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A new approach for the estimation of extreme roughness in torrents by Hydraulic and Photogrammetry

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Abstract

In this paper we present an approach to estimate extreme roughness in torrents based on the transformation of an irregular bed geometry of a torrent reach into a geometrically well determined 'idealized' channel. One basic parameter is the surface of the water, which was determined by a photogrammetric method using stereo photos on the Analytical Plotter WILD AC1. Two torrent segments were photographed with two synchronized Rollei 6006 metric cameras, which were installed above the torrent while the mean velocity was simultaneously measured by the salt-dilution method. The Strickler coefficients derived from our studies at two torrent reaches in the Swiss Alps are also given in this paper.

1. Background - Basics - Problem

We still need calculations of waterlevels or streamflow velocities in natural mountain rivers or torrents based on the Chézy equation for different applications.

$$v = C*(R*S)^{0.5} \quad \text{with } R = A/P$$

This equation is theoretically based on considerations of momentum equilibrium (gravity/friction) of a turbulent uniform flow. Gravity is represented by A, friction (shear stress) by P and C. The hydraulic radius is obviously affected by the channel shape and the fullfilling of discharge.
The Chézy coefficient C is usually expressed by:

$k*R^{1/6}$	k:	Strickler's velocity coefficient
$1/n*R^{1/6}$	n:	Manning's roughness factor

Hydraulic calculations in torrents or mountain rivers are based on information about channel shape, roughness and hydraulic radius. At the moment, there exist no methods to estimate the complex geometry of torrent beds, which is essential for calculating the hydraulic radius. Hydrolgical investigations in small catchments in Switzerland point out that flow velocity in steep headwaters of mountainous river bassins is usually lower than in the mean stream *(Storchenegger, 1984; Hodel, 1993; Hodel and Storchenegger, 1994)*. In torrents, the channel shape varies in a wide range, and even on short reaches. It is often hard to separate the influence of channel

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shape variations from those of roughness elements. The determination of wetted perimeter and cross sectional area in torrents is based on subjective assumptions.

This paper deals with the quantitive evaluation of torrent shape and roughness using the Strickler equation. The evaluation procedure may easily be adapted to Manning's law or even to Darcy-Weisbach's friction factor. The new approach to representatively calculate extreme roughness is based on averaging the irregular bed geometry and translating it into a geometrically well determined ideal channel. The aim is to express these average values numerically in terms of the hydraulic radius and the Strickler coefficient.

2. New approach

The new approach mainly consists of replacing

- **cross sections** by 'horizontal' sections, represented by water surfaces on a short (but possibly representative) reach as system responses to the actual discharge, through averaging the size of water in motion, e. g. the derivation of the surface width B of a short reach by photogrammetry *(Storchenegger, 1988)*.

$$B = A_s/l$$

- **current meter measurements** by the dilution method through averaging velocity over the reach
- **velocity-area-profile** by the concentration graph of tracer to determine the discharge Q
- **the estimation of Strickler coefficient from the grain size distribution curve** (line-by-number analysis) by evaluating the system response

$$k_{St} = v/R^{2/3}*I^{1/2}$$

The new approach assumes

- effects due to expansions and contractions of cross-section to be included in roughness
- the widly varying bed of torrents to be presented by an idealized 'mean' cross-section which smoothly varies on size only along reaches between bifurcations.

3. Data acquisition

3.1. Photogrammetric image data acquisition at selected torrent reaches

Photographs of the water surface were taken at suitable test segments of selected torrents with two Rollei metric 6006 cameras (50 mm lens) using very photosensitive 6x6 cm^2 slide films (Kodak Ektachrom 400 ASA), while the measure-ment of the discharge was simultaneously performed by the salt-dilution method. For the photogrammetric image acquisition, a special manufactured suspension for the cameras was placed above the torrent. To facilitate the orientation of the acquired stereo pair for the subsequent photogrammetric analysis on the Analytical Plotter Wild AC1, signalized plates were positioned in the photographed area of the torrent. The signalized points were used as pass points for the orientation of the photos. Therefore, the signals were solidly fixed on firm ground and their positions were determined by geodetic measurements with a precision of 2 mm in planimetry and 1.5 mm in height.

During the measurement of the torrent' discharge by the salt-dilution method, two or three stereo photographs were simultaneously acquired releasing the shutter of the synchronized cameras through an infrared remote control. Thus, a clear temporal assignment of the discharge measurements and the related photos was warranted, which is essential for the further data analysis.

In the southern Swiss Alps, in Canton Valais (between Simplonpass and Simplon-Village) two torrent reaches were selected, which fulfill the hydrological, geodetic and photogrammetric requirements as discussed in *Hodel et al., 1991*. For the first test segment, the camera suspension (an aluminium ladder with two rolls) was installed on a steel rope stretched between two trees above the torrent (Fig. 1).

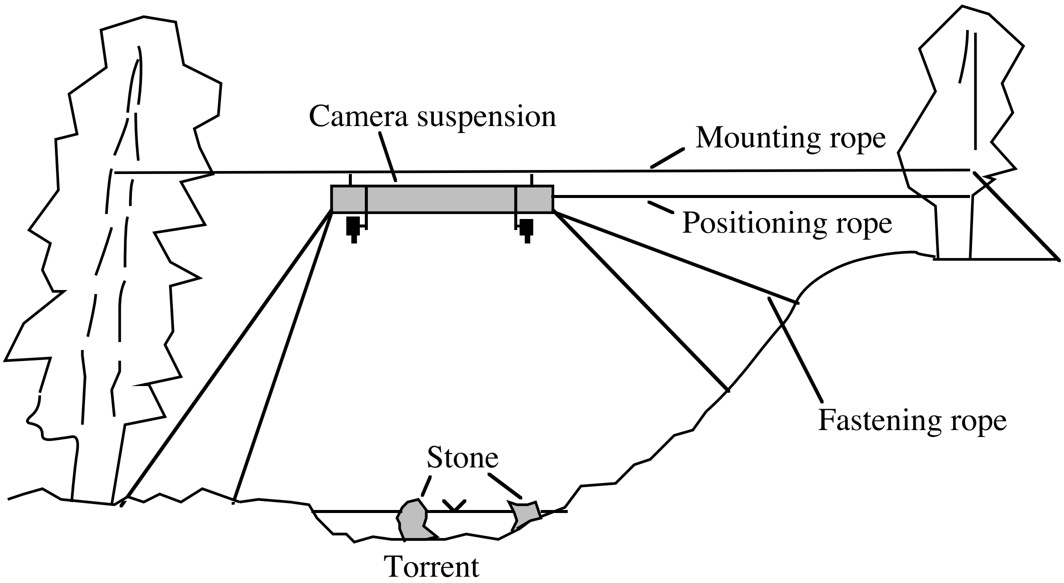

Figure 1: Photogrammetric camera set-up at torrent segment 1

Both cameras rigidly mounted on the ladder could be positioned within a selectable distance on the ladder (up to 3.8 meters). The ladder could be placed on the requested position above the torrent by pulling the positioning rope. To avoid heavy swinging of the cameras due to the wind, the ladder was fixed on the ground using two ropes at each end. For the second torrent reach, a steep, narrow V-valley facilitated the installation of the steel rope, which was fixed on the ground at both sides of the valley.

3.2. Photogrammetric measurements of the water surface

In total, 60 color photos per camera were acquired at different discharge levels. However, for the photogrammetric data processing, only 9 stereo photos were selected, which met the two standard criteria: sufficient number of pass points imaged in the model area and no strong contrasts of light and shadow in the object. The selected images were processed on the Analytical Plotter Wild Aviolyt AC1. After the determination of the interior and absolute orientation of each stereo photos, the bank lines could be measured point by point in 3-D object space. Finally, the joint bank lines were plotted and the area of the surface was calculated. The determined surfaces of the water at different discharge level are summarized in Table 1.

No.	1	2	3	4	5	6	7	8	9
torrent reach	1	1	1	2	2	2	2	2	2
discharge Q [l/s]	519	529	549	220	220	241	247	247	342
water surface A_S [m^2]	44.49	44.86	45.60	30.15	30.32	29.50	30.02	29.81	36.96

Table 1: Results of the photogrammetric determination of the water surface

The results of the photogrammetric investigations showed that the determination of the surface of the water meets the hydrological demands, especially if the relative change of the water surface level is of interest. The precision of the measurements of the bank lines depends on the interpretation and definition of the water boundaries Sometimes it was hard to define the boundary between water and moistened stones. Furthermore, these difficulties were increased at covered and underexposed places of the model area. In future projects, the coloring of the water or the use of infrared films could facilitate the measurements of the bank lines in the stereo pairs.

3.3. Salt-dilution method

The salt-dilution method is the best applicable hydrometric method to determine the discharge and the mean velocity of turbulent uniform flow in mountain rivers. It is based on the injection of a precisely known salt solution quantity, and on the registration of the conductivity graph.

The most important parameter of solute transport, the dispersion coefficient, is obtained through this method. This parameter is of increasing importance for pollution control and risk management.

4. Results

The results of the derived k_{St}-coefficients for two torrent reaches in Switzerland are summarized in Table 2.

reach	**discharge** [m^3/s]	**mean velocity** [m/s]	**k_{St}-coefficient** [$m^{1/3}/s$]
1	0.52 - 0.55	0.34 - 0.35	**5 - 6**
2	0.21 - 0.22	0.55 - 0.58	**9 - 10**
2	0.34 - 0.39	0.67 - 0.68	**10 - 11**

Table 2: k_{St}-coefficients of 2 torrent reaches by the new approach *(Hodel, 1993)*.

5. Conclusions

Although the amount of observations is small, the practicality of this procedure has been proved. The observations, performed within a small range of discharge values lead to lower Strickler coefficients than the commonly assumed values for torrents .

The following are recommended for future use of this approach:

- Color film, or even better infrared film to better discriminate water against river bed, and resolution of at least ASA400.
- photographs should be taken as close to vertical as possible
- in order to get observations over a wide range of discharge values, dilution method and photographs should be performed automatically at distinct rates of flow *(Grunow, 1986)*

6. Application of the proposed approach

Improving and completing this approach through consecutive use at several sites could result in a new type of gauge. This gauge would provide not only hydrographs accompanied by a rating curve of a very confined range of calibration values, but also

- Strickler's k_{St} or Manning's n for a wider range of discharge values
- idealized mean cross-sections of different types of torrents and rivers
- dispersion coefficients

These characteristics may be useful for

- comparison of channel capacity and excessive flood
- possible effects of regulations and constrictions (or the opposite: revitalisation)
- examination of hydrological hypothesis (i.e. $C*R^{1/2}$ = constant) along streams in catchment area
- determining travel time of pollution slushes caused by accident or disaster

7. Future research

Future research directions should be influenced by the following questions:

- Could analog photographs be replaced by digital images?
- Which tracer can be more efficient for automation than salt (conductivity)?
- Is the length of a representative reach comparable to the Representative Elementary Volume (REV) in groundwater hydraulics?

The most important goal though is to automate this procedure in order to avoid endargering the observation staff during peakflow of floods.

Appendix A. References

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Appendix B. Notation

The following symbols are used in this paper:

A	cross-section area of flow
A_S	water surface area
C	Chézy coefficient
k_{St}	Strickler's velocity coefficient
l	reach length
n	Manning's roughness factor
P	wetted perimeter
Q	discharge
R	hydraulic radius = ratio A/P
v	mean velocity