measurement) maintaining more consistency from comparative analysis. Overall wetted width in the pasture reaches had a better range of difference in percentage by more than 10% (Table 5).

However, the 47.2% error from the Jones Creek site may be an observational error, which deserves re-analysis.

Active Channel Bed Width

The majority of reaches surveyed whether pasture or forest, again, exhibit consistent measurement analysis when evaluating upstream and downstream terrestrial photographs with an average difference of 0.1 meters and an average percentage difference of means of 4.6%. With the exception of one forested and one pastured stream reach the variability is consistent with that of the measurement factor identified from the calibration scale bars. Pastured reaches offer added reliability to the measurements involving upstream and downstream (average difference of 0.1 meters and a 3.6% average percentage difference) compared to the actual dimensions captured from the Coweeta survey (average difference of 0.7 meters and an n average percentage difference of 15.7%). One thing to take into consideration is that, in all of the comparisons (upstream or downstream) in opposition to traditional measurements the photographic method continuously underestimates the actual measurement of active channel bed width (Table 6) when compared to the calibration scale bars. Even though there is a consistent trend of underestimation from the photo measurement taken place it is only off by an average difference of 0.1 meters and 4% average percentage of difference (Table 6).

Bankfull Width

This morphological variable has the one of the highest percentages of inconsistency from all width variables surveyed. Pastured Streams give the impression that there is more unpredictability between terrestrial photographs and actual stream measurements taken (Table 7) with an average difference of .9 meters and an average percentage difference of 19.1%. This unpredictability is extremely obvious in larger pastured streams that are consistently underestimating bankfull width, on the order of 10% to 12%. Even though, smaller pastured streams manage to provide adequate review of comparisons maintaining an average difference of less than10%. Forested streams are more dependable in their calculations of bankfull width as seen through the *t* test and *p* values which are less statistically significant than the pasture reaches. However, there seems to be a logical variability as the stream reaches enlarge, with the highest disparity within the Ball 3 watershed, which, maintains the highest difference of percentage from the means (upstream vs. actual -42.8% and downstream vs. actual -47.9%) in all of surveyed streams. Additionally forested reaches show a consistent behavior in underestimating the photographic measurements of bankfull width on the average of 0.7 meters or 16% average difference of percentage within wider streams surveyed (Table 7).

Height and Depth Measurements

A comprehensive list of height and depth variables for stream channel morphology was compiled to compare and determine if terrestrial photography is an applicable approach to quantifying stream morphology (Table 8 thru Table 11 and Table 14). The overall differences of height and depth parameters are calculated below. Thalweg depth and position provided accurate measurements for both the forested and pastured stream surveys with an average difference of less than 0.03 meters and a percentage difference on average of less than 8% for all observations. These comparisons are below the stated numerical factor identified from the correction bars. Left and right bank height provided trends for both pastured and forested watersheds, showing that as the stream size increases, the terrestrial photographic measurements provided less accuracy than traditional measurements of right and left bank height (Figures 19-20). Also, the variability of scale bars, when aspects of height or depth are concerned, can become a concern. This is particularly true for the measurements of right and left bank heights.

Thalweg Depth

Thalweg depth provided accurate results for both the forested and pastured stream surveys (Table 8) when compared to the numerical factor identified from the calibration scale bars. The largest difference in either of the vegetative stream sites surveyed ranged from 0% to 16.7%, which equals 0.2 meters of accuracy overall (Table 8). Forest streams consistently overestimate differences in photographic measurements compared with actual calculations, with the exception of one stream survey, which sustained no variation. Also, this trend of overestimation can be observed while comparing results of pastured streams to include the upstream and downstream photographic measurements that maintained an average difference of less than 0.03 meters or average percentage difference of 3.3%. Thalweg depth maintained a consistent average difference of less than 0.1 meters and less than 5% average percentage difference for all ten of the streams surveyed. There was a very similar result when analyzing the difference between measured data and actual data for both forest and pasture reaches. The forest streams averaged .05 meters of difference while the pastured reaches managed 0.04 meters of difference (Table 10). This trend for Thalweg Depth can also be seen in Figure 19 and 20 across all streams surveyed.

Thalweg Position

Thalweg position displayed good statistical summaries from the paired t-tests performed. When comparing the data from pastured and forested streams the thalweg position variable was very similar overall with an average difference of 0.04 meters and an average percentage difference of 3% (upstream vs. downstream measurement). These differences were all less than 4.5% or 0.04 meters for all forested stream surveyed and 5.6% or 0.06 m for all pastured streams (Table 9). Forested streams were more reliable at determining upstream than downstream measurements with an average difference of less than 3% (Table 9). Forested streams also demonstrated a consistent overestimation of measurements from small to large stream reaches with the exception of two of the stream reaches that both underestimated calculations. The range of error for forest reaches was from less than 1% to 11% with only one of the observations higher than 8%. Pasture reaches ranged from 0% to 18% and had three observations over 10% of the percentage of difference.

Left Bank Height

This was the most inconsistent of all height variables regardless of whether or not measurements were from forested or pastured stream data (Table 8-Table 11). Albeit, upstream compared to downstream measurement calculated less than 10% or 0.10 meters for all ten streams surveyed. Both the forest and pastured reaches illustrate a systematic variability as streams increase in channel width. This is illustrated in Figures 19 and 20. The measured data of upstream vs. downstream remained consistent with the calibration numerical factor of.1 meter average difference for both forest and pasture reaches. Also, both streams display a pattern underestimating photographic measurements when compared to actual survey data (Table 10). One thing to capture from the left bank height is the distinct inconsistency with the larger streams of both forested and pastured reaches (40% or 0.43 meter to 53% 1.17 meters of difference). This can also be reinforced through the many statistically significant *p* values (Table 10). Although there is such a large discrepancy in error, the average difference of means for all measurements is in line with the correction factor from the calibration scale bars (Table 10).

Right Bank Height

Right bank height provides good correlation among upstream and downstream measurements for both types of stream reaches. Forested streams maintain a consistency under

0.1 meters, while pastured streams were less than 0.04 meters with the exclusion of one outlier with 41% or 0.4 meters average difference (Table 11). The range of error for forested reaches is from 5.6% to 41% with only four of the observations over 20%. Whereas pastured streams range from 2% to 76.5% and eight of the observations are over 20%. The *p* values and *t*-test correspond with the percentage of difference between means identifying statistical significance while percentage differences rise (Table 11).

Figures 22 (a)-(c) and figures 23 (a)-(c) illustrate the correlation and regression of photographic measurements when compared to field measurements for each individual variable measured. Data were synchronized from forest and pastured reaches surveyed and graphed accordingly. Because this study was trying to predict that traditional field measurements were no different than photographic measurements, the photo measurement was determined the independent variable and the field measurement was identified as the predictor. These graphs allow the reader to distinguish where the deviations are occurring in the analysis. For example, the residual values (Figure 22 (c)) suggests, that photographic measurements demonstrate bias towards forested rather than pasture reaches.

Dominant Physical Habitat: pools, riffles, and runs

A detailed comparative analysis of in-stream habitat was completed for all 16 cross-sections on each of the ten streams surveyed. A general classification was created to classify three specific types of physical stream habitat (pools, runs, and riffles). Other elaborate classifications (glides, cascades, step pools, etc.) were merged into the three general habitats, as indicated in the methods section. The percentages of habitat classification for each stream was calculated from photographs and actual observations, and then compared for results (Table 12(a)-(j)).

Pastured streams provided a slightly better estimation for determining physical habitat based off of the percentages found in the table 12 (f-j), but it may not be statistically significant. Forested streams had an average difference of 32% while pastured streams maintained a 30% average difference.

Dominant Bed Material: particle size (boulder, cobble, gravel, and sand)

Terrestrial photographs and visual observations were recorded on every cross-section (16) surveyed for all ten streams in the database. The photographs were evaluated to determine the dominant particle size of each cross-section. A primary classification scheme was created to simplify the comparative analysis between photographic results and visual recorded observations. The dominant particle of the entire cross-section (highest percentage of material) was identified as the main type (boulder, cobble, gravel, and sand). These findings were assembled and for their entire reach and then mathematical calculations were performed (Table 13 (a)-(j)).

Forested streams had an average difference of 27.5% while pastured streams averaged 36% difference. There is no systematic variation in either of the reaches when comparing the data, generally only off by one size-class.

CHAPTER 5

DISCUSSION

The measurement of a mixture of physical variables in stream channels from terrestrial photography can be used to define the physical stream conditions of a particular geographical region. If these measurements are used as scientific findings then fluvial geomorphologists can identify and accurately measure channel pattern, dimension, and shape that result from terrestrial photographs. By measuring the morphological variables identified by many federal agencies for this study (Harrelson et al., 1994; Fitzpatrick et al.; 1998; Kaufman et al., 1999; Hall, 2002; Peck et al., 2006), streams can be photographed and measured with accuracy.

Morphological Stream Measurements of Width

Of the four width measurements used to delineate channel morphology (calibration scale bar, active channel bed width, bankfull width, and wetted width), the calibration scale bars is the most important for determining accuracy for this technique of calculating stream channel parameters with terrestrial photography. This error was calculated and used as a correction factor to assess other morphological parameters of the study. The upstream vs. downstream measurement for the correction factor was 0.11 meters average difference between means (forested) and 3.4% average percentage difference between means (forested) and .21 meters average difference between means (pastured) and 4.3% average percentage difference between means (pastured). The upstream vs. actual correction factor for forested was .17 meters (4.7%) and pastured was .55 meters (8.9%). The downstream vs. actual correction factor for forested was .26 meters (7.3%) and pastured was .41 meters (8%). There was a noted increase in the ratio of error in scale bar width for both forested and pastured streams. As the difference in stream width increases, the percentage of error for width measurement increase with the stream size enhancement. Another important portion of this study was the positive (+) and negative (-) symbols in the statistical result tables. These signs made it possible to determine the significance of the data whether it was acceptable by applying the correction factor or if there was some other error occurring. This error was particularly noteworthy as the stream size increased through each of the ten reaches surveyed (Figures 18-21) and (Figure 22 (a)-(c) and Figure 23 (a)-(c)). The differences observed for other morphological variables of stream channel measurement also resulted in unfavorable results due to operator error, observational error, and vegetation. Perhaps if the study would have focused on using multiple observers to collect data, then the results may have been more equal. A medium size (3.4m average stream width) forested stream, provided accurate results when comparing the wetted width and active channel bed width (Figure 18). While the smallest of the pastured streams (1.1m average stream width), also displayed accuracy between wetted width and bankfull width comparisons (Figure 19). According to Fitzpatrick et al, (1998) bankfull width is independent from other stream width measurements and can help successfully identify channel profile, form and shape. Simon and Hupp (1992) state, that bankfull width and others cross-sectional measurements are critical for determining channel widening and stream incision. Additionally, terrestrial photography can provide measurements as well as long term documentation for repeat measurements.

One of the main observations among width measurements was the consistent underestimation of upstream and downstream photographic measurements. This examination of underestimate can result from the interference with vegetation or some technical error in the photo analysis. It is important to note that I was not a part of the Coweeta project data collection and there might have been some discrepancy of identifying morphological features. For example, bankfull width, wetted width, and bank heights although distinguishable, can be difficult to agree on by different observers. Despite these differences in measurements, this is a reliable technique that will need to provide viable corrections for the future.

Morphological Stream Measurements of Height

Thalweg depth and position provided very accurate measurements for forested and pastured stream surveys and one potential explanation is that the format shape of the photograph displays greater levels of accuracy when comparing height to width proportions. This is due to the geometry of the picture frame ratio (Langford, 2000). Left and right bank height proved statistically significant for both pastured and forested watersheds, showing that as the stream size increases, the terrestrial photographic measurements provided less accuracy than traditional measurements of right and left bank height (Table 14). The difference in values for left bank and right bank height can be attributed to many possibilities, including riparian vegetation and observer error. Stream banks are critical to the shape and flow of water through a river. Platts et al. (1987) suggest that the stream banks are a major control to lateral movement of the water and that the degree of stream bank stability is managed by the riparian vegetation. In addition, Gernstein and Kocher (2005) recommend implementing a photographic documentation for stream bank stability to capture changes of the stream for future research. This is in line with Trimble's (2008) description for using historical data and photographic artifacts as powerful tools to document and date fluvial change over time and space.

Identifying Dominant Bed Material

The ability to estimate and accurately identify bed material by particle size was possibly the most effective use of the technique for terrestrial photography. One of the proposed hypotheses of the study was to determine if terrestrial photography could accurately measure dominant bed material of a channel bed. The results did validate the hypotheses and the methodology did provide adequate evidence confirming the research objectives. Lane (2000) argues that fluvial geomorphologists have disregarded photographic methods to measure stream morphology due to the other popular methods of stream sampling and survey, despite the long term documentation that photographs can provide. Wolman and Miller (1960) suggest that flow and magnitude of the streams can also provide good awareness to type and scale of bed material. Also, Wolman (1954) recommends that in order to categorize particle size properly, a regular scheme for monitoring is essential. This was achieved by the consistent cross-sectional terrestrial photographs taken throughout the ten streams surveyed and measured.

Determining Physical Habitat Classification

Categorizing physical habitat for the ten streams (5 forested/5 pastured) surveyed included a primary classification system of pools, riffles, and runs. Kondolph (1995) recommends classification systems variables be measured and inventoried with quantity arranged into various categories. By limiting the bed structures of this study into three distinct categories (Figure 15) the amount of error is restricted. In addition, Montgomery and MacDonald (2002) state that there is a desire to simplify physical habitat classification, with the purpose of a timely evaluation for stream channel monitoring. There is a noted concern for identifying physical habitat at the cross-sections of this study. Although, the observer must display relevance to the geographical region of research.

Advantages and Disadvantages of Terrestrial Photography

One of the primary advantages of using terrestrial photography for measuring stream channel morphology is the repeatability that photographic documentation provides. The ability to review the photograph repeatedly without having to go into the field for additional observation measurements plays an important part in a photographic techniques ability to evaluate the data more than once . Hall (2002) suggests that having a photo point monitoring system in place ensures the measurement of change over time. This is in line with Schumm and Lichty's (1965) analysis of independent and dependent morphological variables with respect to time and scale. Furthermore, Shaff et al, (2007) claims that repeat photography allows for specific changes in the channel profile to be monitored. In addition, the terrestrial photographs can be measured at multiple points throughout the stream to verify accuracy. Terrestrial photography also allows a way to analyze and pose supplementary questions without going back into the field for measurement.

Although the results of this study signify an obvious dissimilarity between the photographic morphological variables surveyed and the measurements used from the traditional method with regards to pastured and forested streams, it is possible that the error observed is due to operator and observation error. Even though, many of these values underestimated are reasonable when the correction factor established from the calibration scale bars is considered. An advantage that the photographic technique has is the ability to conduct multiple measurements from the same cross-sectional area and run statistical tests for computation without having to re-collect data. However, if the amounts of error found in this study are not acceptable, then the photographic technique obviously needs improvements.

Some of the recommendations to better the technique of terrestrial photography for the measurement of stream channel morphology are identified below;

1. Use either the upstream or downstream photographs to compare against traditional measurements (not both).

2. Obtain only one photograph per cross-section. This will lessen the time pertaining to the survey technique while in the field.

3. Continue to refine a measurement error and apply it to the study criterion prior to evaluating results.

4. Identify the possible operator errors (i.e. recognizing bankfull width, bank heights, and active channel bed width).

5. Use a horizontal scale bar for calibration that is similar to the actual stream width being measured. That is, better results may have been obtained in this study if a 2m horizontal scale bar had been used for calibration.

CHAPTER 6

CONCLUSIONS

The scope and objective of this project ultimately was to develop a photographic technique and methodology for measuring and surveying stream channel morphology with validity and accuracy. The study revealed important information on the use of terrestrial photography for fluvial geomorphic research. Photography provided reasonably accurate and measurable outcomes of stream channel morphology. Therefore, it may be of significant interest to fluvial geomorphologists to practice and enhance the technique. Identifying the dominant physical habitat as well as the dominant bed material of a cross-section proved to be as useful as width and height measurements.

The working hypothesis was that terrestrial photography is a valid approach to measuring stream channels when compared to traditional survey techniques (Platts et al., 1987; Harrelson et al., 1994; Fitzpatrick et al., 1998; Kaufman, 1999; Hardy et al., 2005). Ten streams of different vegetative cover were photographically surveyed with five streams being in forested reaches and five being in pastured reaches. At each stream 16 cross-sections were surveyed at a width of two times the active channel (Price and Leigh, 2006) over a reach that is 30 times long as it is wide. Eight morphological variables were analyzed and compared with data from the Coweeta Long Term Ecological Research project on the exact reaches and cross-sections. In addition to the eight morphological variables selected for survey (calibration scale bars, wetted width, active channel bed width, bankfull width, thalweg position and depth, and right and left bank height), this project monitored dominant physical habitat and bed material from cross-section photographs. This method of photographic stream channel survey established acceptable validity and accuracy, especially considering that observational error on the part of the field measurements by the Coweeta LTER stream survey team are unknown. Although there are problems with the techniques, they are not insurmountable and can be corrected with further research. One of the major benefits of this photographic technique is the ability to create a permanent record from the photographs. Also having the capability to re-use photographs allows scientist to make key decisions of a particular area of interest without having to plan extensive field trips.

When preparing new methods for fluvial geomorphology, one must strive to make the data collection process as objective and repeatable as possible. Although future research is needed to improve on the innovations and methodologies, using terrestrial photography to measure stream channel morphology is a valid technique that can be applied to fluvial systems.

REFERENCES

Barnes, H.H. 1967. Roughness Characteristics of Natural Channels. *United States Geological Survey*; United States Government Printing Office, Washington.

Benson, M.A., and Dalrymple, T. 1967. General Field Procedures for Indirect Discharge Measurements. *Techniques of Water-Resources Investigation of the United States Geological Survey;* Book 3, Chapter A1, Washington, DC

Biedenharn, D.S., Elliott, C.M., and Watson, C.C. 1997. The WES Stream, Investigation, and Streambank Stabilization Handbook. *U.S.Army Waterways Experiment Station (WES)*; Vicksburg, Mississippi

Burt, J.E., Barber, G.M, and Rigby, D.L. 2009. Elementary Statistics for Geographers. *The Guilford Press*; New York London

Brewer, L and Berrier, D. 1984. Photographic Techniques for Monitoring Resource Change at Backcountry Sites. *United States Department of Agriculture*; General Technical Report NE-86

Charlton, R. 2008. Fundamentals of Fluvial Geomorphology; *Routledge,* Taylor & Francis Group; London and New York

Crowley, E.R. 1992. Protocols for Classifying, Monitoring, and Evaluating Stream/Riparian Vegetation on Idaho Rangeland Streams. *Water Quality Monitoring Protocols-Report No.8*; Idaho Department of Health and Welfare

Doll, B.A., Grabow, G.L., Hall, K.R., Harman, W.A., Jennings, G.D., and Wise, D.E. 2003. Stream Restoration: A Natural Channel Design Handbook. *NC Stream Restoration Institute*. NC State University; 128 pp.

Dunne, T. and Leopold, L.B. 1978. Water in Environmental Planning; *W.H. Freeman and Company*

Fitzpatrick, F.A, Waite, I.R, D'Arconte, P.J., Meador, M.R., Maupin, M.A. and Gurtz, M.E. 1998. Revised Methods for Characterizing Stream Habitat in the National Water-Quality Assessment Program. *United States Geological Survey*; Water-Resources Investigations Report 98-4052.

Gerstein, J.M. and S.D. Kocher. 2005. *Photographic Monitoring of Salmonid Habitat Restoration Projects*. University of California, Center for Forestry, Berkeley, CA. 21 pp.

Graf, W.L. 1979. Geomorphic Measurments from Ground-Based Photographs. *In Geomorphology: Themes and Trends*. Pitty, A. (ed.), Barnes and Noble, Totowa, NJ, pp. 211-225

Hall, F.C. 2002. Photo Point Monitoring Handbook: Part A and B Field Procedures. *United States Department of Agriculture*. Forest Service, General Technical Report PNR-GTR-526, March 2002.

Hall, R.K., Watkins, R.L., Heggem, D.T., Jones, B.K., Kaufman, P.R., Moore, S.B. and Gregory, S.J. 2009. Quantifying Structural Physical Habitat Attributes using LIDAR and Hyperspectral Imagery. *Environmental Monitoring Assessment Program* (EMAP); 159: 63-83

Hardy, T., Panja, P., and Mathias D. 2005. WinXSPRO, A Channel Cross Section Analyzer, User's Manual, Version 3.0. Gen. Tech. Rep. RMRS-GTR-147. Fort Collins, CO: *United States Department of Agriculture*, Forest Service, Rocky Mountain Research Station. 94 p.

Harrelson, C.C, Rawlins, C.L and Potyondy, J.P. 1994. Stream Channel Reference Sites. *United States Department of Agriculture*; Forest Service, General Technical Report RM-245

Johnson, D. 1932. Streams and Their Significance. The Journal of Geology; Benchmark Papers In Geology*;* ed. by Stanley A. Schumm. Dowden, Hutchinson, and Ross, 1972

Kaufman, P.R, Levine, P, Robinson, E.G, Seeliger, C and Peck D.V. 1999. Quantifying Physical Habitat in Streams. *United States Environmental Protection Agency.* Environmental Monitoring and Assessment Program.

Kondolf, G. M. 1995. Geomorphological Stream Channel Classification in Aquatic Habitat Restoration: Uses and Limitations; *Aquatic Conservation: Marine and Freshwater Ecosystems*, Vol.5, 127-141

Kondolf, G. M. & H. Piėgay.2003. Tools in Fluvial Geomorphology: Problem Statement and Recent Practice. *In Tools in Fluvial Geomorphology*, 3-22. Wiley

Lane, S.N. 2000. The Measurement of River Channel Morphology Using Digital Photogrammetry. *Photogrammetric Record.* 16(96), 937-961

Lawler, D.M. 1993. The Measurement of River Bank Erosion and Lateral Channel Change: A Review. *Earth Surface Processes and Landforms*, Vol.18, 777-821

Leigh, D.S., 2010. Morphology and Channel Evolution of Small Streams in the Southern Blue Ridge Mountains of Western North Carolina. *Southeastern Geographer,* 50(4): pp.397-421

Leopold, L.B. 1994. A View of the River. *Harvard University Press*; Cambridge, Massachusetts

Leopold, L.B, and Maddock, T.Jr. 1953. The Hydraulic Geometry of Stream Channels and Some Physiographic Implications. *Geological Survey Professional Paper 252*: Significance. Benchmark Papers in Geology; ed. by Stanley A. Schumm. Dowden, Hutchinson, and Ross, 1972

Montogomery, David R. and MacDonald, L.H. 2002. Diagnostic Approach to Stream Channel Assessment and Monitoring. *American Water Resources Association,* Vol.38, No.1, FEB

Peck, D. V., A. T. Herlihy, B. H. Hill, R. M. Hughes, P. R. Kaufman, D. Klemm, J. M. Lazorchak, F. H. McCormick, S. A. Peterson, P. L. Ringold, T. MaGee & M. Cappaert. 2006. Environmental Monitoring and Assessment Program-Surface Waters Western Pilot Study: Field Operations Manual for Wadeable Streams. *United States* Environmental *Protection Agency*, Washington, D.C. EPA/620/R-06/003, 2006

Platts, W.S., Armour, C., Booth, G.D., Bryant, M., Bufford, J.L., Cuplin, P., Jensen, S., Lienkaemper, G.W., Minshall, G.W., Monsen, S.B., Nelson, R.L., Sedell, J.R., and Tuhy, J.S. 1987. Methods for Evaluating Riparian Habitats with Application to Management. *United States Department of Agriculture*. USFS, General Technical Report, INT-221

Price, K. and Leigh, D.S. 2006. Morphological and Sedimentological Responses of Streams to Human Impact in the Southern Blue Ridge Mountains, USA. *Geomorphology*. 78; pp. 142-160

Ray, G.A. and Megahan, W.F. 1979. Measuring Cross Sections Using a Sag Tape: A Generalized Procedure. *United States Department of Agriculture Forest Service*; General Technical Report INT-47, Ogden, UT

Rhoads, B.L. 2003. Protocols for Geomorphic Characterization of meander Bends in Illinois. *The Illinois Department of Natural Resources*

Schiff, R., J.G. MacBroom, and J. Armstrong Bonin, 2006, River Restoration and Fluvial Geomorphology White Paper. NHDES-R-WD-06-27.Prepared by Milone & MacBroom, Inc. For the New Hampshire Department of Environmental Services and the New Hampshire Department of Transportation, Concord, N.H.

Schumm, S.A.1971. Fluvial Geomorphology in River Mechanics. *Water Resources*; Benchmark Papers in Geology*;* ed. by Stanley A. Schumm. Dowden, Hutchinson, and Ross, 1972

Shaff, C, Reihler, J and Campbell, J. 2007*. Oregon Watershed Enhancement Board: Guide to Photo Point Monitoring.*

Simon, Andrew, and Hupp, C.R., 1992, Geomorphic and vegetative recovery processes along modified stream channels of west Tennessee: U.S. Geological Survey Open-File Report 91–502, 142 p.

Trimble, S.W. 1998. Dating Fluvial Processes from Historical Data and Artifacts. *Catena*. 31; pp. 283-304

Trimble, S.W. 2008. The Use of Historical Data and Artifacts in Geomorphology. *Progress In* Physical Geography. 32 (1), pp. 3-29

Wolman, M. G., 1954. A Method of Sampling Course River-Bed Material. *Transactions of American Geophysical Union* 35:951-956.

Wolman, M. G. and Miller, J.P. 1960. Magnitude and Frequency of Forces in Geomorphic Processes

Table 1. Example of Photo Documentation and Rapid Geomorphic Assessment Form

Photo Documentation Sheet/ RGA Form

Date/Time:11/18/2010 **Stream Name/Site: Bates 5** **Recorder: JMM (Jake the Snake)**

Cross Section Position	GPS Coordinate ofThalweg Lat/Long	GPS Error (± m)	X-Sect Angle	Active Channel Bed Width(m)	Thalweg Depth(m)	Thalweg Position (%)	Cross Section Physical Habitat	Cross Section Bed Material	Calibration Bars(m)	Photo(#) Bed and Physical Hab	LWD (1-5)
0x, 0 m	0280289 E 3886607 N	4m	166°°	1.02	0.12	50.00	Riffle	G>C>S	2.27	L 105	1
2x, 2 m	0280286 E 3886607 N	4m	167°	1.36	0.11	70.00	Riffle	G>S>C	2.49	L 108,109	1
4x, 4 m	280285 E 3886608 N	4m	170°	1.28	0.12	40.00	Riffle	S>C>G	2.07	L 116,117	1
6x, 6 m	280286 E 3886601 N	3M	173°	1.01	0.14	50.00	Riffle	G >S>C	2.11	L 122,123	1
8x, 8 m	280285 E 3886604 N	4M	148°	1.02	0.11	40.00	Riffle	S>C>G	1.57	L 128,129	1
10x, 10 m	280282 E 3886603 N	4M	162°	0.85	0.09	50.00	Riffle	C>S	1.52	L 134,135	1
12x, 12 m	280280 E 3886603 N	4M	151°	1.02	0.13	50.00	Run	S>G	1.46	L 141,142	1
14x, 14 m	280279 E 3886601 N	3M	152°	0.98	0.16	60.00	Riffle	S>G>C	1.16	L 147,148	1
16x, 16 m	280278 E 3886599 N	3M	154°	1.01	0.08	85.00	Riffle	G>S>C	1.47	L 153,154	1
18x, 18 m	280275 E 3886601 N	3M	160°	1.15	0.11	50.00	Riffle	S>G>C	1.85	L 159,160	1
20x, 20 m	280273 E 3886599 N	4M	163°	1.73	0.12	20.00	Riffle	G>S>C	1.97	L 166,167	1
22x, 22 m	280272 E 3886599N	5M	167°	1.66	0.08	50.00	Riffle	S>G>C	2.45	L 173,174	1
24x, 24 m	280269 E 3886597 N	4M	152°	1.36	0.11	60.00	Riffle	G>S>C	2.26	L 179,180	1
26x, 26 m	280268 E 3886596 N	3M	151°	1.17	0.17	80.00	Run	S>G>C	1.79	L 186,187	1
28x, 28 m	280265 E 3886594 N	4M	164°	1.01	0.16	30.00	Riffle	G>S>C	1.57	R 193,194	1
30x, 30 m	280262 E 3886592 N	4M	169°	1.45	0.1	45.00	Riffle	C>G>S	1.07	R 201,202	1

Weather Forecast: Mostly Cloudy-Mostly Sunny **Camera HT: 0.6M**

Table 2. Camera height above water surface as a function of the width of channel

Standard Camera Height

Camera HT (m):	Cross-Section Width (m)
0.5	1
0.6	2
0.7	3
0.8	4
0.9	5
1	6
1.1	7
1.2	8
1.3	9
1.4	10

Table 3. Example of Photograph conversion chart

Crawford 1	Thalweg Line Segment*	1 Meter Conversion**	Calibration Bars****	Calibration Bars Photo***	Active Channel ***	Act Chann R****	RT Bank ***	RT Bank R****	LT Bank ***	LT Bank R****	WW ***	WW R ****	Bank Full ***	BankFull ****	Thalweg Pos****	Thal Depth****
0x U	380	760	2.54	1929	1599	2.10	852	1.12	395	0.52	1600	2.11	1856	2.44	30.00	0.28
2x U	269	538	3.17	1703	1023	1.90	544	1.01	400	0.74	1023	1.90	1425	2.65	45.00	0.16
4x U	334	668	2.53	1690	1215	1.82	629	0.94	525	0.79	1059	1.59	1418	2.12	30.00	0.28
6x U	309	618	2.73	1688	1227	1.99	665	1.08	543	0.88	1144	1.85	1360	2.20	60.00	0.18
8x U	219	438	2.75	1206	940	2.15	230	0.53	358	0.82	879	2.01	1166	2.66	25.00	0.22
10x U	360	720	2.70	1944	1452	2.02	448	0.62	657	0.91	1188	1.65	1765	2.45	40.00	0.21
12x U	275	550	3.84	2112	1752	3.19	285	0.52	340	0.62	1645	2.99	1877	3.41	20.00	0.33
14x U	290	580	2.94	1708	1434	2.47	245	0.42	265	0.46	1434	2.47	1624	2.80	50.00	0.28
16x U	280	560	4.06	2272	1743	3.11	317	0.57	416	0.74	1700	3.04	1994	3.56	70.00	0.14
18x U	329	658	3.35	2205	1792	2.72	235	0.36	531	0.81	1555	2.36	1850	2.81	30.00	0.19
20x U	291	582	3.87	2251	1831	3.15	600	1.03	502	0.86	1580	2.71	1985	3.41	20.00	0.38
22x U	291	582	4.05	2356	1684	2.89	593	1.02	527	0.91	1680	2.89	1910	3.28	20.00	
24x U	270	540	3.96	2137	1934	3.58	425	0.79	401	0.74	1818	3.37	2081	3.85	40.00	0.50
26x U	273	546	2.65	1449	1143	2.09		0.00	442	0.81	1143	2.09	1323	2.42	60.00	
28x U	248	496	2.93	1452	1158	2.33	683	1.38	465	0.94	1025	2.07	1295	2.61	30.00	0.28
30x U	350	700	3.19	2234	1698	2.43	971	1.39	575	0.82	1600	2.29	1884	2.69	55.00	0.57
0x D	245	490	2.58	1265	1092	2.23	764	1.56	334	0.68	943	1.92	1154	2.36	25.00	0.29
2x D	305	610	2.98	1815	1276	2.09	855	1.40	414	0.68	1134	1.86	1377	2.26	40.00	0.18
4x D	295	590	2.63	1551	1043	1.77	752	1.27	555	0.94	967	1.64	1179	2.00	30.00	0.28
6x D	212	424	2.79	1185	800	1.89	700	1.65	397	0.94	752	1.77	897	2.12	60.00	0.18
8x D	355	710	2.47	1757	1478	2.08	541	0.76	578	0.81	1282	1.81	1506	2.12	20.00	0.21
10x D	286	572	2.75	1574	1213	2.12	279	0.49	589	1.03	1065	1.86	1303	2.28	30.00	0.24
12x D	293	586	3.83	2242	1779	3.04	386	0.66	575	0.98	1675	2.86	1920	3.28	20.00	
14x D	313	626	3.06	1916	1641	2.62	496	0.79	390	0.62	1557	2.49	1741	2.78	50.00	0.28
16x D	306	612	3.91	2393	1858	3.04	331	0.54	528	0.86	1733	2.83	1879	3.07	60.00	0.18
18x D	317	634	3.32	2106	1678	2.65	521	0.82	500	0.79	1600	2.52	1895	2.99	30.00	0.19
20x D	265	530	4.07	2156	1900	3.58	491	0.93	566	1.07	1900	3.58	2000	3.77		
22x D	304	608	4.15	2524	1945	3.20	706	1.16	653	1.07	1900	3.13	2079	3.42	25.00	0.16
24x D	299	598	3.91	2339		0.00	818	1.37	1000	1.67		0.00		0.00	35.00	0.50
26x D	342	684	2.55	1741	1500	2.19	604	0.88	581	0.85	1350	1.97	1565	2.29	60.00	0.29
28x D	320	640	2.72	1740	1387	2.17	751	1.17	750	1.17	1279	2.00	1477	2.31	30.00	0.29
30x D	465	930	3.20	2974	2000	2.15	1100	1.18	1081	1.16	1277	1.37	2400	2.58	60.00	0.58

* = measurement in GIS ArcMap using the thalweg 1/2 meter calibration t bar with measuring tool

**= thalweg line segement multiplied by two for 1 meter conversion factor

*** = line segement distance in photo

**** = converted photo measurement in meters

Table 4 Summary of Statistics for Photo Test-Measurement Scale Bars

	Actual Stream			Means of Observed		Means of Actual				
Forested Streams	Width(m)	Diff=	% of Diff	up (photo)	down	actual	t	p	N=	Average Difference of absolute means and %
A. Crawford 5	1.4									
up vs. down		-0.03	-1.53	1.76	1.78		-0.46	0.65	16	(Forested) Up VS. Down AVG DIFF= .1 meters *
up vs. actual		-0.06	-3.21	1.76		1.82	-1.04	0.32	16	(Forested) Up VS. Down AVG % DIFF= 3.4% **
down vs. actual		-0.03	-1.72		1.78	1.82	-0.64	0.53	16	
B. Skeenah 2	2.4									
up vs. down		0.20	6.98	2.95	2.75		1.31	0.21	16	
up vs. actual		-0.15	-4.72	2.95		3.10	-3.50	***0.00***	16	
down vs. actual		-0.35	-11.15		2.75	3.10	-2.34	**0.03**	16	
C. Ball 5	3.4									
up vs. down		0.07	1.60	4.29	4.22		0.80	0.43	16	
up vs. actual		-0.15	-3.40	4.29		4.44	-1.82	0.09	16	(Forested) Up VS. Actual AVG DIFF= .17 meters *
down vs. actual		-0.22	-4.94		4.22	4.44	-2.21	**0.04**	16	(Forested) Up VS. Actual AVG % DIFF= 4.8% **
D. Ball 3	4.4									
up vs. down		0.12	4.74	2.65	2.53		1.87	0.08	16	
up vs. actual		-0.22	-7.77	2.65		2.87	-4.85	***0.00***	16	
down vs. actual		-0.35	-12.05		2.53	2.87	-4.94	***0.00***	16	
E. Ball 1	6									
up vs. down		0.11	1.96	5.75	5.63		0.87	0.40	16	
up vs. actual		-0.28	-4.66	5.75		6.03	-2.10	**0.05**	16	(Forested) Down VS. Actual AVG % DIFF= 7.3% **
down vs. actual		-0.39	-6.51		5.63	6.03	-9.10	***0.00***	16	(Forested) Down VS. Actual AVG DIFF= .26 meters *
Pastured Streams										
A. Bates 5										
up vs. down	1.1	0.12	6.78	1.83	1.71		3.67	***0.00***	16	(Pastured) Up VS. Down AVG DIFF= .21 meters *
up vs. actual		-0.04	-2.14	1.83		1.87	-2.88	***0.01***	16	(Pastured) Up VS. Down AVG % DIFF= 4.3% **
down vs. actual		-0.16	-8.56		1.71	1.87	-4.25	***0.00***	16	
B. Cowee 3	2									
up vs. down		-0.04	-1.36	2.58	2.61		-1.15	0.27	15	
up vs. actual		-0.15	-5.44	2.58		2.73	-5.55	***0.00***	15	
down vs. actual		-0.11	-4.15		2.61	2.73	-3.08	***0.01***	15	
C. Crawford 1	2.8									
up vs. down		0.02	0.66	3.20	3.18		0.63	0.54	16	
up vs. actual		-0.24	-6.89	3.20		3.44	-7.18	***0.00***	16	(Pastured) Up VS. Actual AVG DIFF= .55 meters *
down vs. actual		-0.26	-7.51		3.18	3.44	-8.14	***0.00***	16	(Pastured) Up VS. Actual AVG % DIFF= 8.9% **
D. Caler 1	5.3									
up vs. down		-0.07	-1.48	4.99	5.06		-0.90	0.38	16	
up vs. actual		-0.32	-5.95	4.99		5.30	-5.96	***0.00***	16	
down vs. actual		-0.24	-4.55		5.06	5.30	-2.87	***0.01***	16	
E. Jones 1	7									
up vs. down		-0.76	-11.21	6.40	7.16		-1.14	0.27	15	
up vs. actual		-2.04	-24.20	6.40		8.44	-3.55	***0.00***	15	(Pastured) Down VS. Actual AVG % DIFF= 8% **
down vs. actual		-1.28	-15.20		7.16	8.44	-3.97	***0.00***	15	(Pastured) Down VS. Actual AVG DIFF= .41 *

Italicized and Bold p = .00 -.01 % of Diff= the percentage difference between mean values

Bold p = .02 - .05 p= p value down= downstream photographic measurement

up= upstream photographic measurement t= test statistic actual= traditional stream survey measurement

diff= the difference between mean1 and mean 2

* = the absolute average of the difference between means in all the reaches (forest and pasture)

** = the absolute average percentage of difference of mean values in a category (forest or pasture)

Table 5 Summary of Statistics for Wetted Width

	Actual Stream			Means of Observed		Means of Actual				
Forested Streams	Width(m)	Diff=	% of Diff	up (photo)	down	actual	t	p	N=	Average Difference of absolute means and %
A. Crawford 5	1.4									
up vs. down		0.03	3.12	1.07	1.04		0.70	0.49	16	(Forested) Up VS. Down AVG DIFF= .16 meters *
up vs. actual		-0.30	-21.98	1.07		1.38	-7.35	***0.00***	16	(Forested) Up VS. Down AVG % DIFF= 8.9% **
down vs. actual		-0.34	-24.38		1.04	1.38	-5.54	***0.00***	16	
B. Skeenah 2	2.4									
up vs. down		-0.28	-16.11	1.60	1.88		-1.38	0.19	16	
up vs. actual		0.09	6.06	1.60		1.51	0.46	0.65	16	
down vs. actual		0.37	24.64		1.88	1.51	2.84	***0.01***	16	
C. Ball 5	3.4									
up vs. down		-0.14	-6.30	2.22	2.36		-0.71	0.49	16	
up vs. actual		-0.02	-1.03	2.22		2.24	-0.08	0.93	16	(Forested) Up VS. Actual AVG DIFF= .43 meters *
down vs. actual		0.12	5.41		2.36	2.24	0.55	0.59	16	(Forested) Up VS. Actual AVG % DIFF= 15.6% **
D. Ball 3	4.4									
up vs. down		0.34	18.18	2.04	1.70		2.57	**0.02**	16	
up vs. actual		-1.18	-36.66	2.04		3.22	-2.95	***0.01***	16	
down vs. actual		-1.52	-47.22		1.70	3.22	-4.46	***0.00***	16	
E. Ball 1	6									
up vs. down		0.04	0.93	4.23	4.19		0.30	0.77	16	
up vs. actual		-0.59	-12.27	4.23		4.83	-4.85	***0.00***	16	(Forested) Down VS. Actual AVG % DIFF= 22.9 **
down vs. actual		-0.63	-13.09		4.19	4.83	-3.46	***0.00***	16	(Forested) Down VS. Actual AVG DIFF= .59 meters *
Pastured Streams										
A. Bates 5										
up vs. down	1.1	0.00	0.00	0.92	0.92		-0.01	0.99	16	(Pastured) Up VS. Down AVG DIFF= .12 meters *
up vs. actual		-0.07	-7.07	0.92		0.99	-1.21	0.24	16	(Pastured) Up VS. Down AVG % DIFF= 3.9% **
down vs. actual		-0.07	-7.07		0.92	0.99	-1.68	0.11	16	
B. Cowee 3	2									
up vs. down		0.03	1.54	1.73	1.70		0.74	0.47	15	
up vs. actual		-0.14	-7.59	1.73		1.87	-2.62	**0.02**	15	
down vs. actual		-0.17	-9.00		1.70	1.87	-2.85	***0.01***	15	
C. Crawford 1	2.8									
up vs. down		0.23	10.58	2.34	2.10		1.04	0.32	16	
up vs. actual		-0.32	-11.95	2.34		2.65	-2.66	**0.02**	16	(Pastured) Up VS. Actual AVG DIFF= .54 meters *
down vs. actual		-0.55	-20.80		2.10	2.65	-2.69	**0.02**	16	(Pastured) Up VS. Actual AVG % DIFF= 13% **
D. Caler 1	5.3									
up vs. down		-0.13	-3.25	4.01	4.14		-0.70	0.49	16	
up vs. actual		-1.01	-20.11	4.01		5.02	-7.10	***0.00***	16	
down vs. actual		-0.88	-17.47		4.14	5.02	-6.35	***0.00***	16	
E. Jones 1	7									
up vs. down		-0.23	-4.39	5.08	5.31		-0.37	0.72	15	
up vs. actual		-1.15	-18.40	5.08		6.23	-3.01	***0.01***	15	(Pastured) Down VS. Actual AVG % DIFF= 13.8% **
down vs. actual		-0.92	-14.74		5.31	6.23	-2.18	**0.05**	15	(Pastured) Down VS. Actual AVG DIFF= .51 meters *

Italicized and Bold p = .00 -.01

Bold p = .02 - .05

up= upstream photographic measurement

p= p value

t= test statistic

% of Diff= the percentage difference between mean values

down= downstream photographic measurement

actual= traditional stream survey measurement

diff= the difference between mean1 and mean 2

* = the absolute average of the difference between means in all the reaches (forest and pasture)

** = the absolute average percentage of difference of mean values in a category (forest or pasture)

Table 6 Summary of Statistics for Active Channel Bed Width

	Actual Stream			Means of Observed		Means of Actual				
Forested Streams	Width(m)	Diff=	% of Diff	up (photo)	down	actual	t	p	N=	Average Difference of absolute means and %
A. Crawford 5	1.4									
up vs. down		0.01	0.66	1.23	1.23		0.16	0.87	16	(Forested) Up VS. Down AVG DIFF= .15 meters *
up vs. actual		-0.24	-16.32	1.23		1.47	-5.24	***0.00***	16	(Forested) Up VS. Down AVG % DIFF= 5.3% **
down vs. actual		-0.25	-16.87		1.23	1.47	-3.72	***0.00***	16	
B. Skeenah 2	2.4									
up vs. down		0.13	5.80	2.24	2.11		1.36	0.19	16	
up vs. actual		-0.14	-5.87	2.24		2.38	-2.01	0.06	16	
down vs. actual		-0.27	-11.17		2.11	2.38	-2.61	**0.02**	16	
C. Ball 5	3.4									
up vs. down		-0.35	-11.09	2.98	3.33		-1.51	0.15	16	
up vs. actual		-0.45	-13.20	2.98		3.43	-1.82	0.09	16	(Forested) Up VS. Actual AVG DIFF= .28 meters *
down vs. actual		-0.10	-3.01		3.33	3.43	-0.59	0.57	16	(Forested) Up VS. Actual AVG % DIFF= 10% **
D. Ball 3	4.4									
up vs. down		0.16	7.16	2.27	2.11		1.68	0.11	16	
up vs. actual		-0.19	-7.55	2.27		2.45	-3.76	***0.00***	16	
down vs. actual		-0.34	-13.94		2.11	2.45	-4.20	***0.00***	16	
E. Ball 1	6									
up vs. down		0.12	2.21	5.38	5.26		0.99	0.34	16	
up vs. actual		-0.42	-7.18	5.38		5.80	-2.51	**0.02**	16	(Forested) Down VS. Actual AVG % DIFF= 10.8% **
down vs. actual		-0.53	-9.20		5.26	5.80	-4.11	***0.00***	16	(Forested) Down VS. Actual AVG DIFF= .29 meters *
Pastured Streams										
A. Bates 5										
up vs. down	1.1	0.01	1.04	0.97	0.96		13.00	0.69	14	(Pastured) Up VS. Down AVG DIFF= .13 meters *
up vs. actual		-0.22	-18.49	0.97		1.19	-5.26	***0.00***	14	(Pastured) Up VS. Down AVG %DIFF= 3.6% **
down vs. actual		-0.23	-19.33		0.96	1.19	-6.33	***0.00***	14	
B. Cowee 3	2									
up vs. down		-0.03	-1.31	1.94	1.96		-0.46	0.65	15	
up vs. actual		-0.08	-4.03	1.94		2.02	-3.05	***0.01***	15	
down vs. actual		-0.06	-2.77		1.96	2.02	-1.17	0.26	15	
C. Crawford 1	2.8									
up vs. down		0.20	8.15	2.50	2.30		0.85	0.41	16	
up vs. actual		-0.38	-13.34	2.50		2.88	-9.59	***0.00***	16	(Pastured) Up VS. Actual AVG % DIFF= 15.7% **
down vs. actual		-0.58	-20.13		2.30	2.88	-2.68	**0.02**	16	(Pastured) Up VS. Actual AVG DIFF= .71 meters *
D. Caler 1	5.3									
up vs. down		-0.11	-2.45	4.44	4.55		-1.32	0.21	16	
up vs. actual		-0.84	-15.96	4.44		5.28	-5.91	***0.00***	16	
down vs. actual		-0.73	-13.87		4.55	5.28	-5.50	***0.00***	16	
E. Jones 1	7									
up vs. down		-0.31	-5.27	5.67	5.98		-0.44	0.66	15	
up vs. actual		-2.05	-26.55	5.67		7.73	-3.90	***0.00***	15	(Pastured) Down VS. Actual AVG % DIFF= 15.7 % **
down vs. actual		-1.74	-22.57		5.98	7.73	-3.96	***0.00***	15	(Pastured) Down VS. Actual AVG DIFF= .67 meters *

Italicized and Bold p = .00 -.01
Bold p = .02 - .05
up= upstream photographic measurement
p= p value
t= test statistic
diff= the difference between mean1 and mean 2
% of Diff= the percentage difference between mean values
down= downstream photographic measurement
actual= traditional stream survey measurement

* = the absolute average of the difference between means in all the reaches (forest and pasture)
** = the absolute average percentage of difference of mean values in a category (forest or pasture)

Table 7 Summary of Statistics for Bankfull Width

	Actual Stream			Means of Observed		Means of Actual				
Forested Streams	Width(m)	Diff=	% of Diff	up (photo)	down	actual	t	p	N=	Average Difference of absolute means and %
A. Crawford 5	1.4									
up vs. down		-0.01	-0.64	1.62	1.63		-0.21	0.84	16	(Forested) Up VS. Down AVG DIFF= .1 meters *
up vs. actual		0.11	7.00	1.62		1.52	1.74	0.10	16	(Forested) Up VS. Down AVG % DIFF= 2.6% **
down vs. actual		0.12	7.69		1.63	1.52	1.96	0.07	16	
B. Skeenah 2	2.4									
up vs. down		0.05	1.91	2.54	2.49		0.54	0.60	16	
up vs. actual		-0.15	-5.56	2.54		2.69	-2.00	0.06	16	
down vs. actual		-0.20	-7.34		2.49	2.69	-2.99	***0.01***	16	
C. Ball 5	3.4									
up vs. down		0.01	0.13	3.93	3.93		0.05	0.96	16	
up vs. actual		-0.68	-14.71	3.93		4.61	-3.51	***0.00***	16	(Forested) Up VS. Actual AVG DIFF= .67 *
down vs. actual		-0.68	-14.82		3.93	4.61	-3.34	***0.00***	16	(Forested) Up VS. Actual AVG % DIFF= 15.5% **
D. Ball 3	4.4									
up vs. down		0.24	9.30	2.72	2.48		2.00	0.06	16	
up vs. actual		-2.04	-42.80	2.72		4.76	-4.09	***0.00***	16	
down vs. actual		-2.28	-47.88		2.48	4.76	-5.10	***0.00***	16	
E. Ball 1	6									
up vs. down		-0.05	-0.96	5.68	5.74		-0.36	0.73	16	
up vs. actual		-0.46	-7.54	5.68		6.14	-2.80	***0.01***	16	(Forested) Down VS. Actual AVG % DIFF= 16.9% **
down vs. actual		-0.41	-6.65		5.74	6.14	-3.45	***0.00***	16	(Forested) Down VS. Actual AVG DIFF= .73 meters *
Pastured Streams										
A. Bates 5										
up vs. down	1.1	-0.08	-6.15	1.26	1.34		-1.26	0.23	16	(Pastured) Up VS. Down AVG DIFF= .22 meters *
up vs. actual		-0.02	-1.56	1.26		1.28	-0.38	0.71	16	(Pastured) Up VS. Down AVG % DIFF= 6.8% **
down vs. actual		0.06	4.69		1.34	1.28	1.56	0.14	16	
B. Cowee 3	2									
up vs. down		0.11	4.13	2.67	2.56		1.49	0.16	15	
up vs. actual		0.41	18.07	2.67		2.26	4.66	***0.00***	15	
down vs. actual		0.30	13.29		2.56	2.26	4.31	***0.00***	15	
C. Crawford 1	2.8									
up vs. down		0.36	13.58	2.84	2.48		1.50	0.15	16	
up vs. actual		-1.42	-33.41	2.84		4.26	-7.61	***0.00***	16	(Pastured) Up VS. Actual AVG DIFF= 1.0 meters *
down vs. actual		-1.78	-41.88		2.48	4.26	-5.03	***0.00***	16	(Pastured) Up VS. Actual AVG % DIFF= 19.3% **
D. Caler 1	5.3									
up vs. down		-0.23	-4.72	4.75	4.98		-2.03	0.06	16	
up vs. actual		-1.08	-18.46	4.75		5.83	-6.28	***0.00***	16	
down vs. actual		-0.85	-14.52		4.98	5.83	-6.17	***0.00***	16	
E. Jones 1	7									
up vs. down		-0.36	-5.47	6.40	6.76		-0.48	0.64	15	
up vs. actual		-2.11	-24.78	6.40		8.51	-4.26	***0.00***	15	(Pastured) Down VS. Actual AVG % DIFF= 19% **
down vs. actual		-1.75	-20.55		6.76	8.51	-3.24	***0.01***	15	(Pastured) Down VS. Actual AVG DIFF= .95 meters *

Italicized and Bold p = .00 -.01
Bold p = .02 - .05
p= p value
t= test statistic
up= upstream photographic measurement
% of Diff= the percentage difference between mean values
down= downstream photographic measurement
actual= traditional stream survey measurement
diff= the difference between mean1 and mean 2

* = the absolute average of the difference between means in all the reaches (forest and pasture)
** = the absolute average percentage of difference of mean values in a category (forest or pasture)

Table 8 Summary of Statistics for Thalweg Depth

	Actual Stream			Means of Observed		Means of Actual				
Forested Streams	Width(m)	Diff=	% of Diff	up (photo)	down	actual	t	p	N=	Average Difference of absolute means and %
A. Crawford 5	1.4									
up vs. down		0.01	0.83	0.15	0.15		0.40	0.70	16	(Forested) Up VS. Down AVG DIFF= .05 meters *
up vs. actual		0.03	2.98	0.15		0.15	0.66	0.52	16	(Forested) Up VS. Down AVG % DIFF= 4.9% **
down vs. actual		0.02	2.13		0.15	0.15	0.51	0.62	16	
B. Skeenah 2	2.4									
up vs. down		-0.10	-10.78	0.15	0.17		-1.44	0.17	13	
up vs. actual		-0.14	-13.84	0.15		0.17	-1.17	0.27	13	
down vs. actual		-0.04	-4.02		0.17	0.17	-0.29	0.77	13	
C. Ball 5	3.4									
up vs. down		-0.01	-1.06	0.22	0.22		-0.49	0.63	13	
up vs. actual		0.07	6.84	0.22		0.20	1.81	0.10	13	(Forested) Up VS. Actual AVG DIFF= .07 meters *
down vs. actual		0.08	7.98		0.22	0.20	2.54	**0.03**	13	(Forested) Up VS. Actual AVG % DIFF= 7.3% **
D. Ball 3	4.4									
up vs. down		0.00	0.46	0.17	0.17		0.09	0.93	13	
up vs. actual		0.04	3.85	0.17		0.16	1.10	0.29	13	
down vs. actual		0.03	3.37		0.17	0.16	0.67	0.52	13	
E. Ball 1	6									
up vs. down		-0.11	-11.56	0.26	0.29		-2.75	**0.02**	15	
up vs. actual		-0.09	-9.24	0.26		0.28	-2.67	**0.02**	15	(Forested) Down VS. Actual AVG % DIFF= 3.9% **
down vs. actual		0.02	1.90		0.29	0.28	1.17	0.26	15	(Forested) Down VS. Actual AVG DIFF= .04 meters *
Pastured Streams										
A. Bates 5										
up vs. down	1.1	-0.09	-9.52	0.10	0.11		-0.85	0.41	16	(Pastured) Up VS. Down AVG DIFF= .03 meters *
up vs. actual		-0.17	-16.67	0.10		0.12	-3.37	***0.00***	16	(Pastured) Up VS. Down AVG % DIFF= 3.3% **
down vs. actual		-0.08	-8.33		0.11	0.12	-1.95	0.07	16	
B. Cowee 3	2									
up vs. down		-0.02	-1.51	0.13	0.13		-0.59	0.57	15	
up vs. actual		-0.04	-3.90	0.13		0.14	-1.42	0.18	15	
down vs. actual		-0.02	-2.44		0.13	0.14	-0.89	0.39	15	
C. Crawford 1	2.8									
up vs. down		-0.03	-3.29	0.27	0.28		-2.20	**0.05**	12	
up vs. actual		-0.04	-4.36	0.27		0.29	-1.26	0.23	12	(Pastured) Up VS. Actual AVG DIFF= .05 meters *
down vs. actual		-0.01	-1.16		0.28	0.29	-0.32	0.75	12	(Pastured) Up VS. Actual AVG % DIFF= 5.2% **
D. Caler 1	5.3									
up vs. down		-0.01	-0.51	0.26	0.26		-0.41	0.68	15	
up vs. actual		0.00	0.00	0.26		0.26	0.00	1.00	15	
down vs. actual		0.01	0.51		0.26	0.26	0.43	0.67	15	
E. Jones 1	7									
up vs. down		0.02	1.57	0.47	0.46		1.03	0.32	15	
up vs. actual		0.01	1.00	0.47		0.46	1.07	0.30	15	(Pastured) Down VS. Actual AVG % DIFF= 2.6% **
down vs. actual		-0.01	-0.57		0.46	0.46	-0.31	0.76	15	(Pastured) Down VS. Actual AVG DIFF= .03 meters *

Italicized and Bold p = .00 -.01

Bold p = .02 - .05

up= upstream photographic measurement

p= p value

t= test statistic

diff= the difference between mean1 and mean 2

% of Diff= the percentage difference between mean values

down= downstream photographic measurement

actual= traditional stream survey measurement

* = the absolute average of the difference between means in all the reaches (forest and pasture)

** = the absolute average percentage of difference of mean values in a category (forest or pasture)

Table 9 Summary of Statistics for Thalweg Position

Forested Streams	Actual Stream Width(m)	Diff=	% of Diff	Means of Observed up (photo)	down	Means of Actual actual	t	p	N=	Average Difference of absolute means and %
A. Crawford 5	1.4									
up vs. down		0.04	4.52	0.79	0.76		2.07	0.06	16	(Forested) Up VS. Down AVG DIFF= .04 meters *
up vs. actual		0.02	2.84	0.79		0.77	0.44	0.66	16	(Forested) Up VS. Down AVG % DIFF= 2.2% **
down vs. actual		-0.01	-1.71		0.76	0.77	-0.24	0.81	16	
B. Skeenah 2	2.4									
up vs. down		-0.01	-0.72	1.14	1.14		-0.27	0.79	15	
up vs. actual		-0.06	-5.34	1.14		1.20	-1.66	0.12	15	
down vs. actual		-0.06	-4.66		1.14	1.20	-1.52	0.15	15	
C. Ball 5	3.4									
up vs. down		0.03	1.61	2.00	1.97		1.00	0.33	16	
up vs. actual		0.13	6.82	2.00		1.87	1.91	0.08	16	(Forested) Up VS. Actual AVG DIFF= .1 meters *
down vs. actual		0.10	5.11		1.97	1.87	1.59	0.13	16	(Forested) Up VS. Actual AVG % DIFF= 4.8% **
D. Ball 3	4.4									
up vs. down		-0.08	-3.29	2.48	2.56		-0.84	0.41	16	
up vs. actual		0.17	7.14	2.48		2.31	2.49	**0.02**	16	
down vs. actual		0.25	10.72		2.56	2.31	2.73	**0.02**	16	
E. Ball 1	6									
up vs. down		-0.04	-1.00	3.75	3.79		-0.52	0.61	16	
up vs. actual		-0.07	-1.96	3.75		3.83	-0.67	0.51	16	(Forested) Down VS. Actual AVG % DIFF= 4.6% **
down vs. actual		-0.04	-0.97		3.79	3.83	-0.46	0.65	16	(Forested) Down VS. Actual AVG DIFF= .1 meters *
Pastured Streams										
A. Bates 5										
up vs. down	1.1	0.02	4.09	0.52	0.50		0.59	0.57	16	(Pastured) Up VS. Down AVG DIFF= .04 meters *
up vs. actual		-0.06	-9.64	0.52		0.57	-0.87	0.40	16	(Pastured) Up VS. Down AVG % DIFF= 4.3% **
down vs. actual		-0.08	-13.26		0.50	0.57	-1.17	0.26	16	
B. Cowee 3	2									
up vs. down		-0.12	-11.86	0.93	1.05		-1.33	0.20	15	
up vs. actual		0.04	4.83	0.93		0.89	0.29	0.77	15	
down vs. actual		0.16	18.05		1.05	0.89	1.03	0.32	15	
C. Crawford 1	2.8									
up vs. down		0.06	5.09	1.13	1.07		1.70	0.11	15	
up vs. actual		0.07	6.13	1.13		1.06	1.61	0.13	15	(Pastured) Up VS. Actual AVG DIFF= .07 meters *
down vs. actual		0.01	0.87		1.07	1.06	0.27	0.79	15	(Pastured) Up VS. Actual AVG % DIFF= 5.6% **
D. Caler 1	5.3									
up vs. down		-0.02	-0.70	2.35	2.37		-0.25	0.81	15	
up vs. actual		0.10	4.42	2.35		2.25	0.17	0.33	15	
down vs. actual		0.12	5.15		2.37	2.25	1.70	0.11	15	
E. Jones 1	7									
up vs. down		0.00	0.00	2.94	2.94		0.00	1.00	15	
up vs. actual		-0.09	-3.07	2.94		3.03	-1.17	0.26	15	(Pastured) Down VS. Actual AVG % DIFF= 8.1% **
down vs. actual		-0.09	-3.07		2.94	3.03	-0.81	0.43	15	(Pastured) Down VS. Actual AVG DIFF= .1 meters *

Italicized and Bold p = .00 -.01
Bold p = .02 - .05
p= p value
t= test statistic
up= upstream photographic measurement
% of Diff= the percentage difference between mean values
down= downstream photographic measurement
actual= traditional stream survey measurement
diff= the difference between mean1 and mean 2

* = the absolute average of the difference between means in all the reaches (forest and pasture)

** = the absolute average percentage of difference of mean values in a category (forest or pasture)

Table 10 Summary of Statistics for Left Bank

	Actual Stream			Means of Observed		Means of Actual				
Forested Streams	Width(m)	Diff=	% of Diff	up (photo)	down	actual	t	p	N=	Average Difference of absolute means and %
A. Crawford 5	1.4									
up vs. down		-0.09	-12.21	0.65	0.74		-2.92	***0.01***	16	(Forested) Up VS. Down AVG DIFF= .1 meters *
up vs. actual		0.09	16.86	0.65		0.56	3.92	***0.00***	16	(Forested) Up VS. Down AVG % DIFF= 15% **
down vs. actual		0.18	32.06		0.74	0.56	5.54	***0.00***	16	
B. Skeenah 2	2.4									
up vs. down		0.12	16.59	0.77	0.66		3.27	***0.01***	16	
up vs. actual		0.05	7.25	0.77		0.72	1.10	0.29	16	
down vs. actual		-0.07	-9.17		0.66	0.72	-1.70	0.11	16	
C. Ball 5	3.4									
up vs. down		0.16	23.95	0.75	0.59		1.91	0.08	15	
up vs. actual		0.01	0.89	0.75		0.75	0.09	0.93	15	(Forested) Up VS. Actual AVG DIFF= .23 meters *
down vs. actual		-0.15	-20.68		0.59	0.75	-2.05	0.06	15	(Forested) Up VS. Actual AVG % DIFF= 23.4% **
D. Ball 3	4.4									
up vs. down		0.08	13.13	0.64	0.56		2.61	**0.02**	16	
up vs. actual		-0.43	-40.33	0.64		1.08	-2.96	***0.01***	16	
down vs. actual		-0.51	-47.68		0.56	1.08	-3.28	***0.01***	16	
E. Ball 1	6									
up vs. down		-0.07	-12.68	0.53	0.60		-1.42	0.17	16	
up vs. actual		-0.56	-51.63	0.53		1.09	-2.23	0.04	16	(Forested) Down VS. Actual AVG % DIFF= 30.8% **
down vs. actual		-0.49	-45.08		0.60	1.09	-2.00	0.06	16	(Forested) Down VS. Actual AVG DIFF= .3 meters *
Pastured Streams										
A. Bates 5										
up vs. down	1.1	-0.03	-11.76	0.24	0.27		-1.75	0.10	16	(Pastured) Up VS. Down AVG DIFF= .1 meters *
up vs. actual		-0.23	-48.94	0.24		0.47	-2.68	**0.02**	16	(Pastured) Up VS. Down AVG % DIFF= 13.2% **
down vs. actual		-0.20	-42.55		0.27	0.47	-2.46	**0.03**	16	
B. Cowee 3	2									
up vs. down		-0.03	-7.39	0.36	0.39		-1.04	0.31	15	
up vs. actual		0.11	44.56	0.36		0.25	3.27	***0.01***	15	
down vs. actual		0.14	55.65		0.39	0.25	2.51	**0.03**	15	
C. Crawford 1	2.8									
up vs. down		-0.19	-21.47	0.77	0.96		-3.22	***0.01***	16	
up vs. actual		-0.05	-6.56	0.77	0.83		-0.66	0.52	16	(Pastured) Up VS. Actual AVG DIFF= .4 meters *
down vs. actual		0.13	15.91	0.96	0.83		1.92	0.07	16	(Pastured) Up VS. Actual AVG % DIFF= 37.4% **
D. Caler 1	5.3									
up vs. down		-0.06	-7.76	0.79	0.85		-2.24	**0.04**	16	
up vs. actual		-0.42	-34.79	0.79		1.21	-5.69	***0.00***	16	
down vs. actual		-0.36	-29.52		0.85	1.21	-4.78	***0.00***	16	
E. Jones 1	7									
up vs. down		-0.20	-17.74	1.04	1.24		-1.16	0.27	15	
up vs. actual		-1.17	-52.89	1.04		2.21	-3.78	***0.00***	15	(Pastured) Down VS. Actual AVG % DIFF= 37.5% **
down vs. actual		-0.96	-43.71		1.24	2.21	-3.27	***0.01***	15	(Pastured) Down VS. Actual AVG DIFF= .36 meters *

Italicized and Bold p = .00 -.01

Bold p = .02 - .05

up= upstream photographic measurement

p= p value

t= test statistic

diff= the difference between mean1 and mean 2

% of Diff= the percentage difference between mean values

down= downstream photographic measurement

actual= traditional stream survey measurement

* = the absolute average of the difference between means in all the reaches (forest and pasture)

** = the absolute average percentage of difference of mean values in a category (forest or pasture)

Table 11 Summary of Statistics for Right Bank

Forested Streams	Actual Stream Width(m)	Diff=	% of Diff	Means of Observed up (photo)	down	Means of Actual actual	t	p	N=	Average Difference of absolute means and %
A. Crawford 5	1.4									
up vs. down		-0.05	-7.37	0.70	0.75		-0.88	0.39	16	(Forested) Up VS. Down AVG DIFF= .1 meters *
up vs. actual		0.13	22.47	0.70		0.57	3.69	***0.00***	16	(Forested) Up VS. Down AVG % DIFF= 12.8% **
down vs. actual		0.18	31.85		0.75	0.57	3.46	***0.00***	16	
B. Skeenah 2	2.4									
up vs. down		0.12	18.27	0.73	0.61		4.01	***0.00***	16	
up vs. actual		0.09	13.53	0.73		0.64	2.70	**0.02**	16	
down vs. actual		-0.04	-5.48		0.61	0.64	-1.01	0.33	16	
C. Ball 5	3.4									
up vs. down		0.11	14.88	0.80	0.69		1.55	0.14	15	
up vs. actual		0.05	6.51	0.80		0.75	0.76	0.46	15	(Forested) Up VS. Actual AVG DIFF= .14 meters *
down vs. actual		-0.06	-8.23		0.69	0.75	-1.05	0.31	15	(Forested) Up VS. Actual AVG % DIFF= 17.8% **
D. Ball 3	4.4									
up vs. down		0.13	17.44	0.81	0.68		2.50	**0.02**	16	
up vs. actual		0.07	9.74	0.81		0.73	0.61	0.55	16	
down vs. actual		-0.06	-7.87		0.68	0.73	-0.49	0.63	16	
E. Ball 1	6									
up vs. down		0.04	6.26	0.59	0.56		1.40	0.18	16	
up vs. actual		-0.35	-36.79	0.59		0.94	-3.61	***0.00***	16	(Forested) Down VS. Actual AVG % DIFF= 18.8% **
down vs. actual		-0.38	-40.63		0.56	0.94	-3.71	***0.00***	16	(Forested) Down VS. Actual AVG DIFF= .14 meters *
Pastured Streams										
A. Bates 5										
up vs. down	1.1	-0.05	-19.61	0.23	0.28		-1.63	0.12	16	(Pastured) Up VS. Down AVG DIFF= .08 meters *
up vs. actual		-0.75	-76.53	0.23		0.98	-5.97	***0.00***	16	(Pastured) Up VS. Down AVG % DIFF= 12.28% **
down vs. actual		-0.70	-71.43		0.28	0.98	-5.08	***0.00***	16	
B. Cowee 3	2									
up vs. down		-0.01	-3.40	0.34	0.35		-0.75	0.47	15	
up vs. actual		0.05	18.61	0.34		0.29	2.04	0.06	15	
down vs. actual		0.07	22.71		0.35	0.29	2.26	**0.04**	15	
C. Crawford 1	2.8									
up vs. down		-0.24	-26.41	0.80	1.04		-3.05	***0.01***	16	
up vs. actual		-1.16	-59.36	0.80		1.96	-4.06	***0.00***	16	(Pastured) Up VS. Actual AVG DIFF= .44 meters *
down vs. actual		-0.92	-46.99		1.04	1.96	-3.27	***0.01***	16	(Pastured) Up VS. Actual AVG % DIFF= 36.3% **
D. Caler 1	5.3									
up vs. down		0.05	6.66	0.73	0.68		0.78	0.45	16	
up vs. actual		-0.24	-24.84	0.73		0.97	-2.55	**0.02**	16	
down vs. actual		-0.29	-29.68		0.68	0.97	-4.77	***0.00***	16	
E. Jones 1	7									
up vs. down		-0.04	-5.32	0.74	0.78		-0.45	0.66	15	
up vs. actual		-0.02	-2.27	0.74		0.76	-0.19	0.85	15	(Pastured) Down VS. Actual AVG % DIFF= 34.8% **
down vs. actual		0.02	3.07		0.78	0.76	0.24	0.81	15	(Pastured) Down VS. Actual AVG DIFF= .4 meters *

Italicized and Bold p = .00 -.01

Bold p = .02 - .05

up= upstream photographic measurement

p= p value

t= test statistic

diff= the difference between mean1 and mean 2

% of Diff= the percentage difference between mean values

down= downstream photographic measurement

actual= traditional stream survey measurement

* = the absolute average of the difference between means in all the reaches (forest and pasture)

** = the absolute average percentage of difference of mean values in a category (forest or pasture)

TABLE 12 (a)-(e) DOMINANT PHYSICAL HABITAT AT CROSS-SECTION (FORESTED STREAM)

(a) CRAWFORD 5

N=	X SECT	ACTUAL	OBSERVED	DIFF
1	0X	RUN	RUN	
2	2X	RIFFLE	RIFFLE	
3	4X	RUN	RUN	
4	6X	RUN	RUN	
5	8X	RUN	RUN	
6	10X	RUN	RIFFLE	X
7	12X	RIFFLE	RUN	X
8	14X	RIFFLE	RUN	X
9	16X	RUN	RUN	
10	18X	RIFFLE	RUN	X
11	20X	RUN	RUN	
12	22X	RUN	RUN	
13	24X	RIFFLE	RUN	X
14	26X	RIFFLE	RUN	X
15	28X	RUN	RUN	
16	30X	POOL	POOL	
	%			0.4

(b) SKEENAH 2

N=	X SECT	ACTUAL	OBSERVED	DIFF
1	0X	RIFFLE	RIFFLE	
2	2X	RIFFLE	RUN	X
3	4X	POOL	RIFFLE	X
4	6X	RIFFLE	RIFFLE	
5	8X	RIFFLE	RIFFLE	
6	10X	RIFFLE	RIFFLE	
7	12X	POOL	POOL	
8	14X	RIFFLE	POOL	X
9	16X	POOL	POOL	
10	18X	RIFFLE	RUN	X
11	20X	RIFFLE	RIFFLE	
12	22X	RIFFLE	RIFFLE	
13	24X	POOL	POOL	
14	26X	RIFFLE	RIFFLE	
15	28X	POOL	POOL	
16	30X	RIFFLE	RIFFLE	
	%			0.25

(c) BALL 5

N=	X SECT	ACTUAL	OBSERVED	DIFF
1	0X	RIFFLE	RIFFLE	
2	2X	POOL	RUN	X
3	4X	POOL	RIFFLE	X
4	6X	RIFFLE	RIFFLE	
5	8X	RIFFLE	RIFFLE	
6	10X	RIFFLE	RIFFLE	
7	12X	RIFFLE	RIFFLE	
8	14X	POOL	RIFFLE	X
9	16X	RIFFLE	RIFFLE	
10	18X	RIFFLE	RUN	X
11	20X	RUN	RUN	
12	22X	RIFFLE	RIFFLE	
13	24X	POOL	POOL	
14	26X	RUN	RUN	
15	28X	RIFFLE	RUN	X
16	30X	RUN	RIFFLE	X
	%			0.38

(d) BALL 3

N=	X SECT	ACTUAL	OBSERVED	DIFF
1	0X	POOL	POOL	
2	2X	RIFFLE	RUN	X
3	4X	POOL	POOL	
4	6X	RUN	POOL	X
5	8X	RUN	RUN	
6	10X	RIFFLE	RUN	X
7	12X	RUN	RUN	
8	14X	RUN	RIFFLE	X
9	16X	RIFFLE	POOL	X
10	18X	RIFFLE	RIFFLE	
11	20X	POOL	RIFFLE	X
12	22X	RUN	POOL	X
13	24X	RUN	RUN	
14	26X	RIFFLE	RIFFLE	
15	28X	POOL	RUN	X
16	30X	RIFFLE	RIFFLE	
	%			0.5

(e) BALL 1

N=	X SECT	ACTUAL	OBSERVED	DIFF
1	0X	RUN	RUN	
2	2X	RUN	RUN	
3	4X	RUN	RUN	
4	6X	RIFFLE	RIFFLE	
5	8X	RUN	RUN	
6	10X	RUN	RUN	
7	12X	RUN	RIFFLE	X
8	14X	RUN	RUN	
9	16X	RIFFLE	RIFFLE	
10	18X	RIFFLE	RIFFLE	
11	20X	RUN	RUN	
12	22X	RIFFLE	RIFFLE	
13	24X	RIFFLE	RIFFLE	
14	26X	RUN	RUN	
15	28X	RIFFLE	RIFFLE	
16	30X	RUN	RUN	
	%			0.1

TABLE 12 (f)-(j) DOMINANT PHYSICAL HABITAT AT CROSS-SECTION (PASTURED STREAM)

(f) BATES 5

N=	X SECT	ACTUAL	OBSERVED	DIFF
1	0X	RIFFLE	RUN	X
2	2X	RUN	RUN	
3	4X	RUN	RUN	
4	6X	RUN	RUN	
5	8X	RUN	RUN	
6	10X	RIFFLE	RIFFLE	
7	12X	RUN	POOL	X
8	14X	RUN	POOL	X
9	16X	RIFFLE	RIFFLE	
10	18X	RIFFLE	RIFFLE	
11	20X	RIFFLE	RIFFLE	
12	22X	RIFFLE	RUN	X
13	24X	RIFFLE	RUN	X
14	26X	RUN	RUN	
15	28X	RUN	RUN	
16	30X	RIFFLE	RUN	X
	%			0.4

(g) COWEE 3

N=	X SECT	ACTUAL	OBSERVED	DIFF
1	0X	RIFFLE	RIFFLE	
2	2X	RIFFLE	RIFFLE	
3	4X	RIFFLE	RUN	X
4	6X	RUN	RUN	
5	8X	POOL	POOL	
6	10X	RIFFLE	RUN	X
7	12X	RIFFLE	POOL	X
8	14X	RUN	POOL	X
9	16X	RUN	RUN	
10	18X	RUN	RUN	
11	20X	RIFFLE	RUN	X
12	22X	RIFFLE	RUN	X
13	24X	RUN	POOL	X
14	26X	RIFFLE	RUN	X
15	28X	RIFFLE	RIFFLE	
16	30X	RIFFLE	RIFFLE	
	%			0.5

(h) CRAWFORD 1

N=	X SECT	ACTUAL	OBSERVED	DIFF
1	0X	RUN	RUN	
2	2X	RIFFLE	RIFFLE	
3	4X	RUN	RUN	
4	6X	RUN	RUN	
5	8X	RUN	RUN	
6	10X	RIFFLE	RUN	X
7	12X	POOL	POOL	
8	14X	RUN	RUN	
9	16X	RIFFLE	RIFFLE	
10	18X	RUN	RUN	
11	20X	POOL	POOL	
12	22X	RIFFLE	RUN	X
13	24X	POOL	POOL	
14	26X	RUN	RUN	
15	28X	RUN	RUN	
16	30X	POOL	POOL	
	%			0.19

(i) CALER 1

N=	X SECT	ACTUAL	OBSERVED	DIFF
1	0X	RUN	RUN	
2	2X	RIFFLE	RIFFLE	
3	4X	RUN	RUN	
4	6X	RUN	RUN	
5	8X	RUN	RUN	
6	10X	RIFFLE	RIFFLE	
7	12X	RIFLLE	RIFFLE	
8	14X	RIFLLE	RIFFLE	
9	16X	RIFLLE	RIFFLE	
10	18X	RUN	POOL	X
11	20X	POOL	POOL	
12	22X	POOL	POOL	
13	24X	RUN	POOL	X
14	26X	RIFFLE	RIFFLE	
15	28X	RUN	RUN	
16	30X	RUN	RUN	
	%			0.1

(j) JONES 1

N=	X SECT	ACTUAL	OBSERVED	DIFF
1	0X	RIFFLE	RIFFLE	
2	2X	RUN	RIFFLE	X
3	4X	POOL	RUN	X
4	6X	RIFFLE	RIFFLE	
5	8X	RIFFLE	RUN	X
6	10X	POOL	POOL	
7	12X	RIFFLE	RIFFLE	
8	14X	RUN	RUN	
9	16X	RIFFLE	RIFFLE	
10	18X	POOL	POOL	
11	20X	RIFFLE	RUN	X
12	22X	RUN	RUN	
13	24X	RIFFLE	RIFFLE	
14	26X	RIFFLE	RIFFLE	
15	28X	RUN	POOL	X
16	30X	RIFFLE	RIFFLE	
	%			0.3

actual = visual observation

observed = photographic estimation of dominant physical habitat

difference = percentage difference between photographic estimation and actual (visual observation)

TABLE 13 (a)-(e) DOMINANT BED MATERIAL AT CROSS-SECTION (FORESTED STREAM)

(a) CRAWFORD 5

N=	X SECT	ACTUAL	OBSERVED	DIFF
1	0X	Gravel	Gravel	
2	2X	Gravel	Sand	X
3	4X	Sand	Gravel	X
4	6X	Sand	Sand	
5	8X	Gravel	Gravel	
6	10X	Sand	Gravel	X
7	12X	Cobble	Cobble	
8	14X	Sand	Gravel	X
9	16X	Gravel	Gravel	
10	18X	Sand	Sand	
11	20X	Gravel	Sand	X
12	22X	Sand	Sand	
13	24X	Sand	Gravel	X
14	26X	Gravel	Gravel	
15	28X	Sand	Sand	
16	30X	Sand	Sand	
	%			0.38

(b) SKEENAH 2

N=	X SECT	ACTUAL	OBSERVED	DIFF
1	0X	Boulder	Boulder	
2	2X	Cobble	Cobble	
3	4X	Gravel	Gravel	
4	6X	Cobble	Cobble	
5	8X	Cobble	Cobble	
6	10X	Boulder	Cobble	X
7	12X	Gravel	Gravel	
8	14X	Boulder	Boulder	
9	16X	Cobble	Boulder	X
10	18X	Cobble	Cobble	
11	20X	Cobble	Cobble	
12	22X	Cobble	Cobble	
13	24X	Cobble	Cobble	
14	26X	Boulder	Boulder	
15	28X	Sand	Gravel	X
16	30X	Cobble	Gravel	X
	%			0.25

(c) BALL 5

N=	X SECT	ACTUAL	OBSERVED	DIFF
1	0X	Gravel	Gravel	
2	2X	Boulder	Cobble	X
3	4X	Boulder	Boulder	
4	6X	Boulder	Boulder	
5	8X	Boulder	Boulder	
6	10X	Boulder	Boulder	
7	12X	Boulder	Boulder	
8	14X	Cobble	Cobble	
9	16X	Gravel	Gravel	
10	18X	Boulder	Cobble	X
11	20X	Boulder	Cobble	X
12	22X	Cobble	Cobble	
13	24X	Boulder	Boulder	
14	26X	Cobble	Cobble	
15	28X	Cobble	Cobble	
16	30X	Boulder	Cobble	X
	%			0.25

(d) BALL 3

N=	X SECT	ACTUAL	OBSERVED	DIFF
1	0X	Gravel	Gravel	
2	2X	Cobble	Cobble	
3	4X	Sand	Sand	
4	6X	Gravel	Gravel	
5	8X	Boulder	Boulder	
6	10X	Gravel	Gravel	
7	12X	Gravel	Gravel	
8	14X	Gravel	Gravel	
9	16X	Gravel	Gravel	
10	18X	Cobble	Gravel	X
11	20X	Gravel	Cobble	X
12	22X	Gravel	Gravel	
13	24X	Gravel	Gravel	
14	26X	Cobble	Cobble	
15	28X	Sand	Gravel	X
16	30X	Gravel	Cobble	X
	%			0.25

(e) BALL 1

N=	X SECT	ACTUAL	OBSERVED	DIFF
1	0X	Cobble	Cobble	
2	2X	Gravel	Gravel	
3	4X	Gravel	Gravel	
4	6X	Cobble	Gravel	X
5	8X	Gravel	Gravel	
6	10X	Gravel	Gravel	
7	12X	Gravel	Gravel	
8	14X	Cobble	Cobble	
9	16X	Cobble	Gravel	X
10	18X	Cobble	Cobble	
11	20X	Gravel	Gravel	
12	22X	Boulder	Boulder	
13	24X	Boulder	Cobble	X
14	26X	Cobble	Cobble	
15	28X	Gravel	Gravel	
16	30X	Gravel	Gravel	
	%			0.2

TABLE 13 (f)-(j) DOMINANT BED MATERIAL AT CROSS-SECTION (PASTURED STREAM)

(f) BATES 5

N=	X SECT	ACTUAL	OBSERVED	DIFF
1	0X	Gravel	Gravel	
2	2X	Gravel	Gravel	
3	4X	Gravel	Sand	X
4	6X	Gravel	Gravel	
5	8X	Gravel	Gravel	
6	10X	Cobble	Cobble	
7	12X	Sand	Sand	
8	14X	Sand	Sand	
9	16X	Gravel	Gravel	
10	18X	Cobble	Cobble	
11	20X	Cobble	Gravel	X
12	22X	Gravel	Gravel	
13	24X	Gravel	Sand	X
14	26X	Gravel	Gravel	
15	28X	Gravel	Cobble	X
16	30X	Cobble	Cobble	
	%			0.25

(g) COWEE 3

N=	X SECT	ACTUAL	OBSERVED	DIFF
1	0X	Cobble	Cobble	
2	2X	Cobble	Gravel	X
3	4X	Gravel	Sand	X
4	6X	Gravel	Sand	X
5	8X	Gravel	Sand	X
6	10X	Gravel	Gravel	
7	12X	Sand	Sand	
8	14X	Sand	Sand	
9	16X	Sand	Sand	
10	18X	Gravel	Gravel	
11	20X	Gravel	Gravel	
12	22X	Gravel	Cobble	X
13	24X	Gravel	Sand	X
14	26X	Gravel	Gravel	
15	28X	Sand	Gravel	X
16	30X	Cobble	Gravel	X
	%			0.5

(h) CRAWFORD 1

N=	X SECT	ACTUAL	OBSERVED	DIFF
1	0X	Sand	Sand	
2	2X	Cobble	Cobble	
3	4X	Sand	Sand	
4	6X	Gravel	Gravel	
5	8X	Sand	Gravel	X
6	10X	Cobble	Cobble	
7	12X	Sand	Sand	
8	14X	Sand	Gravel	X
9	16X	Gravel	Gravel	
10	18X	Gravel	Gravel	
11	20X	Sand	Cobble	X
12	22X	Gravel	Gravel	
13	24X	Sand	Sand	
14	26X	Gravel	Cobble	X
15	28X	Gravel	Gravel	
16	30X	Sand	Sand	
	%			0.25

(i) CALER 1

N=	X SECT	ACTUAL	OBSERVED	DIFF
1	0X	Gravel	Gravel	
2	2X	Gravel	Gravel	
3	4X	Gravel	Gravel	
4	6X	Gravel	Coble	X
5	8X	Gravel	Gravel	
6	10X	Gravel	Gravel	
7	12X	Gravel	Gravel	
8	14X	Gravel	Gravel	
9	16X	Gravel	Cobble	X
10	18X	Gravel	Sand	X
11	20X	Sand	Sand	
12	22X	Sand	Sand	
13	24X	Sand	Sand	
14	26X	Gravel	Cobble	X
15	28X	Gravel	Cobble	X
16	30X	Boulder	Cobble	X
	%			0.38

(j) JONES 1

N=	X SECT	ACTUAL	OBSERVED	DIFF
1	0X	Gravel	Gravel	
2	2X	Gravel	Cobble	X
3	4X	Gravel	Sand	X
4	6X	Gravel	Cobble	X
5	8X	Gravel	Sand	X
6	10X	Gravel	Sand	X
7	12X	Gravel	Gravel	
8	14X	Cobble	Cobble	
9	16X	Cobble	Cobble	
10	18X	Gravel	Cobble	X
11	20X	Gravel	Sand	X
12	22X	Gravel	Gravel	
13	24X	Gravel	Gravel	
14	26X	Cobble	Cobble	
15	28X	Sand	Sand	
16	30X	Gravel	Gravel	
	%			0.4

actual = visual observation

observed = photographic estimation of dominant particle SIZE

difference = percentage difference between photographic estimation and actual (visual observation)

TABLE 14. Average absolute difference of means and percentage of means

		Photo Test-Measurement Scale Bar	Wetted Width	Active Channel Bed Width	Bankfull Width	Thalweg Depth	Thalweg Position	Left Bank Height	Right Bank Height
FORESTED STREAMS									
avg diff	up vs. down	0.11 m	0.16 m	0.15 m	0.1 m	0.05 m	0.04 m	0.1 m	0.1 m
avg % of diff	up vs. down	3.40%	8.90%	5.30%	2.60%	4.90%	2.20%	15.00%	12.80%
avg diff	up vs. actual	0.17 m	0.43 m	0.28 m	0.67 m	0.07 m	0.1 m	0.23 m	0.14 m
avg % of diff	up vs. actual	4.80%	15.60%	10%	15.50%	7.30%	4.80%	23.40%	17.80%
avg diff	down vs. actual	0.26 m	0.59 m	0.29 m	0.73 m	0.04 m	0.1 m	0.3 m	0.14 m
avg % of diff	down vs. actual	7.30%	22.90%	10.80%	16.90%	3.90%	4.60%	30.80%	18.80%
PASTURED STREAMS									
avg diff	up vs. down	0.21 m	0.12 m	0.13 m	0.22 m	0.03 m	0.04 m	0.1 m	0.08 m
avg % of diff	up vs. down	4.30%	3.90%	3.60%	6.80%	3.30%	4.30%	13.20%	12.28%
avg diff	up vs. actual	0.55 m	0.54 m	0.71 m	1.0 m	0.05 m	0.07 m	0.4 m	0.44 m
avg % of diff	up vs. actual	8.90%	13%	15.70%	19.30%	5.20%	5.60%	37.40%	36.30%
avg diff	down vs. actual	0.41 m	0.51 m	0.67 m	0.95 m	0.03 m	0.1 m	0.36 m	0.4 m
avg % of diff	down vs. actual	8.00%	13.80%	15.70%	19.00%	2.60%	8.10%	37.50%	34.80%

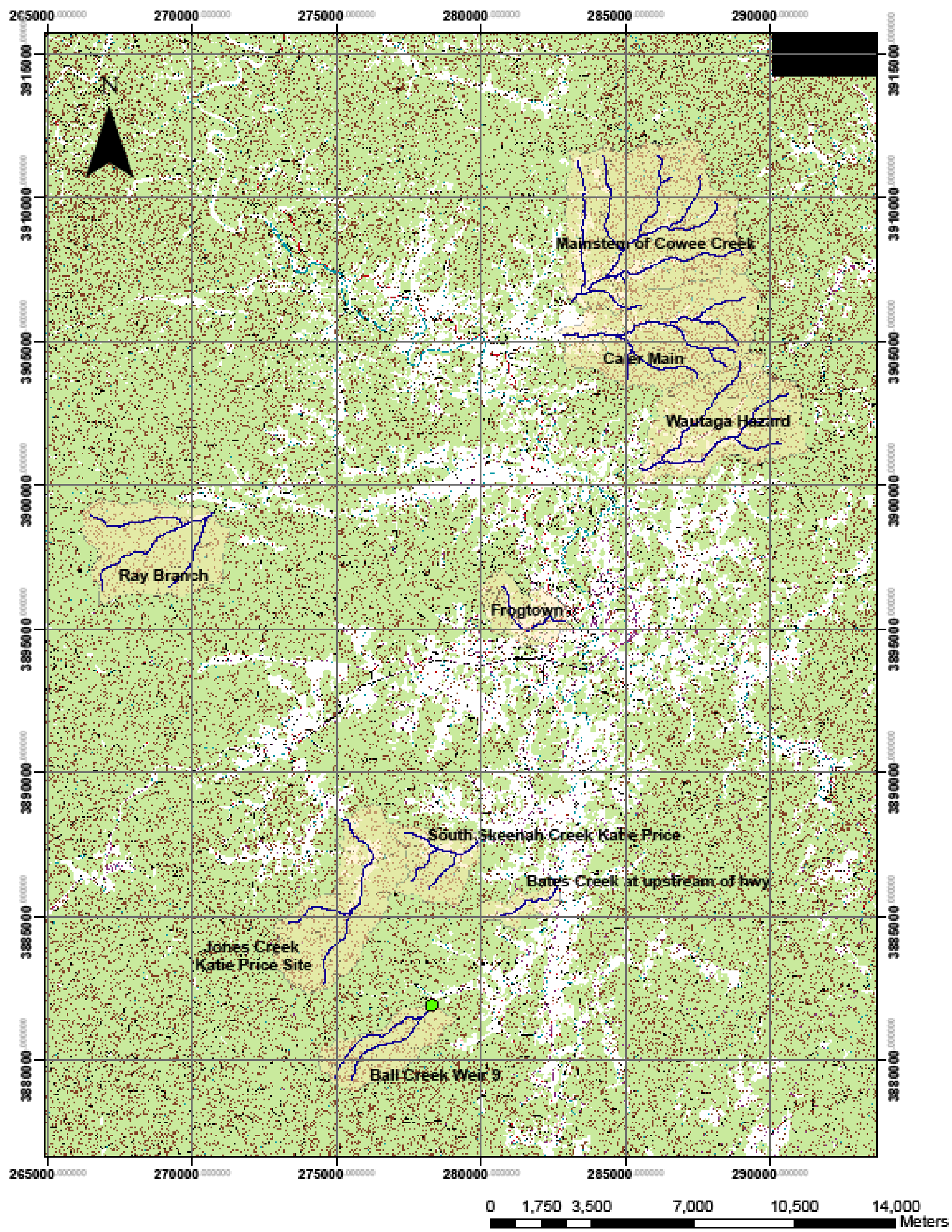


Figure 1. Stream sites selected for terrestrial photographic study.

Figure 2. Skeenah Creek at site 2 (forest reach). Photo taken at 0x cross-section 0m looking upstream.

UTM Coordinate **0281057E 3895670N**

Figure 3. Ball Creek at site 1 (forested reach).   Photo taken at 32x cross-section 160m from 0x looking downstream.

UTM Coordinate **0278239E 3881958N**

Figure 4. Ball Creek at site 5 (forested reach). Photo taken at 0x cross-section 0m looking upstream.

UTM Coordinate **0275798E 3880860N**

Figure 5. Ball Creek at site 3 (forested reach). Photo taken at 20x cross-section 84m from 0x looking downstream.

UTM Coordinate **0275753E 3880815N**

Figure 6. Crawford Creek at site 5 (forested reach). Photo taken at 16x cross-section 24m from 0x looking upstream.

UTM Coordinate **0281048E 3895688N**

Figure 7. Bates Creek at Site 5 (Pastured reach). Photo taken at 16x cross-section 16m from 0x looking upstream.

UTM Coordinate **0280278E 3886601N**

Figure 8. Cowee Creek at site 3 (pastured reach). Photo taken at 2x cross-section 2m from 0x looking downstream.

UTM Coordinates **0286509E 3909129N**

Figure 9. Crawford Creek at site 1. Photo taken at 4x cross-section 12m from 0x looking upstream.

UTM Coordinate **0283019E 3895488N**

Figure 10. Caler Creek at site1 (pastured reach). Photo taken at 4x cross-section 20m from 0x looking upstream.

UTM Coordinate **0283401E 3905405N**

Figure 11. Jones Creek at site 1 (pastured reach). Photo taken at 12x cross-section 96m from 0x looking downstream.

UTM Coordinate **0275129E 3888619N**

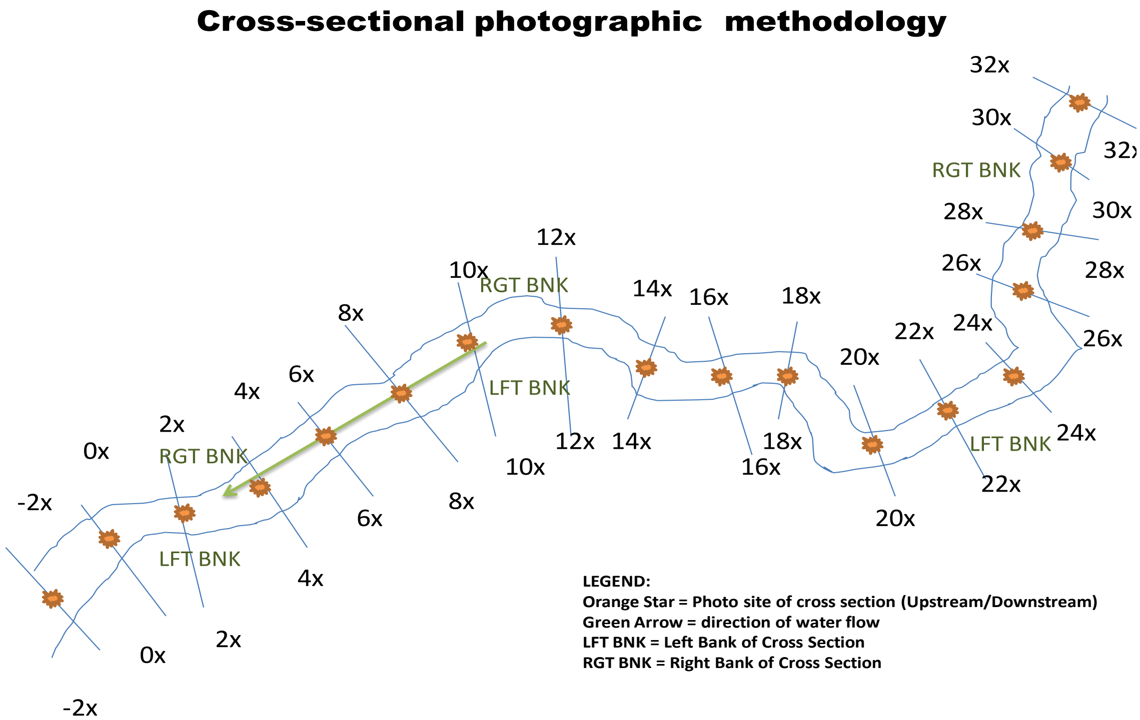


Figure 12. Cross-sectional photographic methodology.

Photo Test-Measurement Scale Bar

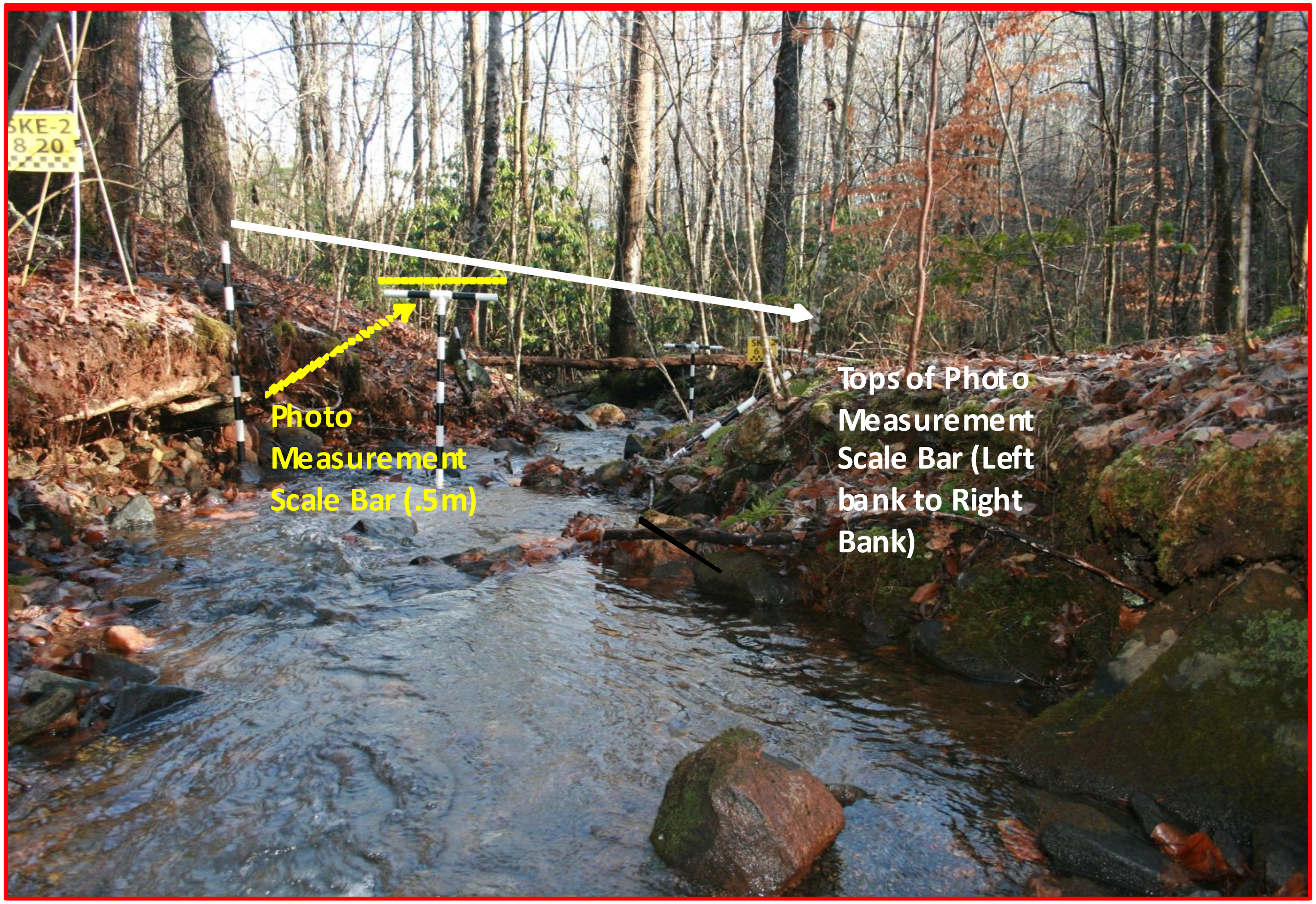


Figure 13. Verification of Photo test-measurement scale bars for correction factor of error.

Width Variables

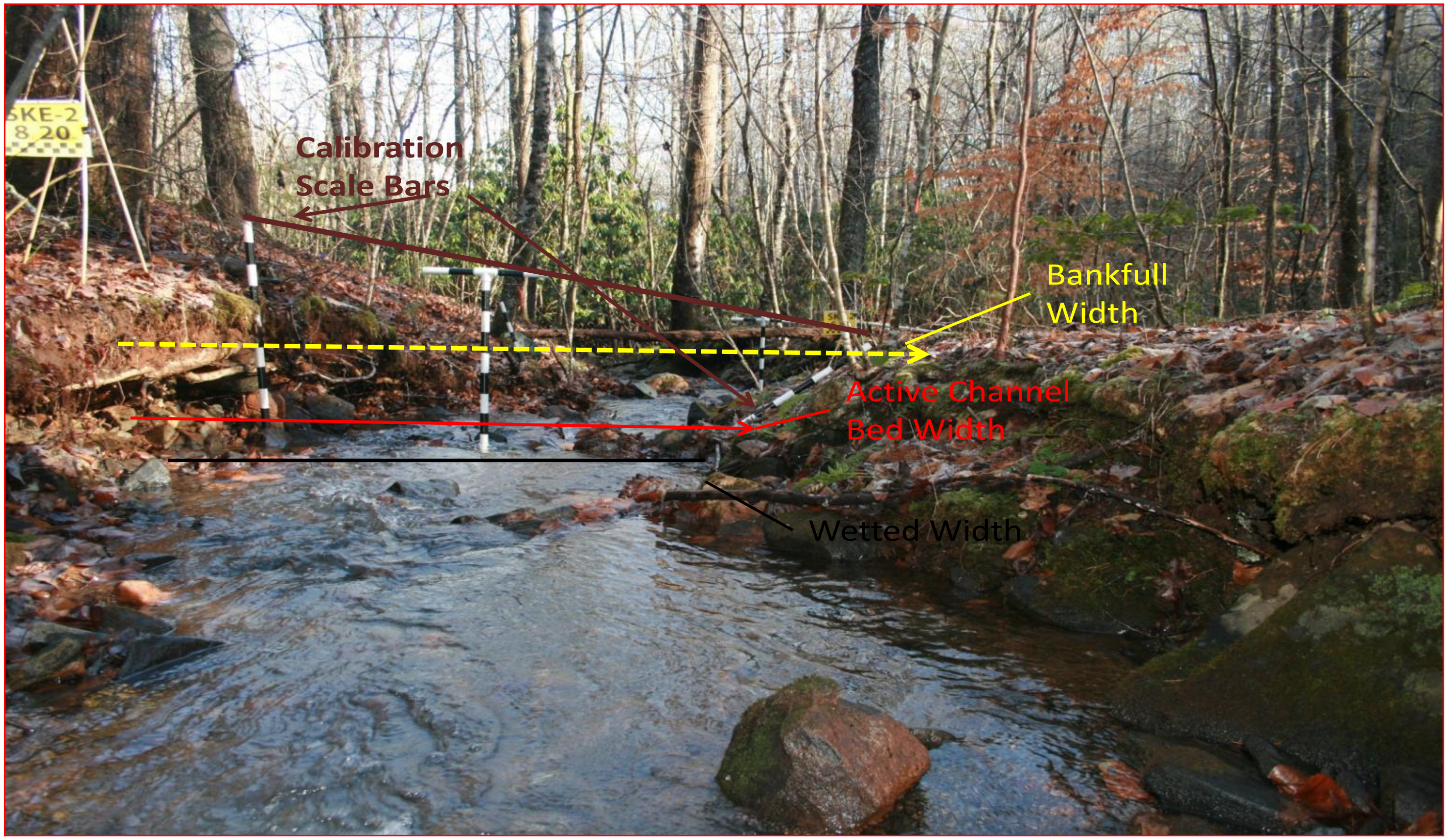


Figure 14. Photograph of Width variables

HEIGHT/DEPTH Variables

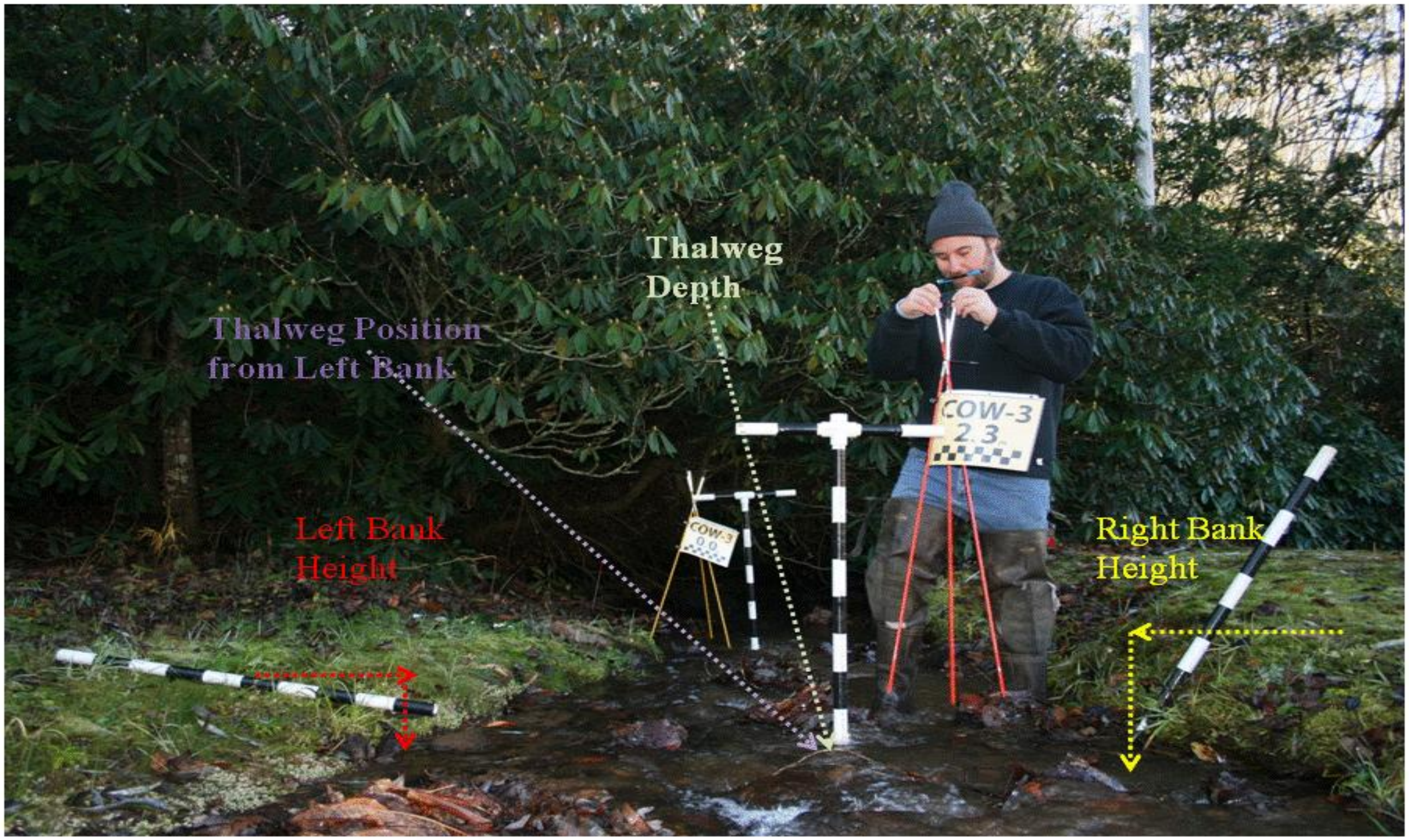


Figure 15. Photograph of height and depth variables.

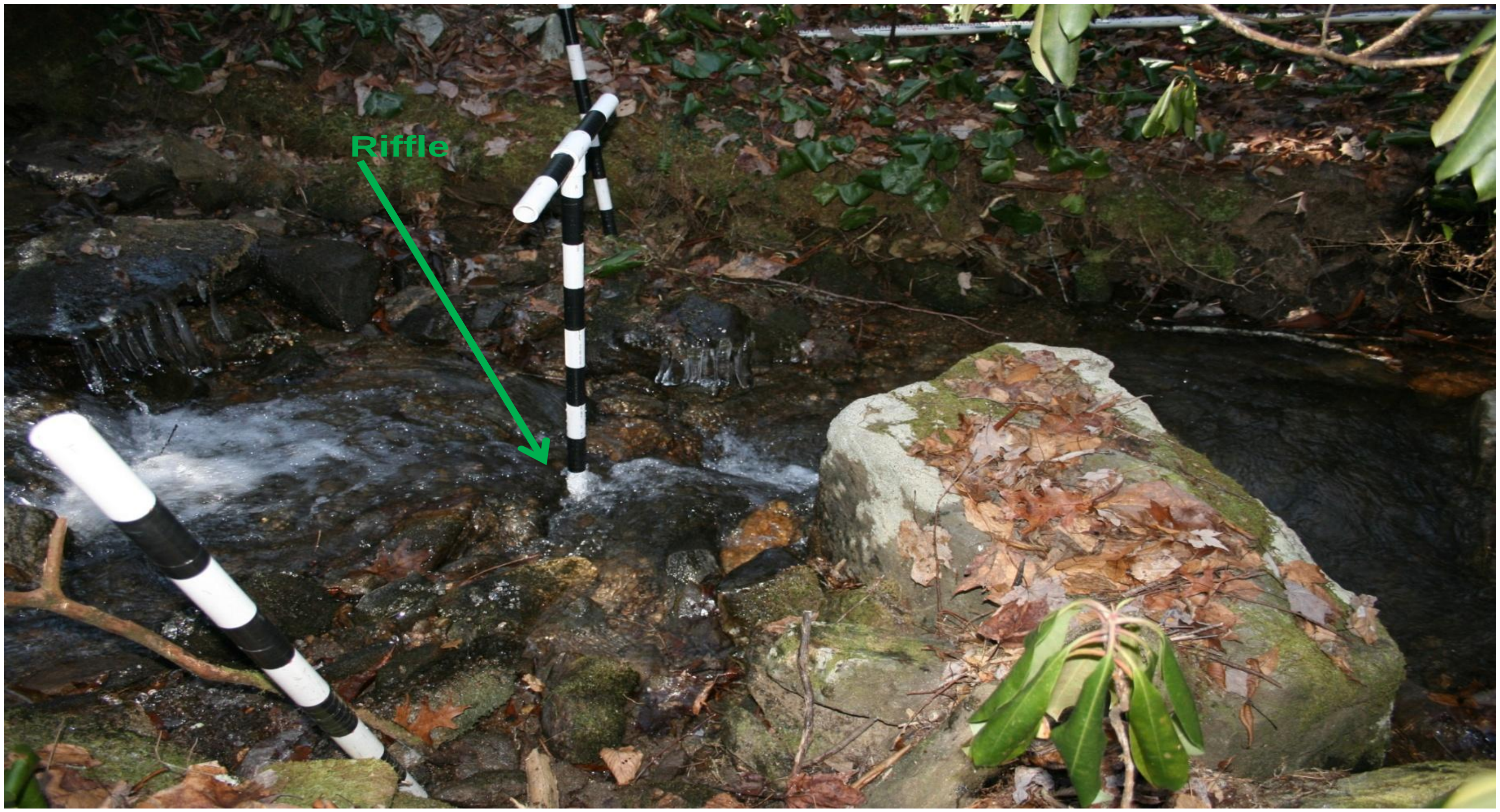


Figure 16. Photograph of sample cross-section for physical habitat.

Figure 17. Photographic example of bed material at a sample cross-section.

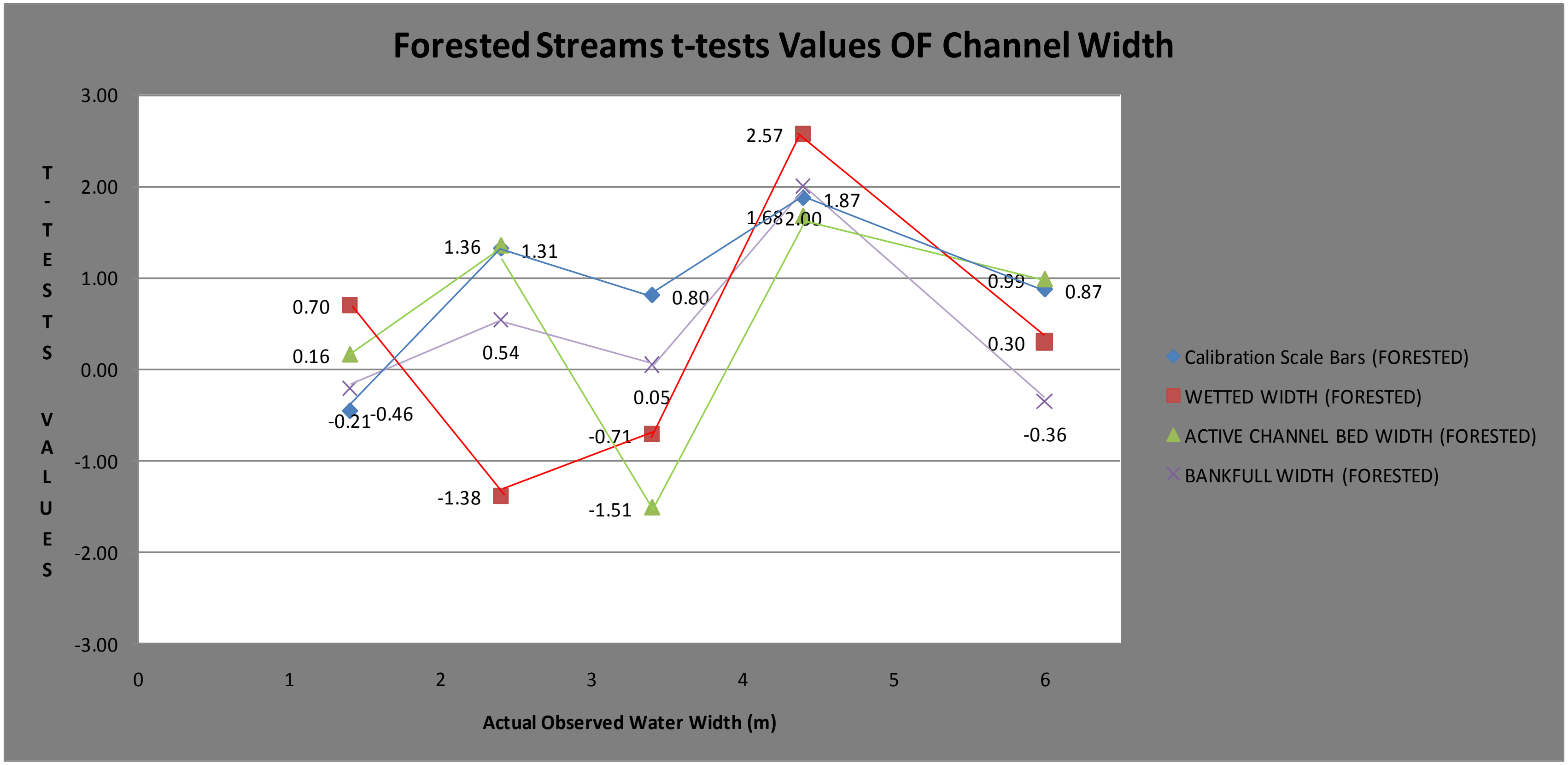


Figure 18. Forested t-tests values of channel width.

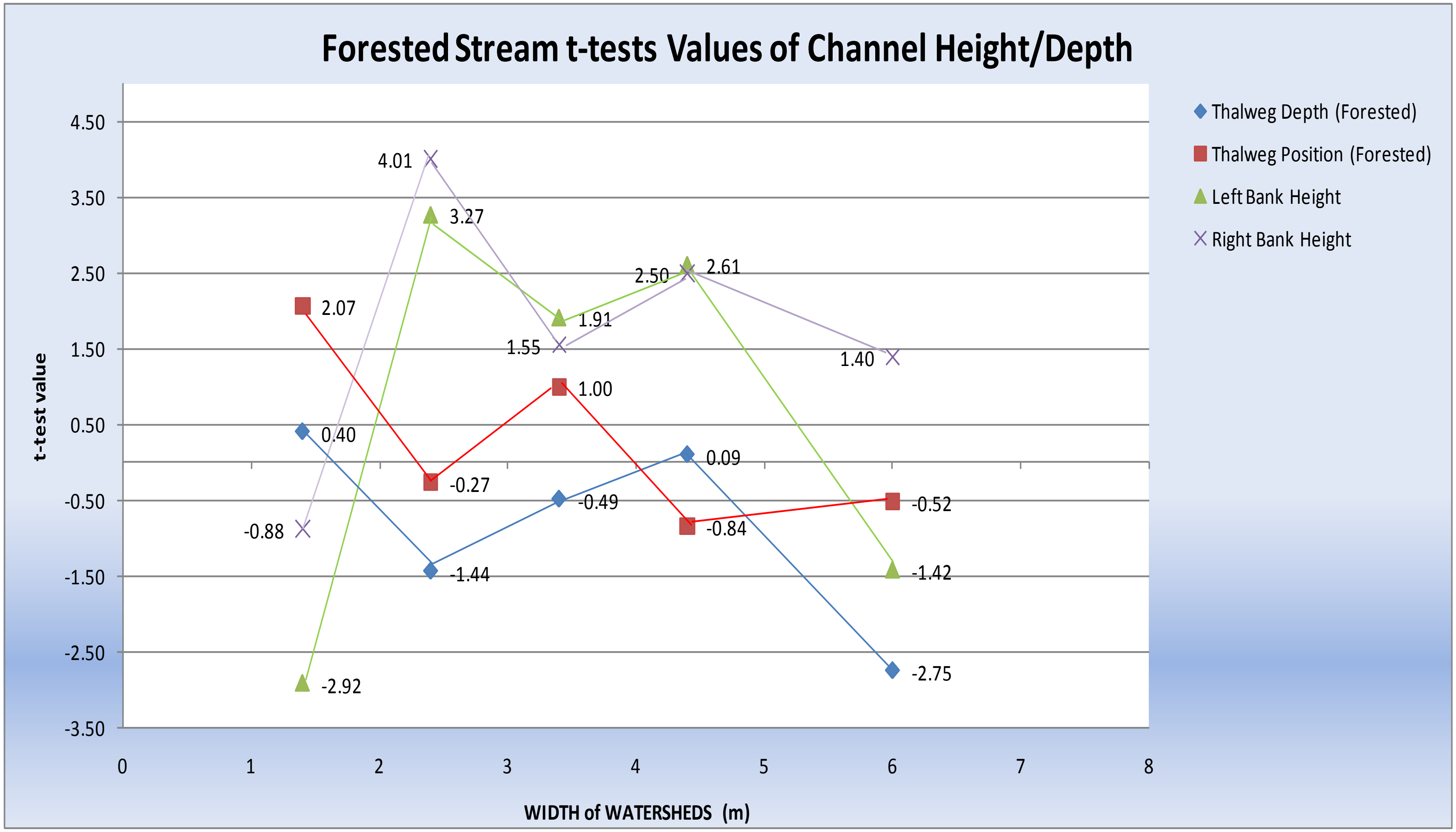


Figure 19. Forested t-tests values of channel height and depth.

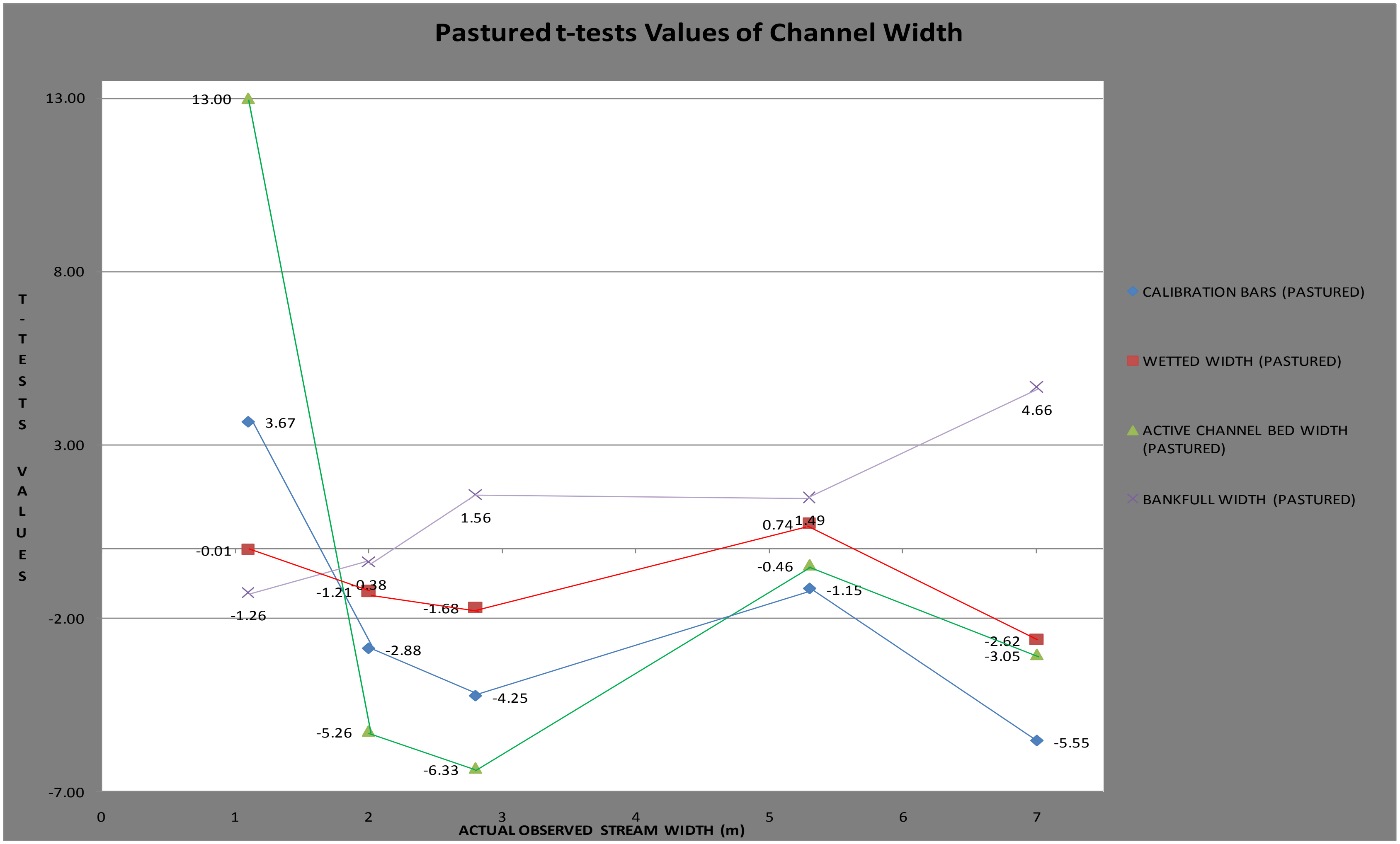


Figure 20. Pastured streams t-tests values of channel width.

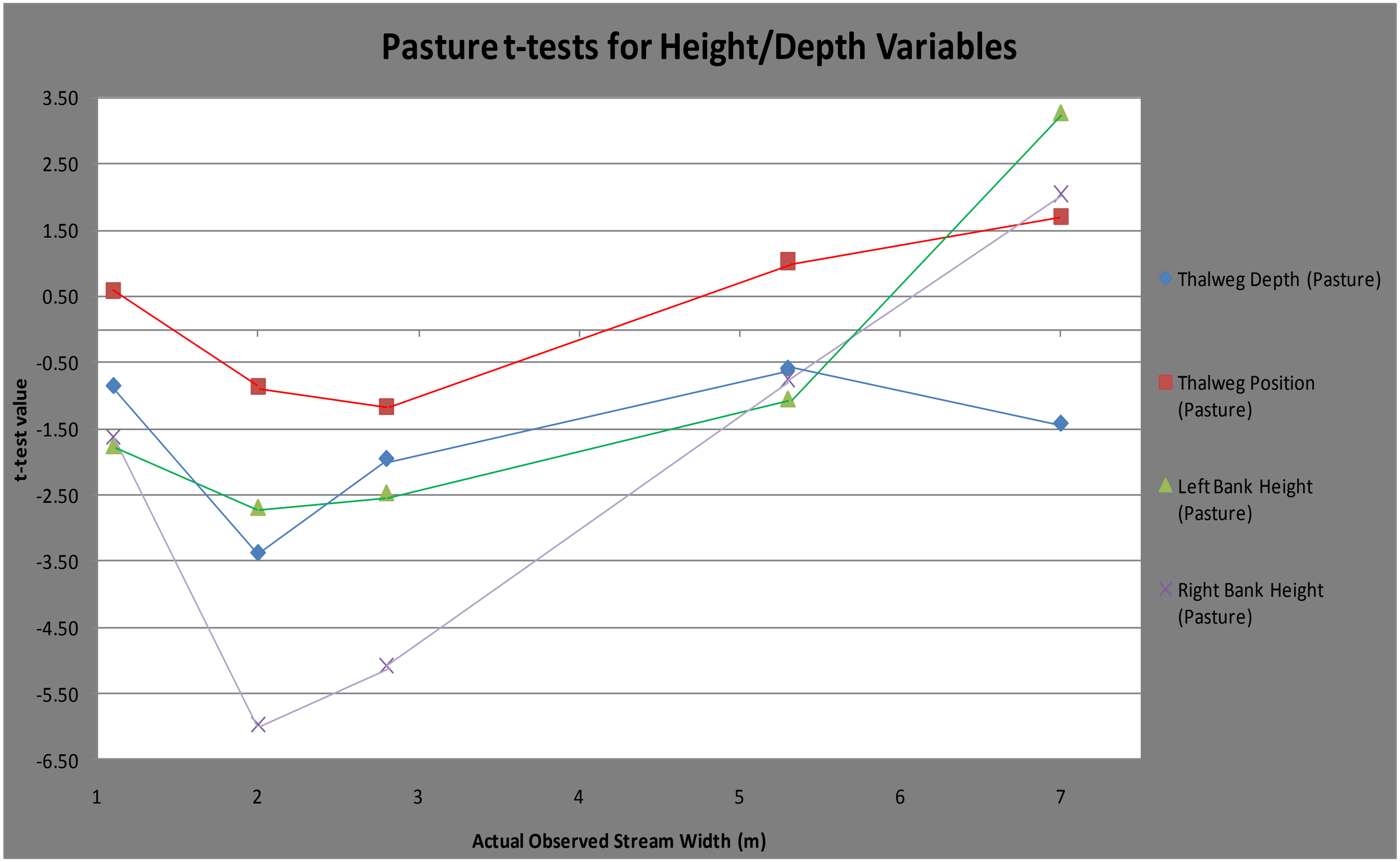
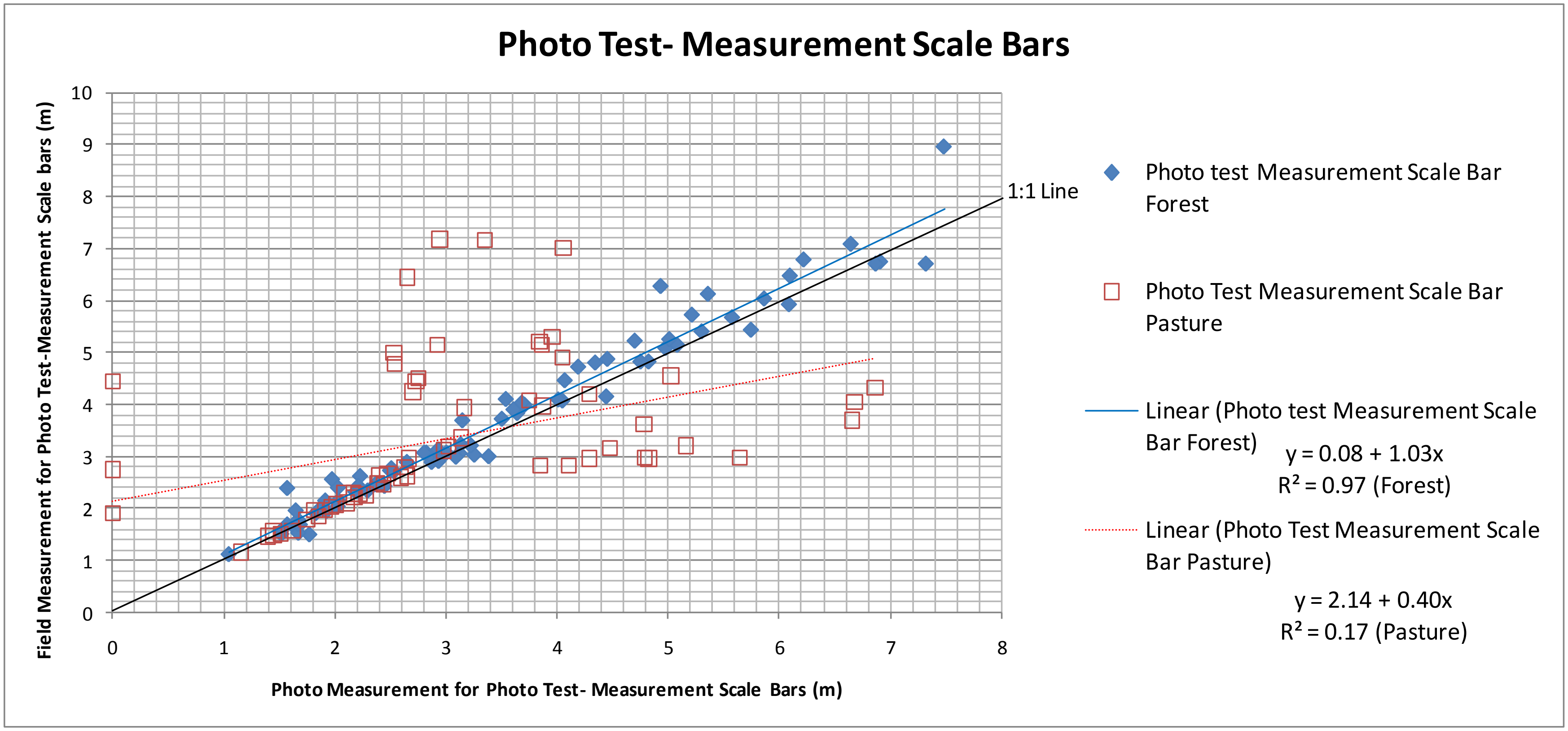
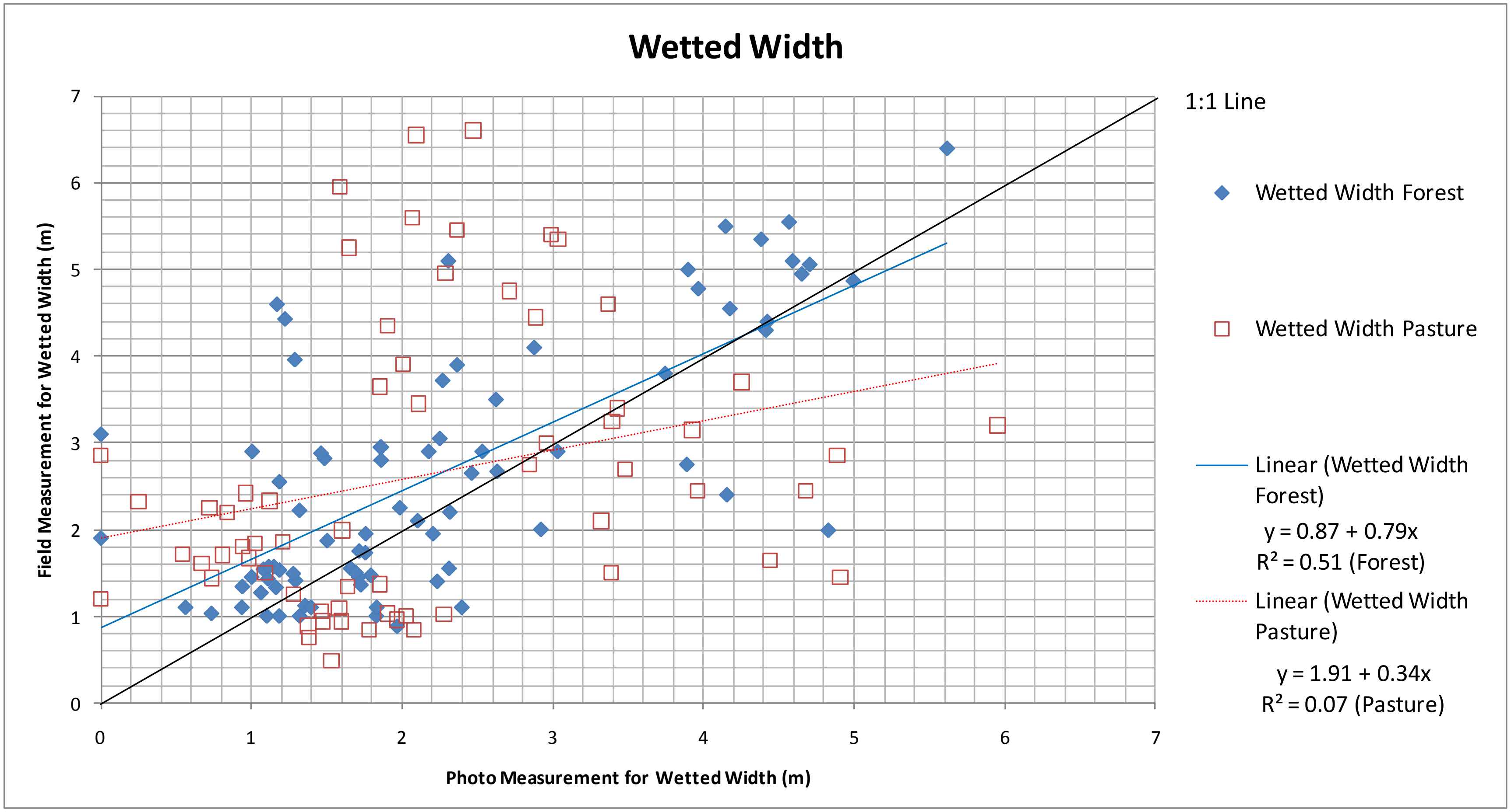
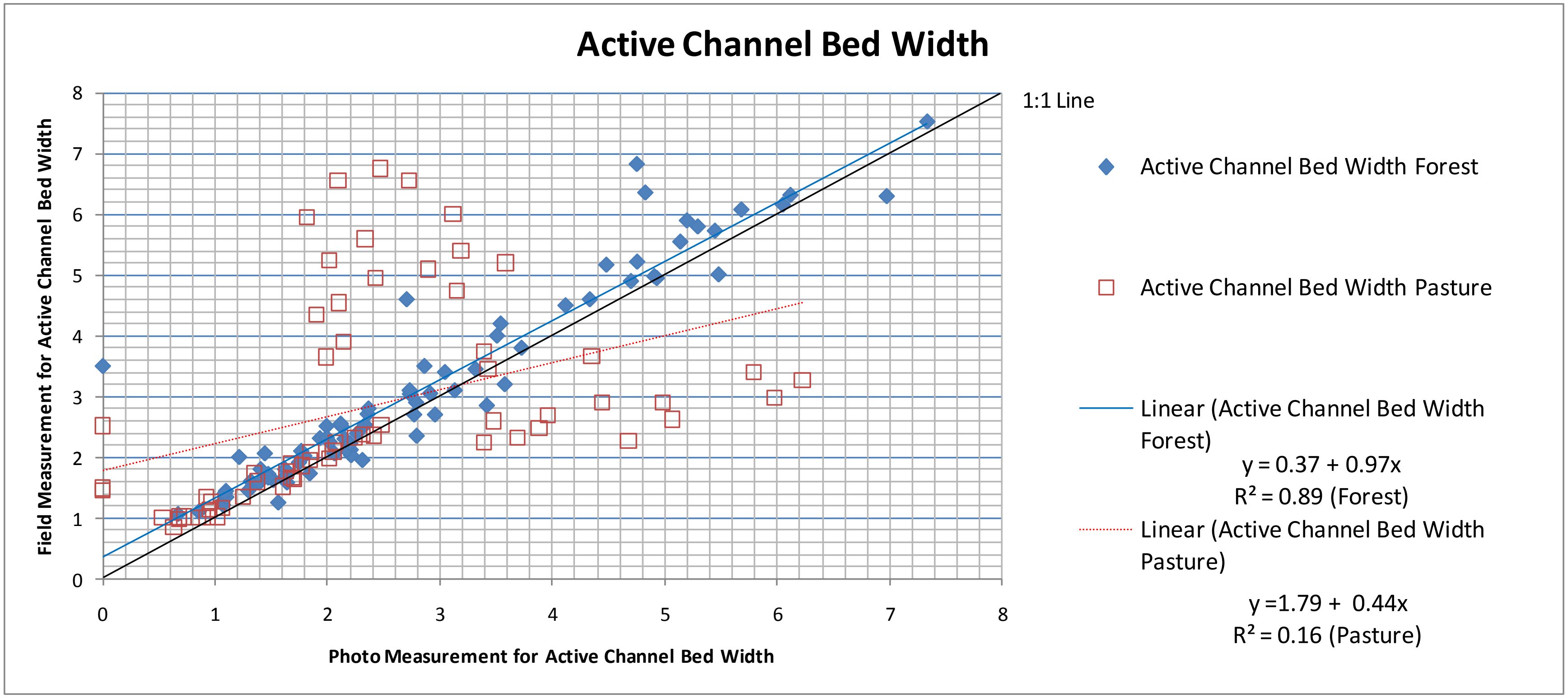


Figure 21. Pastured streams t-tests values of channel height and depth.

Figure 22. Regression relationships of morphological width variables: forested and pastured reaches of field measurements and photographic measurements. (a) photo test-measurement scale bars, (b) wetted width, (c) active channel bed width, and (d) bankfull width.




Wetted Width
Field Measurement for Wetted Width (m)
Photo Measurement for Wetted Width (m)
0
1
2
3
4
5
6
7
1:1 Line
Wetted Width Forest
Wetted Width Pasture
Linear (Wetted Width Forest)
y = 0.87 + 0.79x
R² = 0.51 (Forest)
Linear (Wetted Width Pasture)
y = 1.91 + 0.34x
R² = 0.07 (Pasture)


Active Channel Bed Width
Field Measurement for Active Channel Bed Width
Photo Measurement for Active Channel Bed Width
0
1
2
3
4
5
6
7
8
1:1 Line
Active Channel Bed Width Forest
Active Channel Bed Width Pasture
Linear (Active Channel Bed Width Forest)
y = 0.37 + 0.97x
R² = 0.89 (Forest)
Linear (Active Channel Bed Width Pasture)
y =1.79 + 0.44x
R² = 0.16 (Pasture)

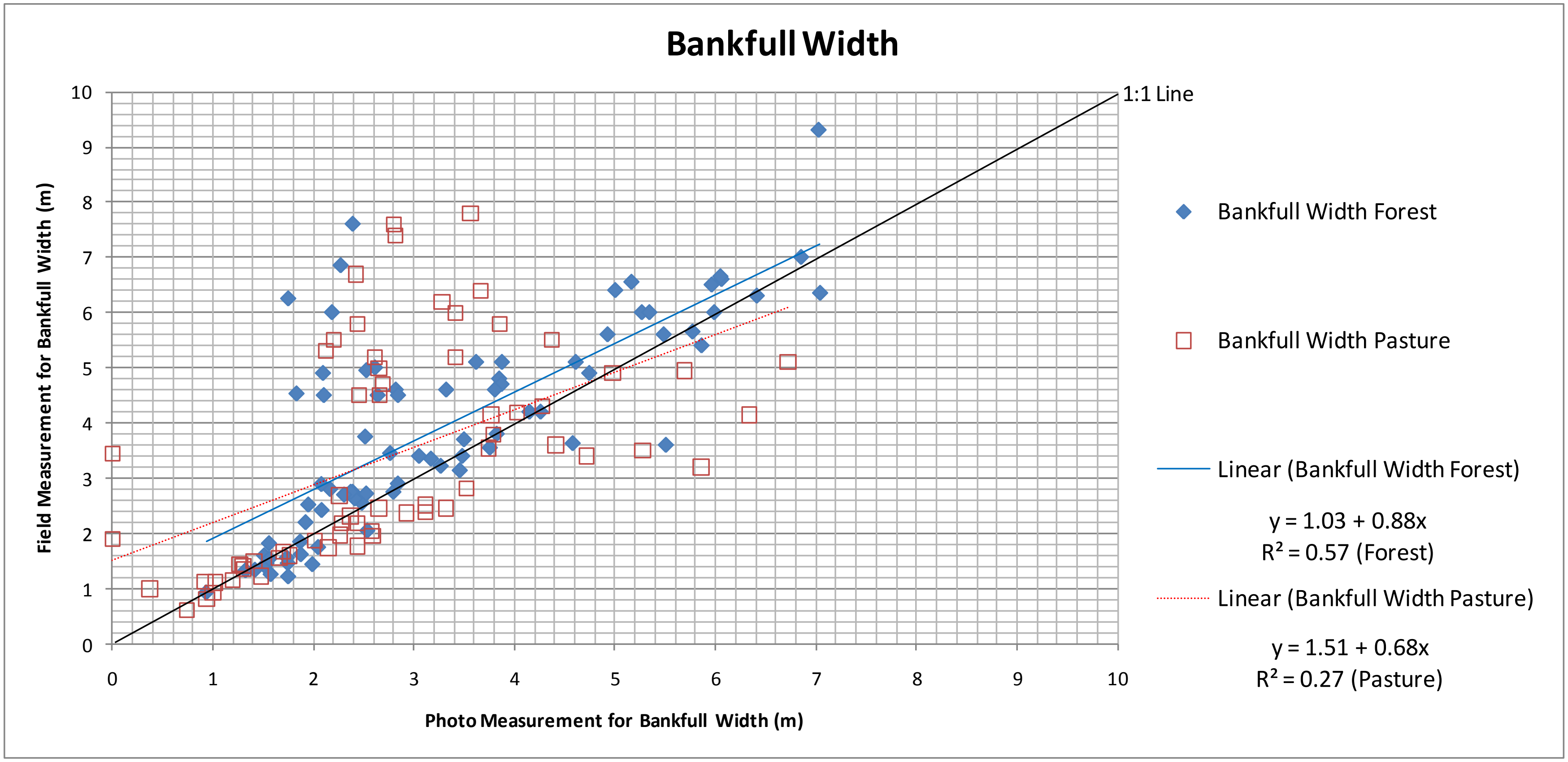
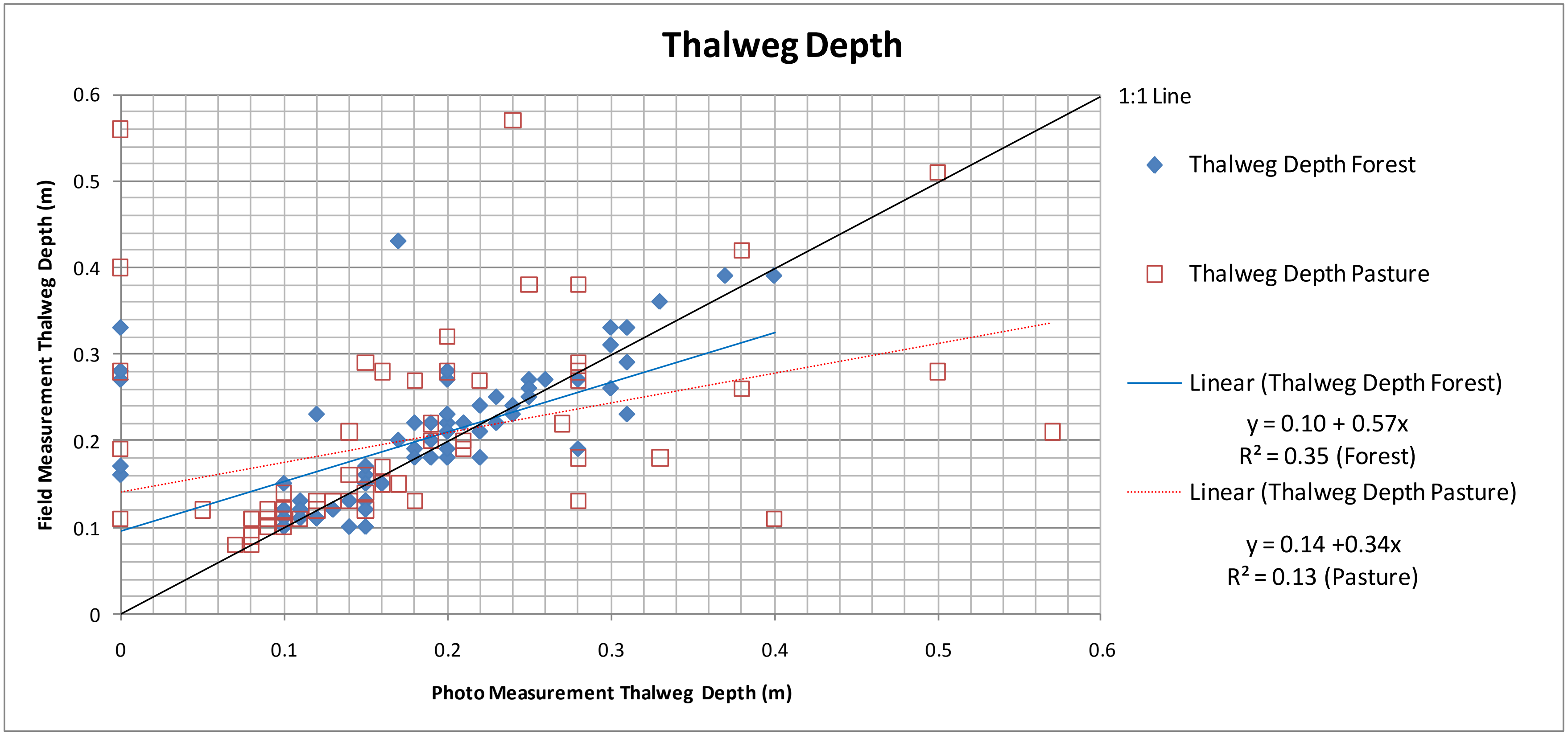
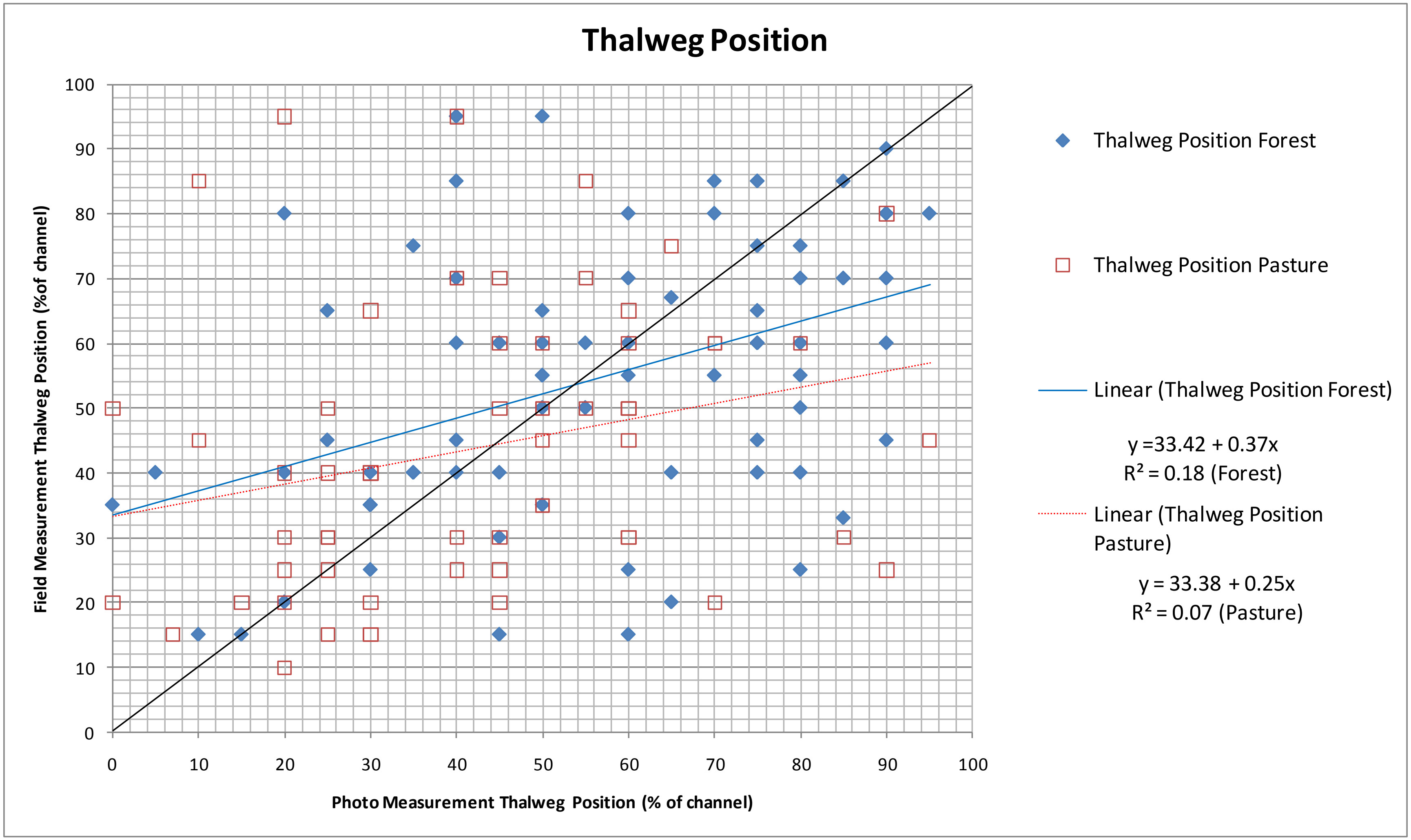
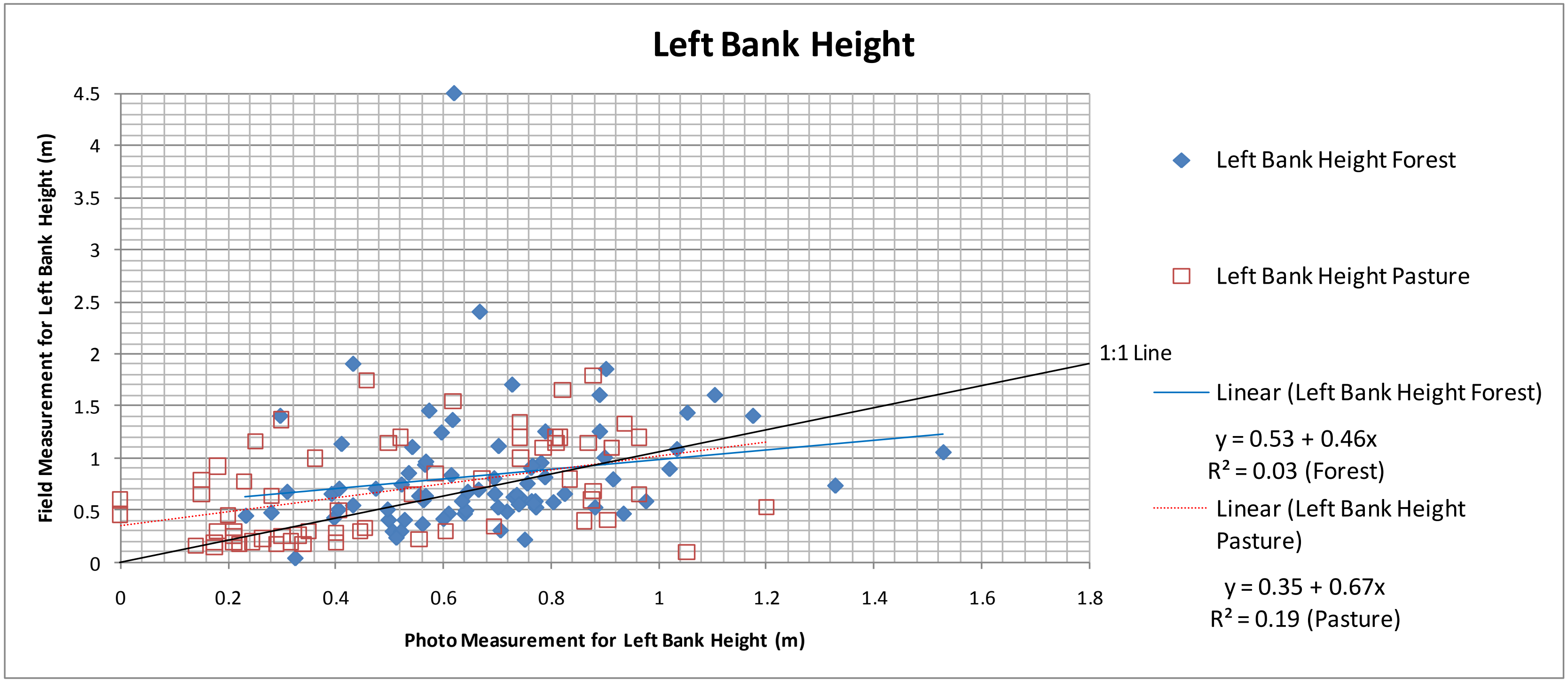

Bankfull Width
1:1 Line
Field Measurement for Bankfull Width (m)
Photo Measurement for Bankfull Width (m)
0
1
2
3
4
5
6
7
8
9
10
Bankfull Width Forest
Bankfull Width Pasture
Linear (Bankfull Width Forest)
y = 1.03 + 0.88x
R² = 0.57 (Forest)
Linear (Bankfull Width Pasture)
y = 1.51 + 0.68x
R² = 0.27 (Pasture)

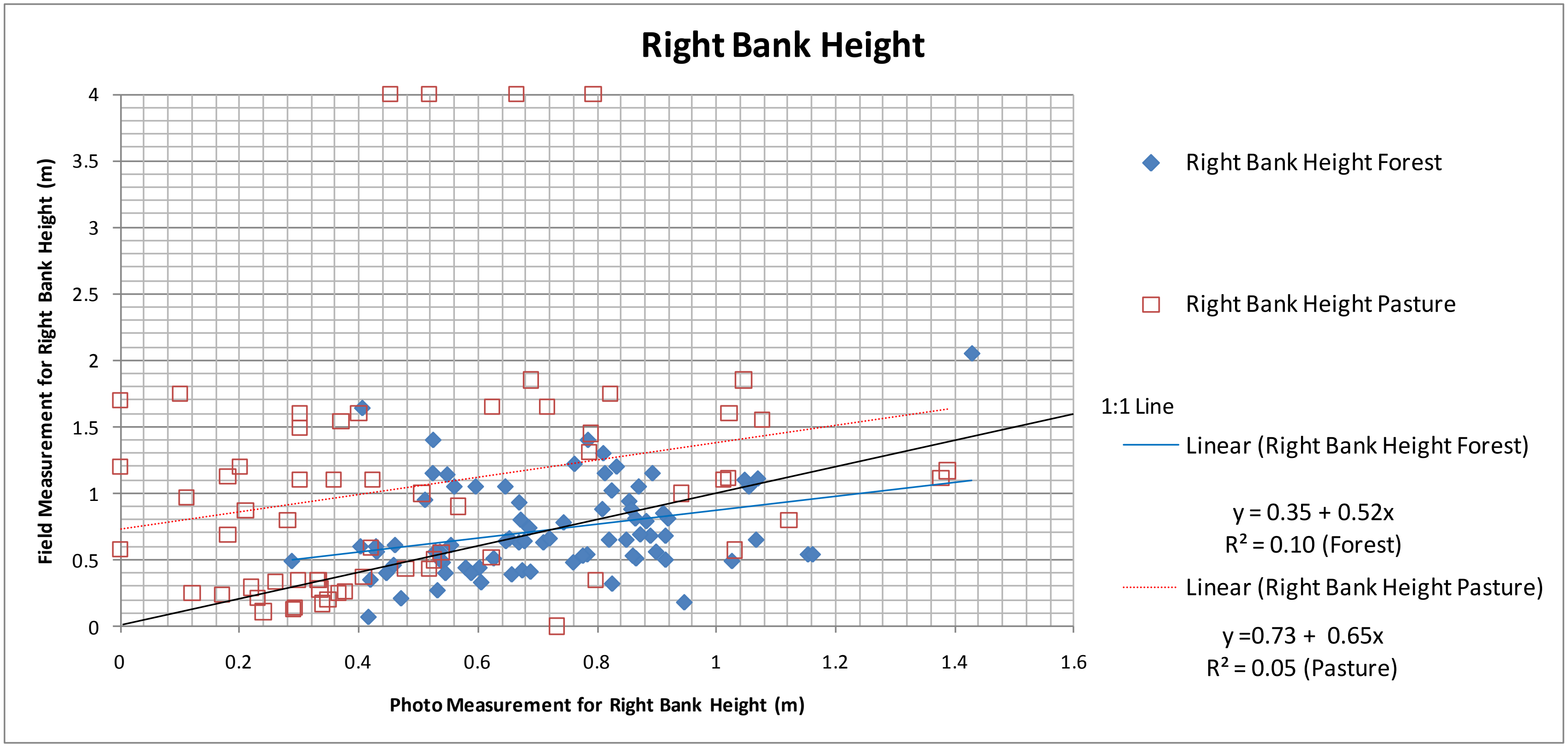
Figure 23. Regression relationships of morphological height and depth variables: forested and pastured reaches of field measurements and photographic measurements. (a) thalweg depth, (b) thalweg position, (c) left bank height, and (d) right bank height.




Thalweg Position
Field Measurement Thalweg Position (%of channel)
Photo Measurement Thalweg Position (% of channel)
100
90
80
70
60
50
40
30
20
10
0
0
10
20
30
40
50
60
70
80
90
100
Thalweg Position Forest
Thalweg Position Pasture
Linear (Thalweg Position Forest)
y =33.42 + 0.37x
R^2 = 0.18 (Forest)
Linear (Thalweg Position Pasture)
y = 33.38 + 0.25x
R^2 = 0.07 (Pasture)



Left Bank Height
Field Measurement for Left Bank Height (m)
Photo Measurement for Left Bank Height (m)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
Left Bank Height Forest
Left Bank Height Pasture
1:1 Line
Linear (Left Bank Height Forest)
y = 0.53 + 0.46x
R² = 0.03 (Forest)
Linear (Left Bank Height Pasture)
y = 0.35 + 0.67x
R² = 0.19 (Pasture)


Right Bank Height
Field Measurement for Right Bank Height (m)
Photo Measurement for Right Bank Height (m)
0
0.5
1
1.5
2
2.5
3
3.5
4
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
Right Bank Height Forest
Right Bank Height Pasture
1:1 Line
Linear (Right Bank Height Forest)
y = 0.35 + 0.52x
R² = 0.10 (Forest)
Linear (Right Bank Height Pasture)
y =0.73 + 0.65x
R² = 0.05 (Pasture)