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BENCH INDEX METHOD AS A WAY OF BANKFULL DISCHARGE DETERMINATION ON MOUNTAIN CREEKS IN THE POLISH CARPATHIAN

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ABSTRACT

The article presents research on bankfull discharge on two Polish Carpathian creeks: the Skawica and the Krzyworzeka. The Woodyer's method was presented as a bankfull criterion within small mountain catchments. A set of plant indicators, for such conditions, was found for each of so called "Woodyer's benches" along the researched sections of the investigated creeks. It was concluded that Woodyer's method could be used not only as an auxiliary one for bankfull determination but also as a decisive method in case of mountain stream.

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Key words: Bankfull discharge, Mountain creek, River cross-section, River banks, Polish Carpathian Mountains.

INTRODUCTION

Using a bankfull discharge value to characterise the flow regime for a river may seem attractive from the geomorphological point of view (Nixon 1959). Therefore different approaches to bankfull concept appear in scientific literature. Bankfull discharge marks conditions of incipient flooding (Henderson 1961). It also shapes a cross-section of a river (Carling 1988).

Only few authors give a definition of bankfull discharge, even less describe how to calculate its value. Perhaps the best and the simplest is a method described by Williams (1978) who defined bankfull as a flow, which just fills the channel to the tops of its banks. The problem is what in fact are and where are situated "banks of the river channel" and what in some cases means "tops of river banks". An accurate measurement of bankfull value is very difficult, since it occurs very rarely and the chances that it would happen at the station or at the gauge are scarce. Woodyer (1968) and Nixon (1959) define bankfull as: the height of the valley flat (also in Williams 1978). Wolman and Leopold (1957) see it as an elevation of the active floodplain. Schumm (1960) and Bray (1972) state that bankfull is an elevation of the "low bench", whereas for Woodyer (1968; also Woodyer and Fleming 1968) it is the elevation of the "middle bench" for rivers with three or four overflow surfaces. Once again Wolman and others (Wolman and Leopold 1957; Flickin 1968; Lewis and McDonald 1973) see bankfull as an average elevation level of the highest surfaces of the channel bars. Shumm (1960) defines bankfull in terms of vegetation, stating that it is the height of the lower limit of perennial vegetation, usually trees (also in Bray1972). Bankfull is also seen as the elevation of the upper limit of sand-sized particles in the boundary sediment (Leopold and Skibizke 1967). Finally, some authors associate bankfull with changes in a river cross-section. Wolman (1955) and also Pickup and Warner (1976) define bankfull as the elevation at which the width/depth ratio (W/D) of the cross-section becomes a minimum.

This paper presents one of the methods for bankfull determination, which by some authors is described as an auxiliary one (Riley 1977). It is known as a bench index method or as a Woodyer's method. In fact, in many cases, especially for mountain creeks, this method could prove a major one.

An alternative definition of bankfull in terms of plants covering riverbanks and flood plain was presented by Woodyer in 1968. As a bankfull criterion the author proposed three river benches: low, middle and high in terms of annual maximum series verified by vegetation cover (Figure 1). Especially in some mountains creeks where plants are abundant this method seems to work successfully. According to Woodyer (1968) the low bench is seen only at low stage and usually shows an obvious relationship to a bed of a stream. If exposed, it is not vegetated or only thinly covered with grass or herbs. The sediments here, are gravel and sands or small boulders. The middle bench occurs for 1.01-1.21 years of frequency flood and some largest species could be found in this zone e.g. water tolerant tree species such as Casuarina Cunninghamina or Eucalyptus Camaldulensis (it should be noticed that Woodyer's study was set up in New South Wales). The high bench is generally the widest and the most clearly developed stream bench with an abundant virgin tree cover e.g. Melia Azaderach or Eucalyptus Camandulensis Camaldulensis. Here the flood frequency varies from 1.24-2.69 years. In the presented paper Woodyer's method was used to calculate bankfull discharge value in two gravel Carpathian creeks with cross-sections thick with plants and trees.

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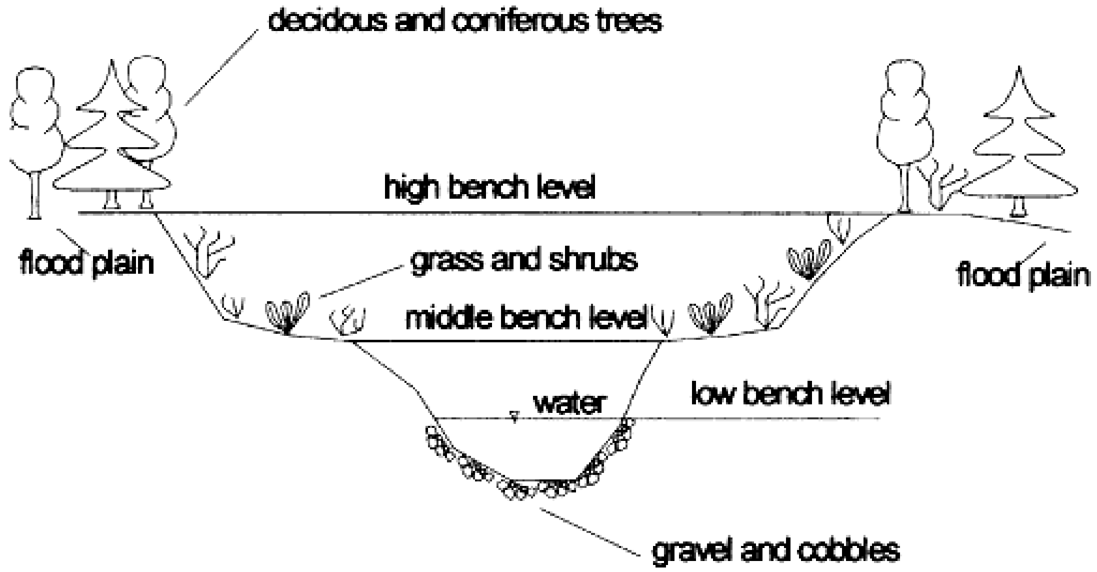
A general sketch presented below contains information on a stream cross-section necessary to understand the Woodyer's concept.

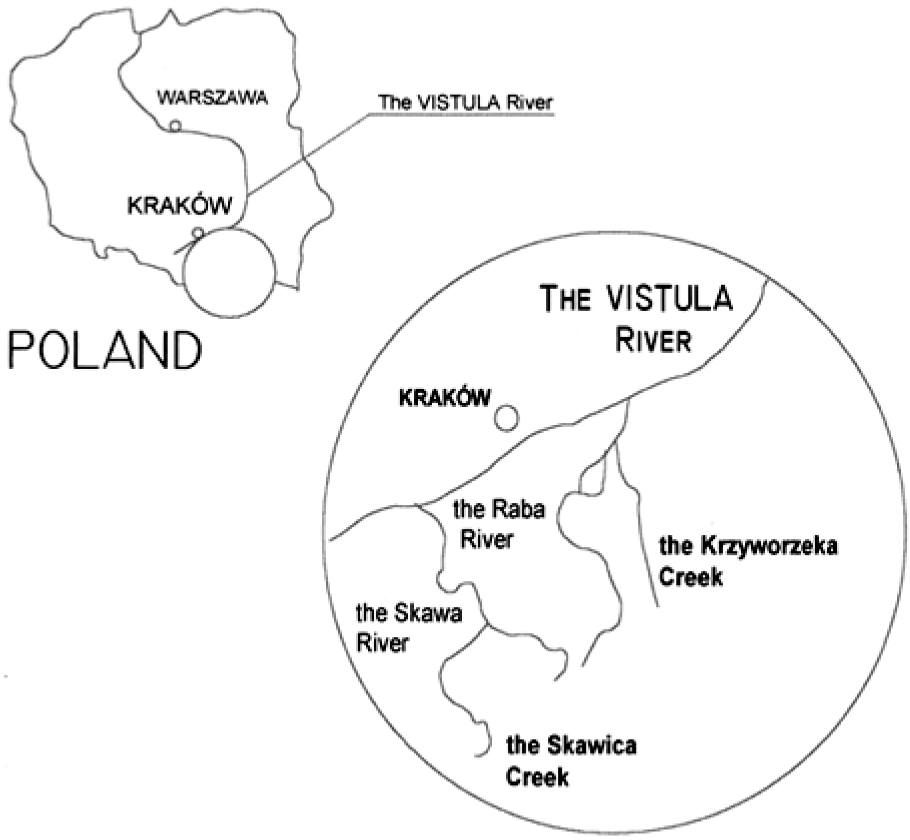
Figure 1. An outlook of Woodyer's method practical application



MATERIALS

Two mountain creeks in the Polish Carpathian were investigated in terms of bankfull discharge value: the Skawica and the Krzyworzeka (Figure 2). Both streams are subjected to frequent spring and summer floods. They are situated in the Carpathian flysh, so their streambeds consist mostly of sandstone and mudestone bed-load pebbles and cobbles forming a framework, the interstices of which are filled by a matrix of finer sediment. Suspended sediment loads are small and contribute insignificantly to channel morphology. Within the studied reach, the Krzyworzeka is an alluvial stream running through a flood plain composed of Quaternary, Holocene mudestones and coarse gravel with occasional Tertiary Paleogen shales, marls and sandstones (Istebnianskie stratums). Up to average of 3.0 m in depth the riverbed consists mostly of coarse sands and gravel with alluvial clays and some boulders. Below that level (3.2 m) are shales, clays and fine-grained sandstones. Strong bank erosion was noticed, especially upstream of the tested reach. Also a strong channel cutting could be noticed upstream of the studied reach. Valley slopes in the Krzyworzeka catchment are between 5-10%, density of river net is 0.92 km/km^2. The Skawica cuts through an alluvial bed, mostly Quaternary, Holocene river gravels, sands and mudstones. Upstream investigated reach just borders upon a Tertiary, Paleogene reach where mica-sandstone, sandstone, mudstone and phyllite predominate. Many gravel river bed-forms, such as point and middle bars, can be noticed within investigated Skawica reach. Mostly, gravel bed-forms growing behind and in front of obstacles, especially those situated at riverbanks, are quite durable.

Figure 2. Investigated creeks in the Polish Carpathians



Some basic physical characteristics of both investigated streams are presented in Table 1. No catastrophic perturbations are known to have affected the two study streams in recent times however spring floods were noticed (June/July of every investigated year) in both catchments. Krzyworzeka riverbanks were much more prone to damage because of those flash spring floods, especially in places where Tertiary deposits are exposed (1-2 km upstream of investigated reach).

Table 1. Physical characteristics of investigated sites

Variables	The Skawica Creek	The Krzyworzeka Creek
Precipitation [mm]	1189	883
Catchment Area [km^2]	19.33	50.5
Max. Altitude [m asl]	1130	904.2
Min Altitude [m asl]	594	227.8
Channel gradient	0.085	0.067
Max. Stream width [m]	16.3	29
Max. Stream depth [m]	0.83	1.45
Mean annual discharge [m^3 s^{-1}]	1.39	1.13
Two years flood $Q_{50\%}$ [m^3 s^{-1}]	12.6	21.92
Ten years flood $Q_{10\%}$ [m^3 s^{-1}]	48.8	69.49

D_{90} [mm]	79.7	53.8
D_{50} [mm]	22.0	11.7
Percentage < 4mm	17	22

METHODS

The Woodyer's method was applied to find out bankfull discharge values within four cross sections of the Skawica research reach and later within three cross sections of the Krzyworzeka creek. It was decided to choose different cross section as they have a different number of riverbank benches, different plants cover and finally they differ as far as river bed configuration is concerned (a flat bed or/and a river bar). Detailed survey was done in every reach using geodesical instruments. Hydrological calculations were done to find t-years floods employing Punzet formulae (Punzet 1981), which is the most appropriate for the Polish Carpathian region and commonly used in Poland. The Punzet equation, which is up to Polish standards, could be used when there is no data available from gauge station. Any t-year flood is calculated as:

$$\mathbf{Q_{p\%} = Q_{50\%} * f}$$

$$\mathbf{Q_{50\%} = f\,(A, P, H, DW, L, N)}$$

where:

$Q_{p\%}$	- t-year flood	[m^3/sec]
$Q_{50\%}$	- flood with probability of occurrence 50%	[m^3/sec]
A	- catchment area	[km^2]
P	- annual rainfall	[mm]
L	- length of a river (from sources to a research site)	[km]
N	- soil coefficient	[-]
DW	- difference in altitude of river source and a research site	[km asl]
f	- probability function (from tables given by Punzet)	[-]

The Punzet formula is developed for mountain regions, lowlands and upperlands. The "WODA-88 v.2.0" computer model (Radecki-Pawlik 1992) was used to help hydrological calculations. All plants necessary for Woodyer method application were collected and recognised in spring while at flowering stage. It was done also in summer and autumn, for comparison. Some plants were collected some just photographed (trees and big shrubs). An example of study cross-section on the Skawica Creek is presented below (Figure 3) with all the plants collected there.

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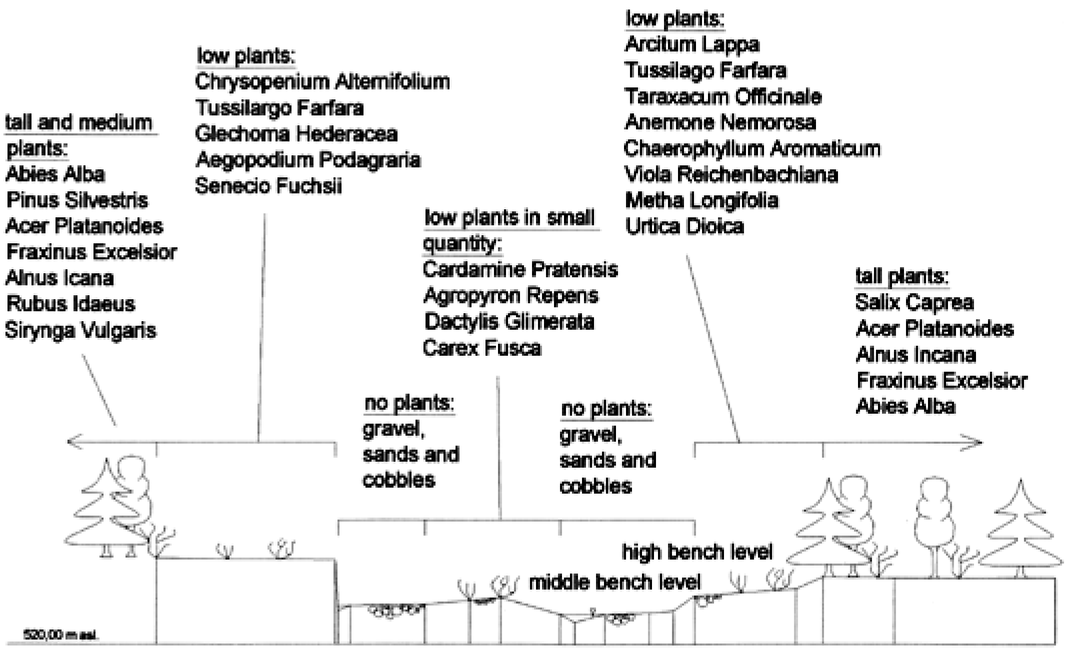
Figure 3. An example of the local river station 1-1 in the Skawica Creek with plants and benches necessary for Woodyer's method



After determining bench levels for all cross sections, discharge values corresponding to those levels were calculated using Gauckler-Manning equation presented below:

$$Q_b = (1.5 / n) A_b D_b^{2/3} S^{1/2}$$

The required variables are therefore the resistance coefficient n, the bankfull flow area A_b, the bank-full depth D_b, and a slope value S. A_b and D_b were measured from surveyed cross-sections, whereas Manning's n=0.040 were constant for all sites (n value was chosen from tables presented in Ven Te Chow, 1959). Values of S were equal to the average stream-bed slope measured to the station (it is worth notice that some scientists even prefer using the S value taken from topographic maps – Williams, 1968). Discharge values were calculated for any of investigated cross-sections and all marked levels within the cross-section by plants. Later, all those values were subjected to a discussion.

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RESULTS AND DISCUSSION

It seems to be the best, for purposes of the clarity to present obtained results in a tabular form. Thus, Table 2 presents all obtained bankfull values using Woodyer's bench index criterion and employing Gauckler-Manning hydraulic formula.

Table 2. Bankfull values obtained using Woodyer's concept

Method and stream name	Bankfull discharge value Q_b [m^3/ sec]			
	Cross-section 1-1	Cross-section 2-2	Cross-section 3-3	Cross-section 4-4
Woodyer (the Skawica Creek)				
-high bench	36.78	39.73	67.81	33.67
-low bench	7.19	33.34	12.11	5.09
Woodyer (the Krzyworzeka Creek)				
-high bench	21.01	34.15	222.00	
-middle bench	13.17	20.55	24.12	
-low bench	1.32	5.97	0.56	

As it was noticed in a presented study, Woodyer's method could be used when distinct river benches are defined. Also when plants are properly recognised and attributed to benches. As it was mentioned before, many authors treat Woodyer's method as an auxiliary one, but in case of mountain creek it seems to be more then that. For the Skawica creek two river benches were clearly recognised: high and low, whereas for the Krzyworzeka one could recognise additionally the middle river bench. It seems to be essential to list all plants, which were found for Skawica and Krzyworzeka streams. In this way, in future studies, they could be associated with appropriate river benches, when one decides to apply Woodyer method for any mountain stream in Carpathians. In the Skawica stream identified plants were as follows:
- for high bench: Abies Alba, Pinus Silvestris, Alnus Icana, Salix Caprea, Fraxinus Excelsior, Picea Excelsa, Betula Verucisa, Salix Fragilis, Acer Platanoides, Fagus Silvatica, Sirynga Vulgaris, Rubus Idaeus, Salix Cardata.

- for low bench: Tussilargo Farfara, Glechoma Hederacea, Arcitum Lappa, Dactylis Glimerata, Carex Fusca, Metha Longifolia, Urtica Dioica, Taraxacum Officinale, Agrostis Vulgaris, Agropyron Repens, Caltha Palustris, Medicago Lupulina, Cardamine Pratensis, Aegopodium Podagraria, Viola Reichenbachiana, Senecio Fuchsii, Anemone Nemerosa, Chaerophyllum Aromaticum, Cynosurus Cristatus, Hypochories Radicata, Dentaria Bulbifera, Laminum Aplexicabule, Centaurea Jacea, Agrostic Alba, Carex Acutiformis, Carex Rostata.

The plants identified in the Krzyworzeka stream, were respectively:

- for high bench: Fagus Silvatica, Carpinus Betulus, Salix Alba, Salix Cardata, Urtica Dioica,
- for middle bench: Sambucus Nigra, Menyantes Trifoliata, Tussilago Fuscus
- for low bench: Bromus Inermis, Arctium Lappa, Urtica Dioica, Tanaceum Vulgaris, Carex Fusca, Dactylis Glomerata, Alopeunis Pratenzis

It could be noticed, in nearly all cross-sections in both examined mountain creeks that plants make a good bankfull index (if they are present). The only trouble for investigator is: how to decide which river bench is a bankfull one. In other words: not always the middle bench or the high bench are bankfull benches. For example for the Krzyworzeka in cross section 1-1 just the high bench is the bankfull index, whereas in 2-2- cross-section it is the middle bench

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which seems to be associated with bankfull. The same situation has place in 3-3 cross-section, where the high bench flow seems to be beside all calculated t-years floods. For the Skawica the high bench is apparent in 1-1, 2-2, and 4-4 cross section and its level gives the value of bankfull. Cross section 3-3 cannot be taken into consideration in any context, as all results obtained here are almost impossible to interpret. Possibly, here appears a problem with the Woodyer method described by Riley (1972): it simply sometimes cannot be used directly because in some cross sections plants do not follow the bench pattern. It could be because of human factor or just because of very unusual shape of a section. Obviously the Woodyer method cannot be used when there are no plants.

Finally, a few general conclusions can be drawn which may be useful for future practical application of the Woodyer's method:

- it is advisable to use Woodyer's method for determining bankfull discharge jointly with other methods, based on hydraulic and hydrological conditions. In such cases bench index method could turn out to be decisive;
- one has to remember that all three Woodyer's benches would not always appear in a cross section. After a careful study the decision has to be made on classification of benches;
- as being indicators in Woodyer's method, plants should be collected late in spring, while at their flowering phase. It simply helps to recognise them. The same applies to taking photos of trees and tall shrubs;
- Woodyer's method is a good indicator for bankfull conditions especially for mountain creeks, where plants are abundant and there is still a small human impact factor on a plant cover on river banks.

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REFERENCES

1. Barnes, H. H. Jr., 1967. Roughness characteristics of natural channels, *U.S. Geol.Surv.Water Supply Pap.,* 1849, 213 p.
2. Carling , P.A., 1988. The concept of dominant discharge applied to two gravel-bed streams in relation to channel stability thresholds, *Earth Surface Proc. and Land*., vol. 13, 355-367.
3. Chow, Ven Te, 1959. Open-Channel hydraulics. McGraww-Hill, New York, p.108-114.
4. Dury, G.H. 1973. Magnitude-frequency analysis and channel morphometry, in *Fluvial geomorphology,* edited by M.Morisawa, State Univ. of N.Y. Binghamton, 91-121.
5. Handerson, F.M., 1961. Stability of alluvial channels, *J. Hydraulic Div*., 87, 109-138.
6. Hickin, E.J., 1968. Channel morphology, bankfull stage and bankfull discharge of streams near Sydney, *Aust.J.Sci.,* 30(7), 274-275.
7. Kellerhal, R., C.R.Neil and D.I.Bray, 1972. Hydraulic and geomorphic characteristics of rivers in Alberta, *Res.Counc.of Alta*., Edmonton, 52p.

8. Kilpatrick, F.A.. and H.H.Barnes.Jr., 1964. Channel geometry of Piedmont streams as related to frequency of floods, U.S. *Geol.Surv.Prof.Pap.* 422-E.10 p.
9. Leopold, L.B. and H.E. Skibitzke, 1967. Observations on unmeasured rivers, *Geogr.Ann.,* 49. 247-255.
10. Leopold, L.B. M.G.Wolman. and JP Miller, 1964. *Fluvial Processes in Geomorphology,* W.H.Freeman, San Francisco Calif., 522p.
11. Lewis, C.P. and B. C. McDonald, 1973. Rivers of the Yukon north slope, in *Fluvial Processes and Sedimentation.,* National Research Council of Canada, University of Alberta. Edmonton.Alta., 251-271..
12. Nixon, M.A., 1959. Study on the bank-full discharges of rivers in England and Wales, *Proc.Inst.Civil Eng.,* 12, 157-174.
13. Nixon, M.A., 1959. A study of the bank-full discharges of rivers in England and Wales, *Proc.Inst.Civil Eng.,* 14, 395-425.
14. Punzet, J., 1981. Pompownie odwadniajace – ustalenie miarodajnej wydajnosci pompowni, Instrukcja CBS i PBW Hydroprojekt, Warszawa, in Polish.
15. Pickup, G. and R.F.Warner, 1976. Effects of hydrologic regime on magnitude and frequency of dominant discharge, *J.Hydrol.,* 29, 51-75.
16. Radecki-Pawlik, A., 1995. WODA-v.2.0, a simple hydrological computer model to calculate the t-year flood, in *Hydrologicall processes in the catchment, by Wiezik B*., Krakow, University of Technology, 131-141.
17. Riley, S.J., 1972. A comparison of morphometric measures of bankfull, *J.Hydrol.,* 17, 23-31.
18. Schumm.S.A., 1960. The shape of alluvial channels in relation to sediment type, *U.S.Gepl.Surv.Prof.Pap.,* 352-B, 30p.
19. Ven Te Chow, 1959. Open Channel Hydraulics, McGraw-Hill Company, Inc, New York – Toronto – London.
20. Williams, P.G., 1978. Bankfull Discharge of rivers, *Water Resources Research,* 14, no6.
21. Woloszyn, J., Czamara W., Eliasiewicz R., Krezel J., 1994. River training works (in Polish), Wroclaw, p.22-23.
22. Woodyer, K.D., 1968. Bankfull frequency in rivers, *J.Hydrol*., 6, 114-142.
23. Woodyer, K.D. and P.M. Fleming, 1968. Reconnaissance estimation of stream discharge frequency relationships, in *Land Evaluation edited* by G.A. Steward, MacMillan of Australia. South Melbourne, 287-298.

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