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Evaluating survey instruments and methods in a steep channel

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ABSTRACT

Methods for surveying and analyzing channel bed topography commonly lack a rigorous characterization of their appropriateness for project objectives. We compare four survey methods: a hand level, two different methods of surveying with a laser rangefinder, and a real-time kinematic GNSS (RTK-GNSS) to explore their accuracy in determining channel bed slope and roughness for a study reach in a small, dry, steep channel. Additionally, we evaluate the variability among four operators for each survey technique. Two methods of calculating reach slope were computed: a regression on the channel profile and a calculation using only survey endpoints. Using data from the RTK-GNSS as our accuracy reference, the hand level and two-person laser rangefinder surveying systems performed with high accuracy (<5% error in estimating slope, <10% error in estimating roughness), while the one-person laser rangefinder survey system performed with considerably lower accuracy (up to 54% error in roughness and slope). Variability between operators was found to be very low (coefficients of variation ranged from 0.001 to 0.046) for all survey systems except the one-person laser rangefinder system, suggesting that survey data collected by different operators can be validly compared. Due to reach-scale concavity, calculating slope using a regression produced significantly different values than those obtained by using only survey endpoints, suggesting that caution must be taken in choosing the most appropriate method of calculating slope for a given project objective. We present recommendations for choosing appropriate survey and analysis methods to accomplish various surveying objectives.

1. Introduction

Topographic surveying is commonly used in geomorphic studies to measure channel slope, channel bed roughness, and other spatial characteristics of geomorphic features; however, multiple survey techniques exist. Investigators often use the most convenient survey technique available and report their methods in insufficient detail, resulting in an inability to assess the appropriateness of the survey procedure for achieving the project objectives. We are unaware of any rigorous comparison of different methods of surveying and calculating channel slope, despite numerous high-profile studies reporting channel bed slopes that provide important evidence for their conclusions without explicitly detailing how slope was calculated (e.g. Adams et al., 2000; Howard and Kerby, 1983; Montgomery et al., 1996; Seidl and Dietrich, 1992; Snyder et al., 2000; Wood-Smith and Buffington, 1996).

Surveying remote, difficult-to-access, or inaccessible locations requires either techniques that are able to measure the surfaces remotely (e.g., airborne laser scanning, terrestrial laser scanning, or structure-from-motion photogrammetry) or equipment that is transportable to the survey site (e.g., Mikoš et al., 2005; Santangelo et al., 2010; Smith et al., 2015; Vianello et al., 2009). We present a rigorous comparison of four topographic survey systems: hand level (HL), handheld laser rangefinder requiring one (LR1) or two (LR2) operators, and a real-time kinematic GNSS (RTK-GNSS). Although there are other field survey systems available (e.g. total station, which is bulky, difficult to operate in steep terrain, and difficult to carry great distances), all of these systems can function well in difficult-to-access locations, are generally portable, and can operate in high-relief terrain. We focus on survey scenarios in difficult-to-access locations because the choice of survey system in easy-to-access locations is typically not dependent on the versatility of the survey system, but instead depends on the resolution needed and cost of the equipment.

The laser rangefinder is a relatively recent development in surveying that permits fast measurement of distance, azimuth, and inclination using a laser projected from the rangefinder to a reflective or non-reflective target. Laser rangefinder systems have been used to measure landslide scars (Santangelo et al., 2010), rock outcrops (Alfarhan et al., 2008), three-dimensional topography (Hayakawa and Tsumura, 2009; Hayakawa et al., 2007), rock fall (Mikoš et al., 2005), sampling distances (Ransom and Pinchak, 2003), and snow depth in inaccessible terrain

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(Hood and Hayashi, 2010). Laser rangefinders display accuracy similar to traditional survey methods such as a GNSS or levels when collecting individual distance measurements or surveying terrain that is measured using an approach that combines independent distance measurements (Hayakawa and Tsumura, 2009; Hayakawa et al., 2007; Hood and Hayashi, 2010; Ransom and Pinchak, 2003). This suggests that laser rangefinders could be a viable method for the rapid and versatile surveying of fluvial features with decimeter-scale accuracy. The relatively cheap cost and the ease, versatility, and speed of operation for a laser rangefinder indicate that it may be a viable surveying choice and an alternative to the more traditional hand level, which is comparable in portability and ease of use. This potential motivates our examination of its appropriateness compared to other methods for channel bed surveys.

Variability between operators (interoperator variability) during repeated measurements of clast size on river beds can be significant and hamper comparisons of clast size measurements taken by different investigators (Wohl et al., 1996). Like clast counting methods, surveying involves the subjective choice of where measurements will be taken along the channel bed. This leads us to hypothesize that it may be similarly problematic to compare channel bed surveys done by different operators. To address this, we compare surveys of the same channel done by different operators to determine whether there is significant variability between operators.

We evaluate the efficacy of the laser rangefinder as a survey tool for determining longitudinal channel profiles, with the specific objectives of determining channel bed slope and roughness. We also address the appropriateness of various methods of calculating channel bed slope from channel bed elevation data. Measuring bed slope and roughness allows for a good evaluation of a survey method's local accuracy (i.e., the ability to determine small changes in elevation for accurately characterizing roughness) and reach-scale accuracy (i.e., the ability to characterize broad-scale topographic trends needed to understand channel slope).

Based on previous evaluations of the laser rangefinder as a surveying system, we hypothesize that a laser rangefinder will perform similarly to a hand level and possibly an RTK-GNSS in terms of the accuracy of slope and roughness estimations, thus making it a viable and potentially more versatile tool for rapidly surveying difficult-to-access channels. We use the results of a test of four survey methods, four separate surveyors, and two methods of calculating channel bed slope to: 1) evaluate the appropriateness of two methods of calculating channel bed slope, 2) test the efficacy of various survey systems, 3) evaluate the degree to which surveys performed by different operators differ from one another, 4) evaluate the effects of temporal and spatial point density on survey accuracy, and 5) provide best-practice recommendations for survey methodologies for a broad set of survey goals.

2. Field site

The unnamed, 0.71 km^2 watershed used in this study lies on the eastern slope of the Colorado Front Range and drains into the Cache la Poudre River (Fig. 1). We surveyed a 61 m study reach that is characterized by a mix of step-pool and cascade morphology and a boulder-dominated bed at the bottom of the watershed just above an alluvial fan (Fig. 2). We completed field surveys on 3 October 2015. The primary mechanism for runoff in the channel is summer convective thunderstorms (Jarrett and Costa, 1988), and the current morphology of the channel is largely the result of post-wildfire generated peak flows and a single long duration flood in September 2013 (Gochis et al., 2015). The study watershed is predominantly comprised of ponderosa pine (*Pinus ponderosa*) woodland supporting scattered trees over a graminoid-dominated understory. In its lower portions, the forest grades into shrubland, supporting mountain mahogany (*Cercocarpus montanus*) and skunkbush sumac (*Rhus trilobata*). In-channel vegetation was sparse and created almost no obstruction to surveying.

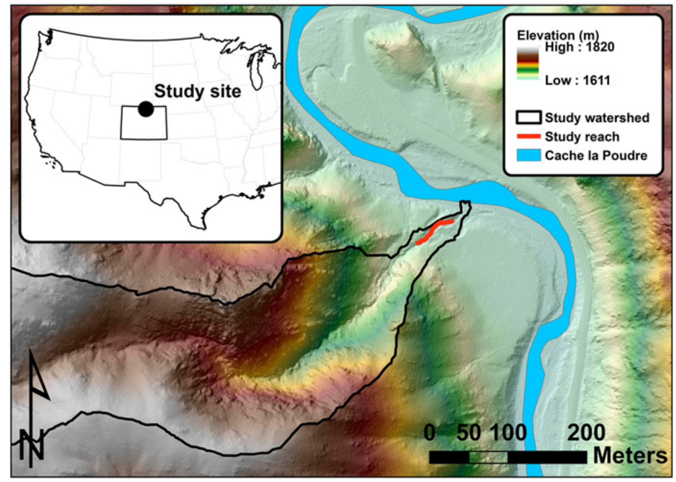

Fig. 1. The study site is located within the northern Colorado Front Range (inset) on a small 0.71 km^2 tributary to the Cache la Poudre River.

3. Methods

3.1. Summary of survey systems and data collection methods

We compared survey methods by developing multiple topographic models of a single channel thalweg as measured by four operators and four survey methods. The HL and LR1 systems are limited in that they can only survey one-dimensional paths along a surface unless special measures are taken to adapt them to a two-dimensional path. The LR2 and RTK-GNSS systems can survey two-dimensional paths along a surface without any modification. All survey systems measure the location and elevation of a point or series of points in space. With the exception of the RTK-GNSS, the location and elevation of survey points are not referenced to a specific coordinate system, but instead are referenced to the starting point of the survey.

3.1.1. Hand level (HL)

The hand level is a simple magnified sighting instrument that allows one to sight a level plane from their eye using a stadia crosshair and a bubble level. Prior to our hand level surveys, we laid a graduated tape with centimeter resolution along the channel thalweg. During each survey, the operator placed the stadia rod on survey locations they selected as being necessary to accurately model the channel bed. The recorder sighted the hand level on the stadia rod, reading the elevation measured by the stadia rod at the given point. This measurement was recorded

Fig. 2. The authors surveying in the study reach. Note the large clasts and incised channel.