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RELATIONS AMONG WATER DISCHARGE, LENGTH OF NETWORK AND TOTAL NUMBER OF STREAM SEGMENTS IN DRAINAGE BASINS

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Abstract

For all causality relations between morphometric variables and the elements of water regime, the number of stream segments and total stream length in the Horton-Strahler system have been overlooked. The aim of the present paper is to verify whether a dependence relation between these variables and water discharge does exist. To this end, determinations have targgeted the drainage model of the law of number of stream segments and the law of summed length by order of magnitude, eventually making a total by basin. The data-base, which contains the values of the Bârlad drainage system, its sub-basins and of representative basins in Romania has been used to correlate the values found in normal and logarithmic co-ordinates. The Bârlad basin case-study has produced good quantitative relations because differences in the geographical conditions that generate water discharge within this space are rather small. In order to establish the extent to which these relations are applicable to the whole Romanian territory, the number and length of stream segments in the Horton-Strahler classification system were determined at the water-gauge stations of representative basins situated in various landform units. In this case, too, the correlation of values in log-log coordinates indicates dependence relations, but looking at the value display it appears that a third variable, or group of variables, intervene in value grouping, influencing the pattern of the dependence relations obtained.

Keywords: length of network, number of stream segments, drainage basins

1 INTRODUCTION

Everywhere on Earth streams represent important environmental elements, water being a *sine qua non* of life and of all human activity on the Planet. At the same time, this element may either restrict or boost development. The way waters behave influences supplies to the population and to other uses characteristic of human communities. When in excess (floods), insufficient, or erosion-inducing, waters have detrimental effects on society and its goods. Therefore, the study of the liquid discharge synthetic indicator, specific to the extent of water resources in a territory, is of great scientific and practical interest since no territorial planning and organisation scheme can ignore this element if long-term sustainable development is to be achieved. It follows that assessing multi-annual average discharge by indirect methods is of primary importance, moreover so, as in many places on Earth the network of water-gauge stations is very small, which makes it difficult to obtain direct discharge measurements. As known, the length and number of stream segments is dependent on land fragmentation grade, and influenced by geology, climate, vegetation, and geological age. The wide diversity of natural and human conditions in Romania accouns for the significant spatial variation of water resources and their regime.

Average specific discharge in this country shows obvious vertical zonality, from 40-45 l/s km^2 on the highest Carpathian summits to a mere 0.5 l/s km^2 in the north – east of the Romanian Plain. The great many water-gauge stations provide data-rows dating to the 1950, so that researchers could study water resources far back in time and discover numerous dependence relations between liquid discharge and the physical-geographical factors, or morphometric elements of drainage basins and the stream network. Some contributions in this respect are: the Map of Average Specific Discharge elaborated by the Hydrology Sector of the General Direction of Hydrometeorology in 1953; I. Ujvari's studies (1959, 1972) into the physical-geographical conditions of discharge formation, average discharge and water balance in Romania. In 1969, Diaconu elaborated statistical analyses of the stream network in this country, but without speaking of water discharge. Very many of the relations between discharge and a series of morphometric elements of water basins and the drainage network (Diaconu, Şerban, 1994) were used in synthesis studies and hydrological regionalisations. Analysing the characteristic features of the drainage network between the Ialomiţa and the Trotuş rivers, Platagea and Popa (1963) discovered a very good relation between multi-annual average flows and the magnitude of stream segments of successively increasing order (Horton-Strahler classification system). The morphometric variables most often used to outline the relation between drainage basins and water discharge were drainage basin area and average location altitude (Mociorniţa, 1961, 1965).

Out of the multitude of environmental factors determining and influencing liquid discharge, the present paper focusses only on the dependence relations between water discharge and the drainage morphometric model determined by the law of stream segments and the law of summed length by order of successively increasing magnitude. Achieving it and elaborating morphometric drainage models for the Bârlad River (our case-study) and for other 55 basins in Romania, required digitizing the drainage network, stream length and number, according to Horton-Strahler's classification system.

2 METHODOLOGY

In order to discover the functional dependences among water flows, length of stream network and number of stream segments, we proceeded from the idea that a series of dependence relation between agent and form, shaped over time, must exist. These relations had to be taken into consideration whenever elaborating liquid discharge prediction models. Currently, stream network morphometry, the outcome of a whole set of erosion processes developed within drainage basins during their evolution, carries encoded information useful for scientific and practical purposes. The elaboration of morphometric models was based on the law of summed lengths and number of stream segments by order of magnitude, according to Horton-Strahler's classification system of the stream network.

The study of the drainage network followed Gravelius' classification which goes from big to small, basically from the 1st-order mainstream to the remotest arteries of lowest order. In 1945, Horton reversed the system and assigned the first order to the smallest morfologically established arteries instead of the mainstream; arteries have the capacity to direct and organise surface discharge, receiving no tributary on their course. The system completed by Strahler (1952) reads that a 2nd-order stream is formed by the junction of two 1st-order streams, a 3rd-order stream emerges from the junction of two 2nd-order streams, and so on, up to the highest-order mainstream. The higher the order of magnitude, the larger the afferent basin area, the bigger the water discharge, the longer the length of the network and the greater the number of segments, also the lower the basin slope, etc. The classification sets a series of rules that must be observed in hierarchisation. Thus, a certain stream-order may receive lower-order tributaries without changing its order of magnitude. A change of order occurs only if it joins a similar-order stream segment (Zăvoianu, 1985).

The data-base was formed by digitizing the drainage network on maps of scale 1:25 000 and by determining the number of successively increasing order of stream segments and their length in the Bârlad Basin (case-study) and in another 55 representative drainage basins in Romania. Several informaţion concerning the network of various-order stream segments, such as hydronym, order and length were stored in the data-base and further verified topologically lest the vector line holds errors, e.g. intersections, superpositions, free segments, etc. (Zăvoianu et al. , 2011).

The digitization of the drainage network began with 2nd-order up to higher-order streams, because in this case the source point indicated by contour level inflexion can be better individualised, because in the case of 1st-order streams the operator's subjectiveness intervenes so that the source point cannot be identified precisely the values of morphometric elements becoming under-or overestimated compared to the general tendency of the progression. As the law holds in the majority of cases, 1st-order values can easily be calculated, which reduces also the volume of work to half.

The stream segments with lengths summed by successively increasing orders of magnitude, from 2 to 8 in the Bârlad Basin, are represented graphically in semilogarithmic co-ordinates, outlining perfectly well two geometrical progressions (Fig 1 a,b). The method of selected points, basically 2nd-and 4th-order values, is used to calculate the confluence ratios for the law of the number of stream segments and the lengths ratio for the law of lengths summed by order of magnitude (Zăvoianu et al., 2011). The two relations can further be used to calculate 1st-order values that had not been digitized. Using the values of all orders of magnitude enables one to calculate the total number of stream segments of successively increasing order and the overall length of each basin at junction points or water-gauge stations for which water flow data are available. This procedure has been applied to all drainage basins and sub-basins of the Bârlad system and to all basins studied in România.

Direct measurement data of multi-annual average water discharge, obtained over the 1982-2007 period in the Bârlad drainage system and in all representative basins with an area below 1,000 km^2, have been supplied by the National Institute of Hydrology and Water Management. The data sets have facilitated the analysis of dependence relations among water discharge, length of drainage network and number of stream segments.

3 RESULTS AND DISCUSSION

In order to find out whether or not dependence relations among basin water discharge at water-gauge stations, drainage network length and total number of stream segments exist, investigations focussed on the Bârlad Basin (our case-study) and on some basins selected from all of the country's major landform units.

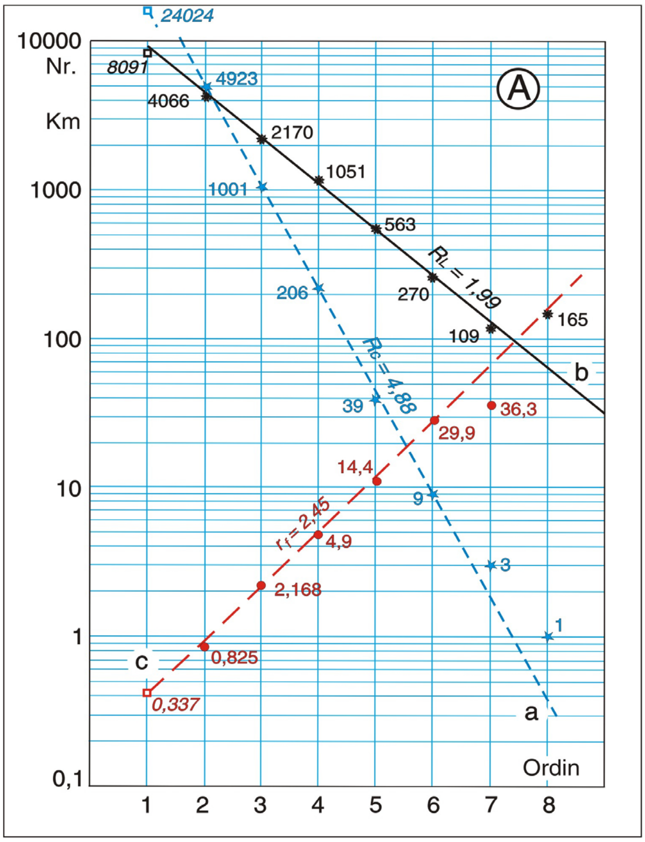

Fig. 1. The Bârlad basin. A. The morphometrical model of drainage; a) the law of numbers of stream segments, b) the la of summed stream lengths (km), c) the la of average stream length (km).

3.1 Assessment of relations in the Bârlad Basin

The basin area of the Bârlad River, a lefthandside tributary of the Siret, is of 7,220 km^2. Its network drains most of the Central Moldavian Plateau, the Tutova Hills, Fălciu Hills and the Lower Siret Plain. The Basin extends at altitudes between 564m and 40m, average height 211m. Geological deposits are mainly low resistant sedimentary (marls, clays, ash tuff, sands, etc.), and monoclinal with low-declivity slopes of the initial surface. As a result, the present-day physical-geographical factors of the big geomorphological units are not very different from one unit to another, a similar situation also in the case of the drainage network morphometric features.

Water discharge dependence on the length of stream segments. Considering that water discharge measured at gauge stations is the result of physical and biological processes occurring within basins and that streams are partly supplied by phreatic water, the question was to see if the length of drainage arteries could be involved in dimensioning the water flow. Besides, bearing in mind that the current configuration of landform, inclusive of the channel network, is the outcome of a long process of evolution, it follows that a dependence between form and agent does exist.

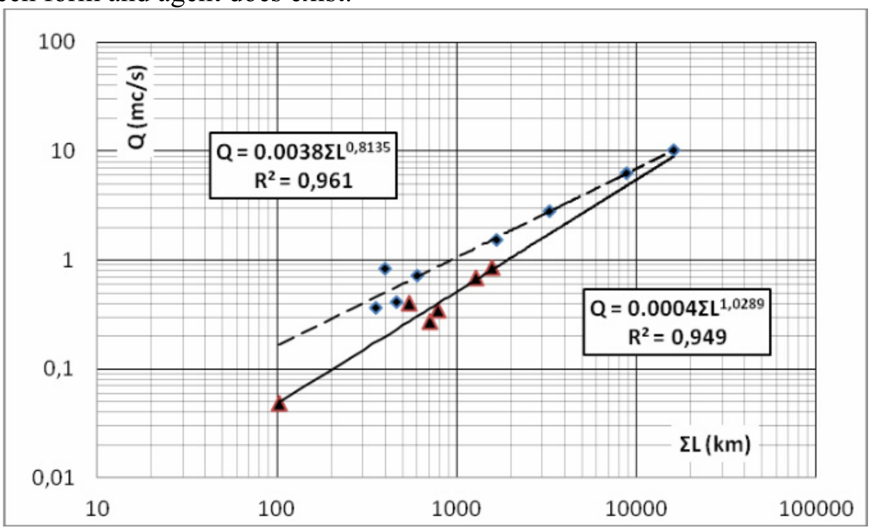

Fig. 2 Relation between water discharge Q (mc/s) and total drainage network length ΣL(km) in the Bârlad Basin

This suggests that the channel network has been shaped by erosional processes developing within drainage basins under the influence of the whole complex of physical-geographical factors and that a more or less obvious dependence relation between the length of the stream and water discharge really exists. In order to verify these assertions for the Bârlad Basin, the multi-annual average water flows at the gauge station were correlated with the total length of stream segments of successively higher orders in normal co-ordinates. The very good determination coefficient (R^2=0.989) proves that water discharge is dependent upon the length of stream segments in the Bârlad drainage system and that this relation could be used to verify water flows by this methodology. Having in view value scattering for small sub-basins and the great variation interval required, imposed the representation of values in log-log coordinates. The two value groups obtained have well-defined lines and determination coefficients above 0.900 (Fig. 2). The first line (0.961 coefficient) is assignable to sub-basins in the Central Moldavian Plateau and in all those of the Bârlad Basin except for the Tutova Hills area. The second line (0.927) represents Tutova Hills values. The display of lines suggests that the same water discharge needs a shorter network of stream segments in the Central Moldavian Plateau than in the Tutova Hills due to distinctively different relief fragmentation grade and drainage density in the two units (Fig, 2).

Water discharge dependence on number of stream segments. The main environmental element involved in the drainage and transport of water flows and suspended sediment load is the drainage network (Knighton, 1998). The number of segments increases with basin area resistance which is dependent on the whole complex of geographical factors and of rock in the first place. The methodology discussed herein was resorted to in order to find out whether any connection between the two elements exists or not. Eventually, the total number of stream segments for each basin controlled by a water-gauge station has been obtained. Correlating these values with the quantity of water flows has revealed a direct connection with good determination coefficients in normal co-ordinates throughout the drainage system, but for smaller basins the degree of value scattering is higher. Values represented in log-log co-ordinates outline a first line for the Central Moldavian Plateau and the rest of the basin (0.971 coefficient) and a second line for the Tutova Hills with a more branched out network and a lower coefficient (0.883) (Fig. 3). Therefore, it appears that fewer stream segments are necessary for the same water discharge in the Central Moldavian Plateau than in the Tutova Hills, due to stronger relief fragmentation in the latter case.

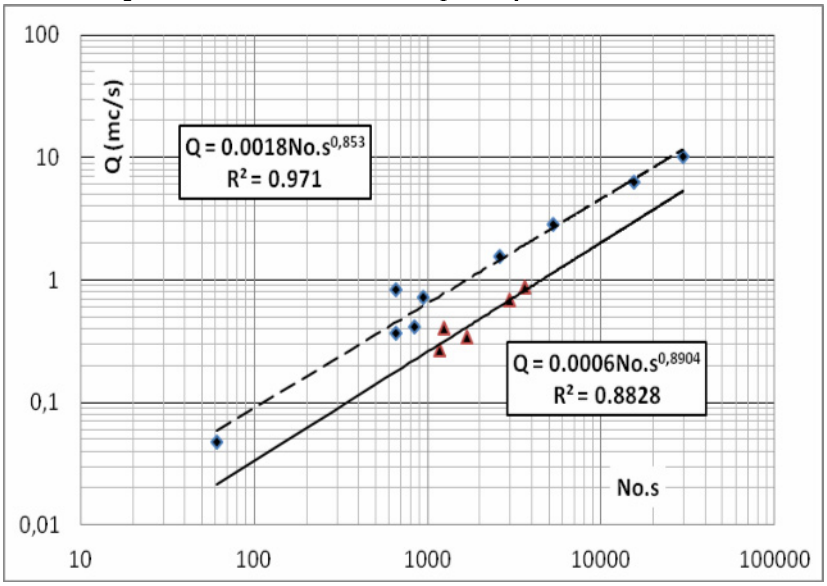

Fig. 3 Water discharge (Q) dependence on total number of stream segments (No.s) in the Bârlad Basin

3.2 Assessment of relations in representative basins.

Since relations in the Bârlad drainage system with extremely good determination coefficients had been established, the question arose of whether similar relations could be proven also for other basins in Romania. To answer it, a number of 55 basins, inclusive of the Bârlad drainage system, situated in major landform units, with a distinctively different rock composition and geological resistance, were taken into the study. In order to classify and digitize each basin's drainage network by order of magnitude, the length of the network and number of stream segments were determined by order of magnitude. The values obtained were used in working out the drainage morphometric model, while ratios of confluence and of summed lengths were introduced to establish 1st-order values and eventually the length of the entire stream network and the total number of segments for each basin.

The relation between water discharge and drainage network length within representative basins was defined by correlating the data obtained from 55 drainage basins in Romania. At first sight, the determination coefficient was fairly low (0.354), basically unpracticable. However, a more detailed analysis indicated that despite the small number of cases in the territory compared to the great diversity of environmental conditions, some value groups can develop pretty good dependence relations. Thus, the Bârlad Basin values are situated on the same correlation line as those of other basins in Transylvania (Olpret at Maia station and Agriş at Românaşi station), in the Curvature Subcarpathian, or in the Cândeşti piedmont, all these basins lying in areas underlain by unconsolidated or partly low erosion-resistant consolidated rocks (Fig. 4). The geological resistance coefficient of the 14 basins covered by this relation varied from 1.5 to 4.5, with 2.21 on average, values that are specific to this type of rock formations (Marin, 2011). The determination coefficient yielded by the relation between the two magnitudes was 0.984, which stands for a very good connection between the two elements. The second group, including 13 basins, outlines a relation characteristic of basins which, as a rule, have a much smaller length of stream segments for the same water discharge, in which case basins are far more resistant, coefficient 4.6 - 9.6, with 7.03 / sample on average.

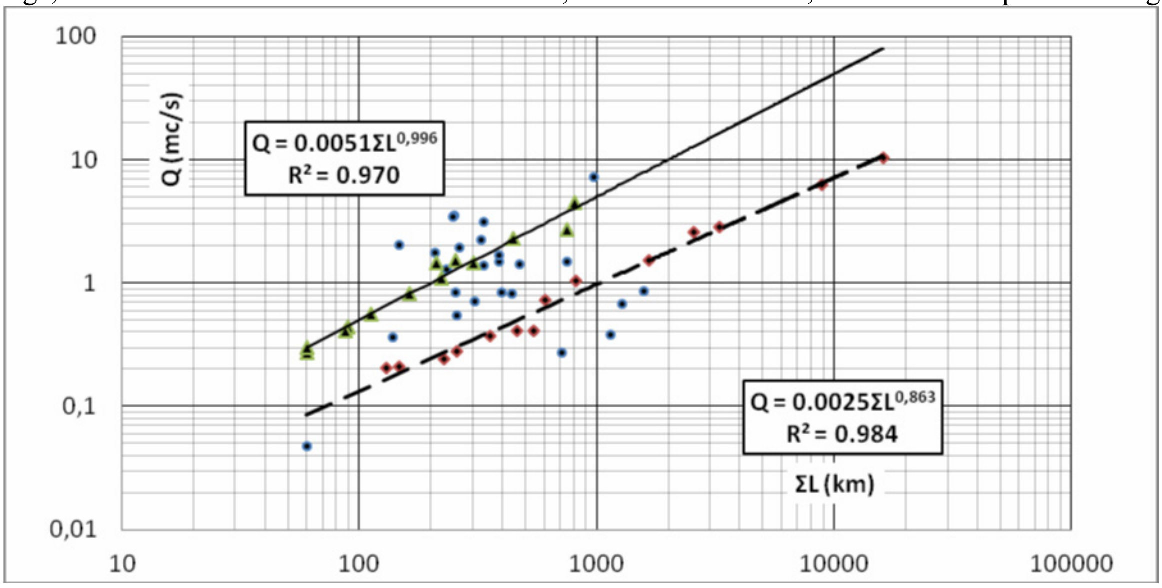

Fig. 4 Water discharge (Q) dependence on total number of stream segments (No.s) in representative basins

These values designate hard rocks, very resistant to the erosive action of the sub-aerial agent, and implicitly to river flow. All these basins, lying in the mountain area of the Eastern and Southern Carpathians, have a determination coefficient of 0.970. Comparing the two lines it emerges that in the mountain area characterized by solid and hard rocks, the length of the drainage network is much smaller for the same water flow than in a Subcarpathian or tableland basin underlain by low erosion-resistant rocks. For example, in a mountain basin, 1 m^3/s discharge is obtained by waters collected from a 200-km long network, whereas in Subcarpathian or tableland basins, it takes a 1,000-km long network to have the same discharge. For practical purposes it is worth continuing the analysis on a larger number of basins and to determine correlation lines for geomorphological units located in similar environmental conditions, or for drainage systems.

Relation between water discharge and number of stream segments. In order to find out if a relation between the number of stream segments and water discharge in the drainage basins studied does exist, a correlation was established between the two value groups in log-log co-ordinates. The findings have revealed once again that great value scattering suggests low a determination coefficient with all basins. A more detailed analysis distinguished a value group tending to form a correlation line with a determination coefficient of 0.99 (Fig. 5). The line is given by values for Bârlad drainage system, the Râmnicu Sărat Basin at Tătaru station in the Curvature Subcarpathians, Agriş at Românaşi etc. In this case, too, this relation was determined largely by geological resistance, with coefficients in the range of 1.5 – 4.0 and 2.5 on average, a proof of the presence of unconsolidated low erosion-resistant rocks (Marin, 2011). Value scattering obviously reveals that the relation is influenced by other variables as well, and identifying them may contribute to elucidating dependence relations between water flows and the group of variables involved.

4 CONCLUSIONS

The relations obtained in the cases studied illustrate that the close connection developed between form and agent during the evolution of drainage basins can be used to decipher the relationships between different variables. The findings have revealed positive relations among water discharge, total length and number of stream segments in the Bârlad drainage basin were the physical-geographical factors are not very different from one sub-basin to another, nor is resistance to erosion of underlying rocks either. Speaking of the relations yielded by the sample of basins in Romania, it appears that results are not fully relevant. However, grouping these basins by similar geographical conditions and geological resistance in particular, might produce very good and useful relations for elaborating prediction models. The relations yielded by basin areas under 1,000 km^2 can be studied for drainage systems or basins situated in geomorphological units in which discharge is determined by similar geographical conditions.

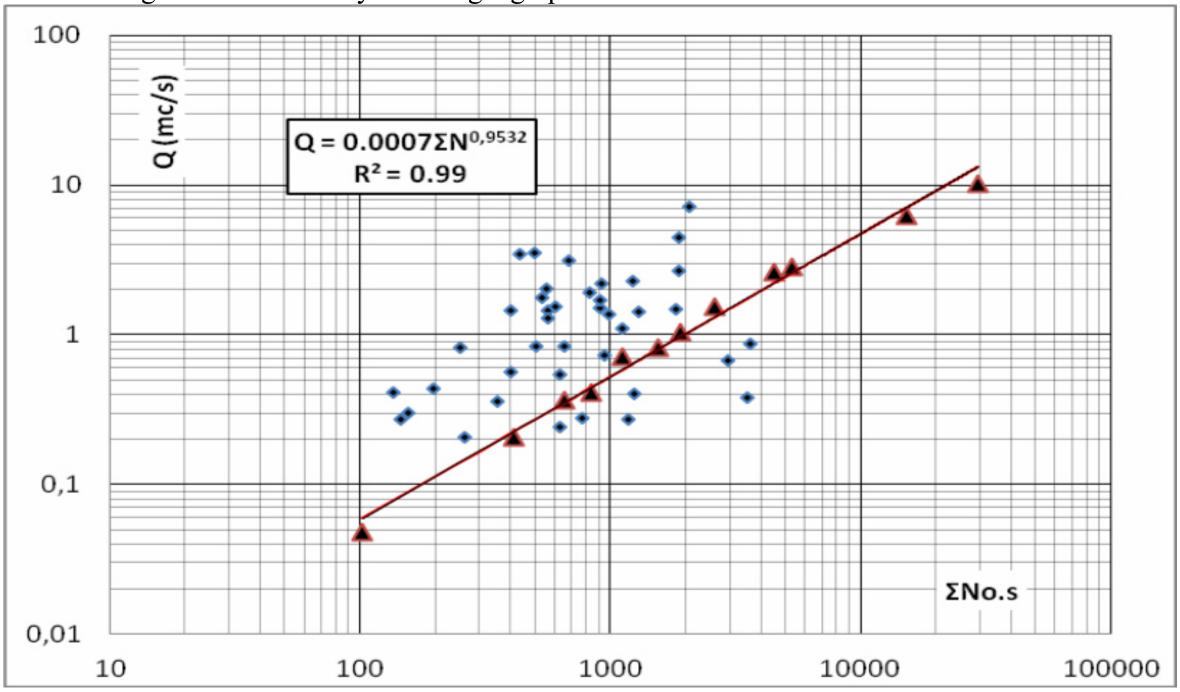

Fig. 5 Water discharge Q (mc/s) dependence on total number of stream segments (No.s) in representative basins

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