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Identification of steps and pools from stream longitudinal profile data

André E. Zimmermann *, Michael Church, Marwan A. Hassan

Department of Geography, The University of British Columbia, 1984 West Mall, Vancouver British Columbia, Canada V6T 1Z2

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ABSTRACT

Field research on step–pool channels has largely focused on the dimensions and sequence of steps and pools and how these features vary with slope, grain sizes and other governing variables. Measurements by different investigators are frequently compared, yet no means to identify steps and pools objectively have been used. Automated surveying instruments record the morphology of streams in unprecedented detail making it possible to objectively identify steps and pools, provided an appropriate classification procedure can be developed.

To achieve objective identification of steps and pools from long profile survey data, we applied a series of scale-free geometric rules that include minimum step length (2.25% of bankfull width (W_b)), minimum pool length (10% of W_b), minimum residual depth (0.23% of W_b), minimum drop height (3.3% of W_b), and minimum step slope (10° greater than the mean slope). The rules perform as well as the mean response of 11 step–pool researchers who were asked to classify four long profiles, and the results correspond well with the channel morphologies identified during the field surveys from which the long profiles were generated. The method outperforms four other techniques that have been proposed. Sensitivity analysis shows that the method is most sensitive to the choice of minimum pool length and minimum drop height.

Detailed bed scans of a step–pool channel created in a flume reveal that a single long profile with a fixed sampling interval poorly characterizes the steps and pools; five or more long profiles spread across the channel are required if a fixed sampling interval is used and the data suggest that survey points should be located more frequently than the diameter of the step-forming material. A single long profile collected by a surveyor who chooses breaks in slope and representative survey points was found to adequately characterize the mean bed profile.

1. Introduction

For decades much of the research about step–pool channels has revolved around how the dimensions of the step and pool vary with changes in characteristics such as discharge, basin area, channel slope, and the size of the step-forming material in the channel (Hayward, 1980; Grant et al., 1990; Abrahams et al., 1995; Chin, 1999). To determine the dimensions of step–pool units, long profile surveys are commonly completed and the steps and pools are identified in the field. The surveys are usually comprised of breaks in slope and points that identify important channel features (Zimmermann and Church, 2001; Milzow et al., 2006; Nickolotsky and Pavlowsky, 2006), but may alternatively be comprised of survey points collected using a fixed sampling interval (Wooldridge and Hickin, 2002). Subsequently, metrics such as the step length, step height, residual pool depth, and pool length are calculated for each step–pool unit using the survey data. Some researchers (e.g., Chin, 1999; Wooldridge and Hickin, 2002; Milzow et al., 2006) have attempted to identify the location of steps and pools using only the long profile data. Thus the traditional approach includes two important subjective components. First, the surveyor must decide where to run the long profile and put the rod to capture the overall channel morphology, and second, the step–pool unit must be identified, either in the field or afterwards.

As the study of step–pools has progressed, authors (Wohl and Grodek, 1994; Zimmermann and Church, 2001; Chin and Wohl, 2005; Curran and Wilcock, 2005; Church and Zimmermann, 2007) have incorporated data from other studies without apparently considering the subjectivity associated with identifying the step–pool channels. As Nickolotsky and Pavlowsky (2006) illustrated, the noise introduced by different operators describing step–pools in different ways can lead to important differences in the metrics of step–pools (pool length, step height etc). In addition, we believe that some researchers will classify a particular unit as a step–pool, while others will not; hence, an objective means of classifying step–pool channels is needed.

While a few objective means of classifying step–pools using long profile surveys have been presented in the literature (Wooldridge and Hickin, 2002; Milzow et al., 2006), these techniques have not been widely tested. Furthermore, they overcome only the subjectivity associated with deciding where the steps and pools are, based on a long profile; they do not suggest how to overcome the subjectivity

* Corresponding author. Tel.: +1 604 738 8899; fax: +1 604 822 6150.
E-mail addresses: andre.zimmermann@mail.mcgill.ca (A.E. Zimmermann), mchurch@geog.ubc.ca (M. Church), mhassan@geog.ubc.ca (M.A. Hassan).

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associated with surveying the long profile data. Wooldridge and Hickin (2002) concluded that subjective field-based classification works best.

Traditionally, survey points are chosen so that the data represent significant breaks in the channel morphology. The data do not reproduce the actual details of the channel as this would take too much time. In recent years however, technological advances that include low-level aerial photos, tracking total stations, and tripod-mounted laser scanners have made it possible to objectively record the shape of the channel. As a result, producing detailed digital elevation models (DEMs) that record the morphology of the channel is now possible, but objective means to classify the channel units using these DEMs do not exist.

The objectives of this paper are as follows:

i. to show that subjective classification leads to considerable ambiguity as to what is a step–pool and what is not and that different "experts" classify the same long profile in substantially different ways;
ii. to show that a scale-free, rule-based classification scheme can delineate step–pool units based on long profiles in a manner equivalent to the modal response of "experts" and can identify most of the step–pool units observed in the field;
iii. to demonstrate that objectively classifying a step–pool channel based on subjectively collected long profile survey data yields results similar to classifying the channel in the field;
iv. to illustrate that the scale-free, rule-based classification scheme performs better than four objective methods previously presented in the literature: minimum slope (Milzow et al., 2006), zero-crossing, bed elevation differencing, and spectral analysis (Wooldridge and Hickin, 2002); and
v. to investigate the effectiveness of a single, fixed sampling interval long profile to characterize the mean long profile for the purpose of classifying step–pool channels.

The development of a scale-free classification scheme will enable all researchers to interpret long profile data in an objective manner and thus facilitate valid comparisons of their results. The focus on the long profile preserves the possibility to recover objectively classified step–pools from past studies for which profile data are available.

2. Methods

2.1. Field surveys

Field surveys were completed by two different crews at 13 steep channels in British Columbia using either a level-tape survey or a total station survey. The density of field survey points is either systematically every 20 cm or every few meters at breaks in slope. With the exception of Deeks Creek where four short reaches (25–80 m in length; 3.5–10.4 bankfull widths) were visited, between 19.4 and 50.1 bankfull widths of channel were surveyed (50 to 362 m of channel). Channel subunits were identified when they spanned the channel and a dominant hydraulic function appeared to exist. Steps and pools were always identified as a pair, and it was required that the step span the channel and that during low to moderate flood events water plunges off the step into the pool downstream as an impinging jet (see Church and Zimmermann, 2007, after Wu and Rajaratnam, 1996, 1998). This requires subcritical flow conditions at the reach scale and the step height to be comparable to flow depth during floods. At high flows, whether the flow conditions change to the subcritical surface jet regime or the supercritical nappe, transitional or skimming/rapid regime is an unresolved research question.

In order to identify a step–pool unit, it was necessary to assess whether, during high flows, a step–pool unit visible at low flows would still persist and whether new units would become evident at higher flows. Other studies considering only low flow features may not put the same emphasis on the hydraulic function of the channel units at high flows and may establish different classification results. The emphasis on hydraulics is driven by the notion that water plunging off the steps scours the bed, forming the pools, and plays a major role in controlling the dissipation of energy in mountain streams. Thus, the field surveys were intended to identify steps and their downstream pools and to characterize the bed roughness for flow resistance considerations (a topic of much research, see Marston, 1982; Abrahams et al., 1995; Maxwell and Papanicolaou, 2001; Lee and Ferguson, 2002; Aberle and Smart, 2003; Wilcox et al., 2006; Comiti et al., 2007). The step–pools considered here are distinct from micro-cascade (Grant et al., 1990) features that may include drops, pools, and steps that do not span the channel. None of the survey data was collected with the idea that the profiles would subsequently be used to objectively identify step–pool units, rather the data was initially collected in order to characterize the channel slope and step–pool dimensions.

2.2. Variability among step–pool researchers

To assess how much variability there is in the way different step–pool researchers classify a channel given a long profile, four long profiles were sent to 15 step–pool researchers. We explicitly sought people who had experience classifying step–pool channels by reviewing the step–pool literature and e-mailing the researchers directly.

For each profile, lengths of channel representing six to eight bankfull widths were provided (Fig. 1) as this was sufficiently long to characterize a number of step–pool units while still being short enough that the details were not obscured on a sheet of letter-sized paper (21*28 cm). An initial set of trial long profiles was created with no vertical exaggeration and distributed to two researchers. It was observed that these were particularly difficult to classify and many of the step–pools that were identified in the field were not readily evident. For this reason vertical exaggeration was adjusted by eye in order to make the bed forms appear reasonable. This is a subjective adjustment that we observed to have an effect on classification results, further supporting the need for an objective means of classifying the bed.

Each respondent was given the following instructions:

> We seek to analyze how a number of researchers, who have previous experience classifying step–pool channels, classify the same long profiles. Thus, we have prepared four long profiles that vary in slope from 5 to 15 percent and in width from 0.47 m to 7.2 m. Three profiles were taken from field surveys and one is the result of a flume experiment. The density of field survey points is either systematically every twenty centimeters or every few meters at breaks in slope. In the case of the flume data, there is a point every 2 mm.
>
> To help guide you in this exercise we ask that you consider a step–pool bedform to be a single entity with two sub-sections, the step and the pool. Thus one cannot have a step without a pool and vice-versa. We also ask that you consider the step to be upstream of the pool as we consider the pool to be a morphology caused by water plunging off a step. We consider a step–pool unit to be a channel-spanning bedform that has water plunging off the step into the pool at low to modest discharges. Whether the plunge persists at high flows remains an active research question (Church and Zimmermann, 2007). It may be useful to estimate the low flow water profile and thereby identify the pools.
>
> On each profile please identify where you believe the pool starts, the pool ends/step starts, the step ends and where 'other' sections of channel exist. While the 'other' sections of the channel can be classified as a range of morphologies (including riffle–pool, cascade,