

Unique discharge rating curve based on the morphology parameter Z

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Abstract The paper introduces a new parameter Z which can be used to generalize the diversity of hydromorphometric relationships for the shape of cross-sections of simple unbraided river reaches at gauging stations along the river network. Thus, over several years, universal discharge rating curves might be designed to suit many gauges in a river basin. This should allow the number of regular discharge measurements to be reduced. In addition, the Z parameter favours the quality control of the information collected and the generation of missing data for some extreme events, which should result in an improvement of the accuracy of data and therefore hydrological calculations. The case has been proven for many rivers in countries including Bulgaria, UK, New Zealand, Canada and Australia.

Key words discharge rating curve; morphometric and hydromorphometric characteristics; river-bed shape

NOTATION

A_{ca}	catchment area (km^2)
B	river width, at surface (m)
H	mean stream depth (m); $H = F/B$
Z	morphology parameter
Q	water discharge ($\text{m}^3 \text{s}^{-1}$)
WL	water level (m)
F	area of flow cross-section (m^2)
n	Manning's roughness coefficient
MQ	runoff yield

“REGIME” BACKGROUND

Hydromorphometric relationships are considered to be an analytical expression of the dynamic interaction between flow hydraulic conditions, the morphometric characteristics of river cross-sections and specific river-bed and plan forms. A number of authors, partly listed by Wharton *et al.* (1989), have postulated the leading role of discharge in the formation of a river cross-section and “the way in which shape relates to hydrological regime”. Gergov (2001), Hedman & Osterkamp (1982), Park (1995), Wharton (1995), and Wharton *et al.* (1989) confirm the application of hydromorphometric relationships in engineering practice and river management for the plan form and depth of river channels. It was noted that the ratio B/H , termed the “morphometric relationship”, is included in the formulae used by this group of authors, and they have

assumed a constant value of B/H , which should indicate a preservation of the regularities in the outline of the river cross-section along the depth.

The case of $B/H = a$ constant corresponds to a triangular cross-sectional form, which is rather unusual and seldom occurs. In the case $B^p/H = \text{constant} = k$ (Blench, Glushkov) (p is an empirical index), the shape of the cross-section looks like an acute triangular curve (Gergov, 1968), which does not correspond well to field observations. This was proved after a comparative analysis of diverse field cases. It was found that a particular B/H value can appear for two or even more rivers simultaneously. For instance:

- At the Lom River gauge station at Traikovo ($A_{ca} = 1087 \text{ km}^2$) in Bulgaria on 3 December 1986, a discharge $Q = 0.418 \text{ m}^3 \text{ s}^{-1}$ was measured ($MQ = 0.384 \text{ l s}^{-1} \text{ km}^{-2}$); $B = 20 \text{ m}$; $H = 0.125 \text{ m}$, i.e. $B/H = 160.3$. The same value $B/H = 160.3$ was calculated, as the morphometric index, for the Danube River at Lom, ($A_{ca} = 588\,860 \text{ km}^2$) on 2 May 1981 ($Q = 6657 \text{ m}^3 \text{ s}^{-1}$; $MQ = 11.30 \text{ l s}^{-1} \text{ km}^{-2}$, $B = 1154 \text{ m}$; $H = 7.20 \text{ m}$), although these two rivers are quite different in size and hydrological conditions.
- On 10 April 1995 on the Meece Brook at Shallowford, UK, $Q = 0.98 \text{ m}^3 \text{ s}^{-1}$, $H = 0.55 \text{ m}$, $B = 8.291 \text{ m}$ and thus $B/H = 11.44$, while for the Severn River at Montfort UK on 19 December 1977 at $Q = 143 \text{ m}^3 \text{ s}^{-1}$, $B = 39.12 \text{ m}$; $H = 3.4 \text{ m}$, giving almost the same value, $B/H = 11.51$.

Obviously the ratio B/H does not carry reliable information about the river cross-section outline, which limits its practical application.

PARAMETER Z

This paper deals with the applicability of a new parameter $Z = (H/B)^{2B - 0.5}$ for the outline of stable river beds at arbitrary water discharges. The determination of Z requires measurements of the river cross-section, surface width B , and mean depth H , which are easy to determine with high precision. The expression Z stresses the width B of the river flow having it as an exponent $\alpha = 2B - 0.5$. It is assumed that B and H are random variables, independent of Q , which should mean the Z parameter is a morphometric characteristic of stable relief forms. The likely reason for this is the interaction between the runoff, geology of the river bed and soil cover, river sediments, river sand forms, etc.

For natural rivers usually $H/B < 0.1$ (Dolgopolova, 1993), while the Z parameter varies in the range $0 < Z < 1$ (see Fig. 1), as:

$$\lim Z = \lim (H/B)^{2\sqrt{B}} \rightarrow 1 \quad \text{for } B \rightarrow \infty$$

In most field cases the values of Z approach 0.5. Empirical data (613 cases) for many rivers from a number of countries worldwide, which cover a large range of hydrological condition, confirms this conclusion.

The Z parameter was investigated for a wide range of natural rivers in different geographical regions. The information collected comes from measurements performed on prismatic bed rivers from the UK, Bulgaria, Canada, New Zealand, etc. (Charlton, *et al.*, 1978). A range of relationships between Z and B , H , WL , Q , F , and n have been derived for them e.g. $Z-F$, presented in Fig. 2.

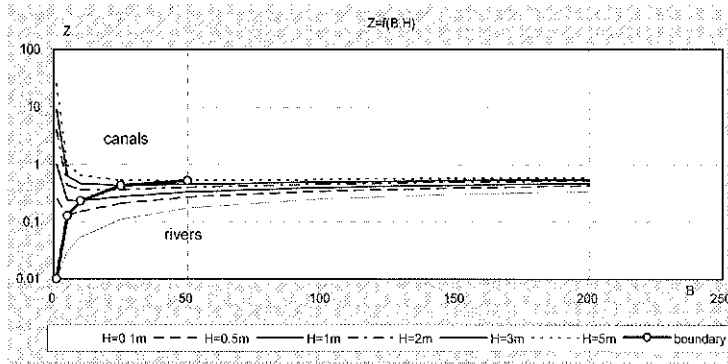


Fig. 1 Change of Z parameter with the mean depth H (natural rivers).

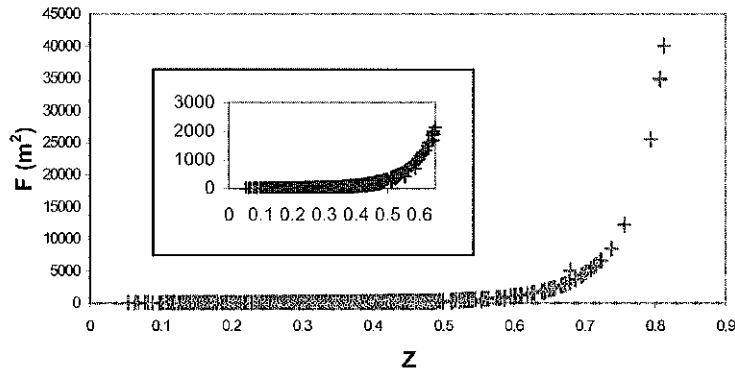


Fig. 2 Change of Z parameter with the cross-sectional area of the flow.

Table 1 Empirical relationships for the rivers studied in the UK.

Gauging station	R^2	FSE	$Z = a \times WL^b$		Difference (%)
			a	b	
Chatsworth	0.998	0.001	0.2788	0.3409	-0.75/+0.75
Ilam*	0.991	0.003	0.2986	0.2449	-2.5/+2.5
Llanyblo	0.997	0.002	0.2763	0.2620	-1.0/+1.0
Llanybyn	0.990	0.005	0.2830	0.3384	-3.5/+1.0
Tenbury	0.998	0.002	0.2970	0.2849	-1.2/+0.9
Bewdley	0.997	0.001	0.3760	0.1956	-0.45/+0.35
Drakelow	0.992	0.001	0.3387	0.2541	-0.25/+0.25
Evesham	0.980	0.003	0.4180	0.1052	-1.1/+1.6
Montford	0.995	0.003	0.3630	0.1702	-1.1/+0.8
Shallowf†	0.973	0.004	0.1970	0.2976	-3.0/+4.0

* Ilam: $WL = MAOD - 131.00$. † Shallowf: $WL = MAOD - 81.00$. FSE = factorial standard error.

Gauging station	R^2	FSE	$Z = a \times B^{b \times 10^3} : B^m$			Difference (%)
			a	b	m	
Chatsworth	0.986	0.003	0.6490	-4.4680	3	-1.9/+1.7
Ilam	0.985	0.004	0.3980	-15.4540	4	-1.2/+2.5
Llanyblo	0.979	0.004	0.3426	-222.2890	5	-3.5/+3.5
Tenbury	0.998	0.002	0.5094	-42.5530	4	-0.6/+0.6
Evesham	0.974	0.003	0.5540	-263.7400	4	-1.2/+1.2
Shallowf	0.935	0.006	0.1982	-0.1139	3.5	-5/+5

The analytical equations for a number of English rivers have been calculated and are listed in Table 1; the terms a , b , m are regional empirical coefficients, R is the coefficient of correlation, FSE is the factorial standard error and Difference (%) is deviation in %.

The relationships shown in Table 1 are based on the basic morphometry, the water level WL and corresponding width B and hydraulic characteristics of the rivers (Fig. 3).

The high degree of correlation (see R^2 in Table 1) and the small values of FSE, confirm the initial assumption that the regularity of the river cross-section shape is well defined and presented by the introduction of the parameter Z . They are stable for a wide range of conditions and over a long period of time (the source data available cover 3–9 years for the British rivers, 4–8 years for the Bulgarian rivers and 26 years for the River Danube).

It is of special interest to consider the Z - n relationship for the Derwent River, UK at Chatsworth (Fig. 4) and many other similar rivers, which are being studied (n is the roughness coefficient). Their analysis reveals a general trend of a decrease in n value with increasing values of Z . This means that the surface roughness effect, measured by n , on the hydraulic flow resistance decreases with the enlargement of the river cross-section. At $Z > 0.41$, the roughness coefficient n declines to an almost constant value of approximately 0.04. It is assumed that for larger rivers, with Z values close to 0.5, the roughness coefficient might reach 0.025. The same result appears when empirical data from several rivers in Canada and New Zealand have been examined. Thus a conclusion might be drawn that for large rivers the hydraulic resistance is due mainly to the turbulent energy losses exchange rather than the surface roughness of the river bed.

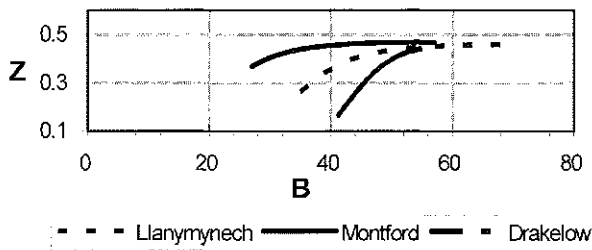


Fig. 3 Change of Z parameter according to the mean width B (natural rivers).

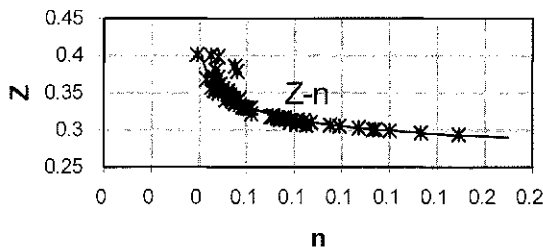


Fig. 4 Empirical relationships between Z and the roughness coefficient n for Derwent River (UK) at Chatsworth.

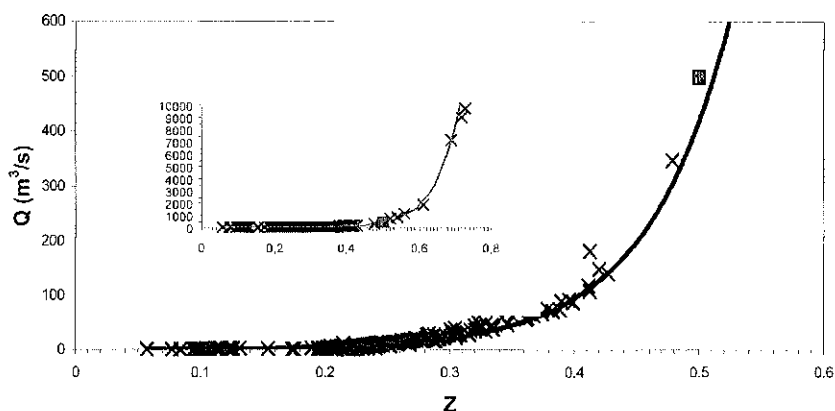


Fig. 5 An integrated Q - Z rating curve for sequences of consecutive years for gauging stations along the main river course of the Struma River, and rivers in the UK, Canada, New Zealand, etc.

The authors have applied the morpho-parameter Z for discharge rating curves pertinent to a number of gauge stations in a physically homogeneous geographical region. Based on the available hydrometric information for them the appropriate values of Z parameters have been calculated and used for:

- Individual Q - Z rating curves for a sequence of consecutive years for several gauging stations (Pernik, Rajdavitzta, Boboshevo, Krupnik, Marino Pole) on the Struma River.
- An integrated Q - Z rating curve for a sequence of consecutive years for all gauging stations along the main river course (Fig. 5).

From Fig. 5 it becomes clear that the rating curve drawn summarizes all water discharge measurements, made during 1993–1995, at five hydrometric gauging stations, and it fits the data very well. The use of data from lots of large rivers abroad (UK, Canada, New Zealand, Australia) let us extend the fitted line up to $12\,000\text{ m}^3\text{ s}^{-1}$ (Fig. 5). Evidently the data coincide well, as if the universal multi-annual discharge-rating curve has been successfully determined.

Thus, once the relationships $Z = f(X)$ have been established, then, based on water level (WL) readings, the corresponding value of Z and B , H , Q , or n might be determined. *Vice versa*, if the river width is accurately measured, then the water discharge Q might be estimated. In the case of a stable river reach this allows a reduction in the frequency of water discharge Q measurements to a minimum number, which will greatly facilitate practical hydrometric duties (Child, 2000).

CONCLUSIONS

1. A new morphological parameter Z has been offered as a characteristic of the river cross-section outline. It is determined by two linear measures of the flow—the width and the mean depth. The Z parameter tends to remain stable when the free water surface width, B , increases.

2. The study reveals a possibility of determining the water discharge Q based on the Z parameter.
3. Due to the progressive change of the Z parameter with distance downstream and simultaneously with Q , a unique discharge rating curve for the whole river length might be drawn.
4. The use of the unique discharge rating curve for a particular river permits reduction of the number of hydrometric measurements of Q required to several representative values for the verification of the rating curve.
5. As the Z - Q rating curve is rather stable in time and along a river, this allows the multi-annual discharge rating curve to be used.

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