RELATIONSHIPS BETWEEN THE MODULAR VALUES AND VARIATION COEFFICIENTS OF MAXIMUM DISCHARGES IN THE DANUBE RIVER BASIN IN CROATIA

Danko Biondić[1], Darko Barbalić[2]

Croatian Water, Zagreb, Croatia, e-mail: [1]dbiondic@voda.hr; [2]darkob@voda.hr

Abstract: This paper presents regional relationships between the modular values and variation coefficients for maximum annual discharges of the 10, 100 and 1.000-year return periods in the Danube River basin in Croatia. Those are calculated on the basis of 90 available sufficiently long homogenous time series of measured discharges. Practical aspects of the relationships use in planning and designing of hydrotechnical systems has also been mentioned.
Keywords: regional relationships, modular values, variation coefficients, maximum discharges, The Danube River basin, Croatia.

VERHALTNISSE ZWISCHEN MODULIWERTEN UND KOEFFIZIENTEN VON VARIATIONEN VON MAXIMALEN FLÜSSEN IM DONAU-FLÜSSGEBIET IN KROATIEN

Zusammenfassung: Dieses Dokument präsentiert regionale Verhältnisse zwischen Moduliwerten und Koeffizienten von Variationen von maximalen 10, 100 und 1.000-Jahresflüsse im Donau-Fluβgebiet in Kroatien. Diese wurden auf der Basis von 90 vorhandenen, genügend langen homogenen Serien der Durchflüsse bemessenen auf den Fluβwarten kalkuliert. Praktische Aspekte des Gebrauchs von Verhältnisse in Planung und Konstruktion von hydrotechnischen Systemen wurden auch erwähnt.
Schlüsselworte: regionale Verhältnisse, Moduliwerten, Koeffizienten von Variationen, maximale Flüsse, Donau-Fluβgebiet, Kroatien.

1. Introduction

The Danube River basin is after the Volga River basin the second largest one in Europe with a size of about 817.000 km^2, with 18 riparian states and about 82 millions inhabitants. In Croatia it covers approximately 34.000 km^2, roughly 60 % of the country's land area, where approximately 65 % of the total population live. Major Croatian rivers, the Danube, the Sava, the Drava, the Kupa, the Una and the Mura flow through this area. It is located in the Pannonian plain and its rims, with the water divide separating it from the Adriatic catchments running through the Dinaric karst.

A particular socio-economic significance of this area, not only for the Republic of Croatia but also for the greater region emphasizes importance of efficient flood control. Although certain flood control activities in this area date from 19th century, systematic development of flood control systems did not begin until catastrophic floods of the Sava, the Drava and their tributaries during the 1960s. Gradual development of flood control systems in the last four decades has significantly reduced potential damages, a fact proven by successful reduction of numerous recent floods. The most of constructed systems are partially completed, which results in a still existing significant risk of flooding in large areas. Further development of the flood and torrents control systems remains therefore one of the strategic tasks of Croatian water management.

Basic hydrological informations for further planning and designing of flood control systems are maximum discharges of required return periods. Those can be estimated by applying stochastic methods for sufficiently long homogenous time series of measured discharges at gauged locations or by different PUB (**P**redictions in **U**ngauged **B**asins) methods (Hubert, 2002) at locations where time series of measured data are insufficiently long or non-existent. Common hydrological practice also recognizes the use of various methods for evaluation of reliability of such calculated values.

In some cases when time series are insufficiently long for applying standard stochastic methods, maximum discharges of required return periods can be estimated by applying regional relationships between its modular values and variation coefficients of maximum annual discharges. For application of this method, time series of maximum annual discharges should be homogenous, without significant trends and its values of coefficient of variation errors should be sufficiently small.

The aim of this paper is to present these relationships for maximum annual discharges of the 10, 100 and 1.000-year return periods.

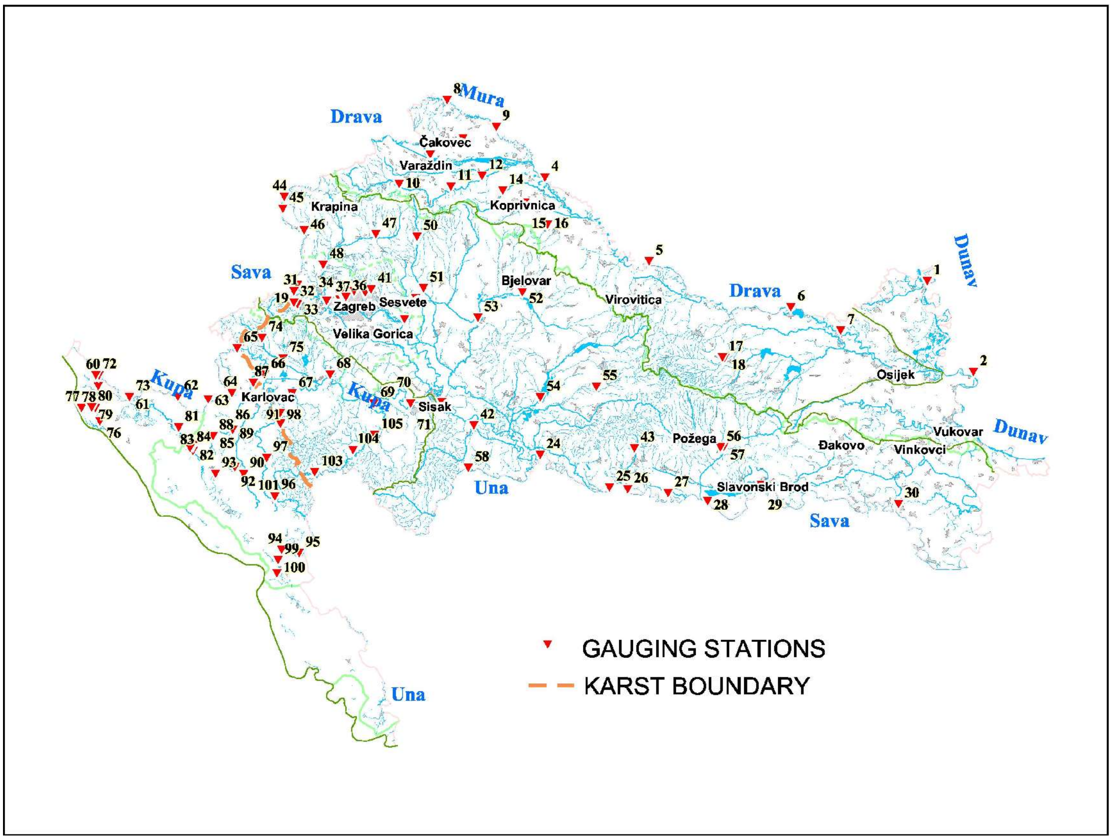

Figure 1. Overview map of the locations of analysed gauging stations in the Danube River basin in Croatia

2. Theoretical approach and investigation procedure

Regional relationships between the modular values and variation coefficients of maximum annual discharges for the 10, 100 and 1.000-year return periods in the Danube River basin in Croatia are formulated as follows:

$$\frac{Q_{M,RP}}{Q_{M,AV}} = a_{RP}\, C_{VM} + b_{RP} \tag{1}$$

where:

$Q_{M,RP}$	-	maximum annual discharge for the RP-year return period (m^3/s)
$Q_{M,AV}$	-	average maximum annual discharge (m^3/s)
C_{VM}	-	variation coefficient of time series of maximum annual discharges
a_{RP}, b_{RP}	-	regional parameters for the RP-year return period.

Subject relationships are defined on the basis of available time series of daily discharges which are stored in the Hydrological data base of Croatian Meteorological and Hydrological Service (Plantić, 1996).

Described theoretical approach can be applied only when the series are sufficiently long (values of its variation coefficient errors should be smaller than 10 %), homogenous and when there are no significant trends. Analysis of time series homogeneity, trends and variation coefficient errors were performed for maximum annual discharge series at all gauging stations in the Danube river basin in Croatia which have observation periods longer or equal than 25 years (105 stations).

The analyses of homogeneity were performed by application of the Wilcoxon‘s test in such a way that the available series was split into two sub-series dependent on times of replacement of hydrometrical equipment on the stations (rods to limnigraphs) and dependent on times of constructions of main hydrotechnical structures with significant impacts on water regimes (reservoirs, main dykes and distribution structures). The presence of trends in time series of maximum annual observed discharges were tested by the Mann’s test. Analysis of coefficient of variation errors were performed by Kritzky-Menkel‘s:

$$\sigma_{CVM} = \pm \frac{C_{VM}}{\sqrt{2(n-1)}} \cdot \sqrt{1 + 3C_{VM}^2} < 0{,}10 \qquad (10\ \%) \qquad (2)$$

and UNESCO‘s tests (Žugaj, 1998):

$$\sigma_{CVM} = \pm C_{VM} \sqrt{\frac{1 + 2C_{VM}^{\ \ 2}}{2n}} < 0{,}10 \qquad (10\ \%), \qquad (3)$$

where:

σ_{CVM}	-	variation coefficient error
C_{VM}	-	variation coefficient of time series of maximum annual discharges
n	-	number of years.

On the basis of performed analysis, 90 time series of maximum annual discharges were selected for further analysis.

The next step was probabilistic analysis of selected time series of maximum annual discharges. Maximum annual discharges of 10-years return period were calculated by application of empirical distribution, and maximum annual discharges of 100 and 1.000-year return periods were calculated by applications of Normal distribution (2 stations), Log-Normal distribution (24 stations), Gamma two-parameters distribution (7 stations), Gumbel distribution (10 stations), Pearson III distribution (23 stations) and Log-Pearson III distribution (24 stations). The goodness of fit was tested by application of the Kolmogoroff-Smirnoff test.

The last step was regression analysis of the modular values and variation coefficients of maximum annual discharges. Correlation coefficients (r) of calculated linear relationships amount 0,81 for 10-year return period and 0,92 for 100 and 1.000-year return period. Confidence intervals for 95 % probability (σ) amount ±15,1 % for 10-year return period, ±15,3 % for 100-year return period and ±28,4 % for 1.000-year return period.

Table 1. Basic characteristics of analysed gauging stations in the Danube River basin in Croatia

No. (Fig.1)	RIVER	GAUGING STATION	OBSERVING PERIOD (NUMBER OF YEARS)	DISCHARGES (m^3/s)		VARIATION COEFFICIENT OF TIME SERIES OF MAXIMUM ANNUAL DISCHARGES	MODULAR VALUES OF MAXIMUM DISCHARGES FOR RETURN PERIODS (years)		
				MEAN	AVERAGE MAXIMUM ANNUAL		10	100	1000
THE DANUBE RIVER									
1	DUNAV	BATINA	1951. - 1989. (39)	2313	4841	0.228	1.31	1.62	1.92
2	DUNAV	ERDUT	1950. - 1989. (40)	2852	5443	0.242	1.34	1.76	2.20
THE DRAVA RIVER BASIN									
3	DRAVA	VARAŽDIN	1951. - 1981. (31)	341	1286	0.350	1.41	2.16	2.81
4	DRAVA	BOTOVO	1961. - 1998. (38)	517	1596	0.297	1.48	1.93	2.47
5	DRAVA	TEREZINO POLJE	1961. - 1998. (38)	526	1506	0.327	1.58	2.12	2.93
6	DRAVA	DONJI MIHOLJAC	1926. - 1998. (71)	543	1360	0.232	1.29	1.67	1.99
7	DRAVA	BELIŠĆE	1962. - 1993. (31)	556	1405	0.265	1.44	1.83	2.31
8	MURA	MURSKO SREDIŠČE	1926. - 1998. (67)	171	732	0.390	1.60	2.31	3.11
9	MURA	GORIČAN	1926. - 1998. (70)	161	642	0.395	1.55	2.14	2.67
10	BEDNJA	ŽELJEZNICA	1959. - 1998. (40)	4.04	59.9	0.409	1.60	2.55	3.57
11	BEDNJA	TUHOVEC	1958. - 1998. (36)	6.46	80.9	0.341	1.39	1.70	1.80
12	BEDNJA	LUDBREG	1947. - 1998. (52)	7.29	80	0.411	1.60	2.15	2.65
14	GLIBOKI POTOK	MLAČINE	1970. - 1998. (29)	0.747	19.2	0.385	1.56	1.89	2.18
15	KOPRIVNICA	KOPRIVNICA	1951. - 1998. (46)	0.645	23.5	0.551	1.93	3.07	4.51
17	VOĆINKA	MIKLEUŠ	1960. - 1998. (39)	2.18	54.5	0.460	1.71	2.07	2.27
THE SAVA RIVER BASIN									
19	SAVA	JESENICE	1964. - 1995. (32)	276	1846	0.341	1.45	2.03	2.54
20	SAVA	PODSUSED	1949. - 1995. (47)	306	1738	0.295	1.48	2.01	2.73
21	SAVA	ZAGREB	1926. - 1995. (70)	314	1775	0.266	1.32	1.73	2.05
22	SAVA	RUGVICA	1926. - 1995. (67)	312	1502	0.246	1.38	1.77	2.21
23	SAVA	CRNAC	1955. - 1992. (38)	529	1935	0.101	1.11	1.22	1.28
24	SAVA	JASENOVAC	1926. - 1991. (64)	784	1977	0.112	1.16	1.35	1.54
25	SAVA	STARA GRADIŠKA	1937. - 1991. (54)	788	1899	0.127	1.16	1.34	1.48
26	SAVA	MAČKOVAC	1951. - 1990. (40)	823	2115	0.153	1.19	1.43	1.63
27	SAVA	DAVOR	1958. - 1993. (34)	931	2321	0.132	1.17	1.37	1.53
28	SAVA	SLAVONSKI KOBAŠ	1926. - 1993. (65)	974	2411	0.145	1.23	1.40	1.58
29	SAVA	SLAVONSKI BROD	1945. - 1993. (49)	944	2466	0.148	1.17	1.38	1.52
30	SAVA	ŽUPANJA	1929. - 1998. (65)	1159	2942	0.163	1.28	1.49	1.76
31	BREGANA	BREGANA REMONT	1970. - 1998. (29)	1.38	21.5	0.295	1.45	1.92	2.41
32	LIPOVAČKA GRADNA	HAMOR	1948. - 1998. (50)	0.381	4.26	0.322	1.42	2.05	2.65
33	RUDARSKA GRADNA	RUDARSKA DRAGA	1957. - 1994. (38)	0.255	4.49	0.393	1.53	2.31	3.11
35	VRAPČAK	ZAGREB	1961. - 1998. (38)	0.168	4.73	0.585	1.51	2.83	4.16
42	SUNJA	SUNJA	1965. - 1992. (32)	2.82	87.4	0.370	1.53	1.99	2.33
43	ŠUMETLICA	CERNIK	1972. - 1998. (27)	0.291	6.45	0.421	1.52	2.32	3.08
44	SUTLA	BREZNO	1946. - 1975. (30)	1.34	21.8	0.277	1.35	1.85	2.28
45	SUTLA	MILJANA	1947. - 1976. (30)	4.19	65.8	0.062	1.08	1.16	1.22
46	SUTLA	ZELENJAK	1958. - 1998. (41)	7.27	123	0.323	1.42	2.00	2.52
48	KRAPINA	KUPLJENOVO	1964. - 1998. (35)	11.8	154	0.278	1.34	1.78	2.13
49	ZELINA	BOŽJAKOVINA	1957. - 1998. (38)	1.64	28.9	0.362	1.55	2.24	2.99
50	LONJA	BISAG	1952. - 1982. (31)	0.768	15.6	0.190	1.21	1.44	1.59
51	LONJA	LONJICA	1972. - 1998. (27)	1.88	21.8	0.393	1.27	2.23	2.94
52	ČESMA	NARTA	1958. - 1998. (41)	5.43	51.1	0.323	1.38	1.95	2.41
53	ČESMA	ČAZMA	1963. - 1998. (36)	15.1	98.3	0.314	1.50	2.01	2.60
54	ILOVA	VELIKO VUKOVJE	1945. - 1998. (52)	7.36	71.5	0.336	1.25	1.94	2.36
55	BIJELA	BADLJEVINA	1949. - 1975. (27)	1.53	19.4	0.257	1.29	1.47	1.56
56	ORLJAVA	PLETERNICA	1946. - 1998. (53)	5.22	60.7	0.414	1.53	1.96	2.28
58	UNA	HRVATSKA KOSTAJNICA	1926. - 1991. (65)	228	1138	0.209	1.22	1.47	1.60
THE KUPA RIVER BASIN									
59	KUPA	KUPARI	1951. - 1998. (48)	13.5	141	0.161	1.21	1.43	1.60
60	KUPA	HRVATSKO	1957. - 1998. (40)	20.5	287	0.221	1.34	1.65	1.96
61	KUPA	PETRINA	1951. - 1992. (42)	26.6	455	0.339	1.41	1.97	2.51

62	KUPA	RADENCI	1951. - 1992. (42)	53.7	647	0.209	1.25	1.46	1.60
63	KUPA	PRIBANJCI	1949. - 1985. (37)	61.8	675	0.203	1.28	1.58	1.85
64	KUPA	LADEŠIC DRAGA	1956. - 1998. (42)	58.4	700	0.187	1.22	1.39	1.50
65	KUPA	KAMANJE	1957. - 1998. (40)	73.3	811	0.158	1.18	1.40	1.56
66	KUPA	BRODARCI	1957. - 1998. (41)	110	944	0.162	1.20	1.38	1.50
67	KUPA	REČICA	1948. - 1982. (35)	171	1137	0.236	1.28	1.47	1.58
68	KUPA	JAMNIČKA KISELICA	1948. - 1978. (31)	180	967	0.256	1.46	1.85	2.43
69	KUPA	ŠIŠINEC	1950. - 1991. (41)	182	949	0.148	1.17	1.41	1.58
70	KUPA	FARKAŠIĆ	1965. - 1992. (26)	196	1048	0.195	1.22	1.52	1.75
71	KUPA	BREST	1926. - 1974. (49)	206	1006	0.170	1.21	1.37	1.47
72	CABRANKA	ZAMOST	1950. - 1998. (49)	3.72	76	0.341	1.51	2.15	2.82
73	KUPICA	BROD NA KUPI	1951. - 1998. (48)	13.7	146	0.322	1.33	2.01	2.58
74	KUPČINA	STRMAC	1959. - 1998. (40)	2.18	22.7	0.403	1.75	2.53	3.88
75	KUPČINA	LAZINA BRANA	1973. - 1998. (26)	2.07	22.9	0.188	1.21	1.35	1.41
76	KRIŽ POTOK	C.P. KRIŽ	1963. - 1998. (36)	0.312	14.3	0.371	1.57	2.29	3.21
77	VELA VODA	CRNI LUG	1963. - 1998. (36)	0.208	7.98	0.326	1.50	2.10	2.81
78	BELA VODA	CRNI LUG	1963. - 1998. (36)	0.106	5.42	0.389	1.68	2.49	3.44
79	LESKA	LESKA	1963. - 1998. (26)	0.015	0.603	0.414	1.55	2.39	3.19
81	GORNJA DOBRA	LUKE	1947. - 1998. (51)	7.04	109	0.207	1.22	1.54	1.76
82	GORNJA DOBRA	OGULINSKI HRELJIN	1948. - 1975. (28)	4.65	52.3	0.129	1.15	1.35	1.49
83	GORNJA DOBRA	TURKOVIĆI	1963. - 1998. (33)	10	118	0.180	1.25	1.51	1.74
84	VITUNJČICA	BRESTOVAC	1948. - 1973. (25)	3.44	28.9	0.173	1.27	1.49	1.73
85	DONJA DOBRA	TROŠMARIJA	1960. - 1998. (39)	27.9	163	0.164	1.19	1.44	1.64
87	DONJA DOBRA	DONJE STATIVE	1960. - 1998. (39)	34.9	249	0.219	1.24	1.58	1.81
88	RIBNJAK	LUČANJEK	1948. - 1975. (27)	3.01	16.4	0.261	1.39	1.82	2.29
89	GLOBORNICA	GENERALSKI STOL	1949. - 1975. (27)	1.02	18.8	0.350	1.60	2.26	3.22
90	MREŽNICA	JUZBAŠIĆI	1947. - 1998. (46)	12.4	92.4	0.260	1.32	1.70	2.00
91	MREŽNICA	MRZLO POLJE	1947. - 1998. (52)	29.5	254	0.204	1.29	1.54	1.75
92	TOUNJČICA	OŽANIĆI	1948. - 1975. (28)	10.4	70.1	0.176	1.24	1.55	1.87
93	MUNJAVČICA	JOSIPDOL	1948. - 1975. (27)	0.431	3	0.380	1.53	2.26	3.02
94	KORANA	KORANA	1952. - 1986. (35)	3.09	19.2	0.280	1.46	1.95	2.63
96	KORANA	SLUNJ	1964. - 1998. (29)	11.1	137	0.353	1.59	2.17	2.94
97	KORANA	VELJUN	1949. - 1998. (44)	23	264	0.283	1.37	1.75	2.05
98	KORANA	VELEMERIĆ	1946. - 1997. (46)	28.8	327	0.285	1.38	1.88	2.35
99	PLITVIČKA JEZERA - KOZJAK	KOZJAK MOST	1953. - 1991. (33)	3.55	16.2	0.361	1.50	2.05	2.47
100	PLITVIČKA JEZERA - MATICA	PLITVIČKI LJESKOVAC	1952. - 1991. (37)	2.42	12	0.555	1.14	1.95	2.48
101	SLUNJČICA	SLUNJ	1949. - 1983. (35)	9.48	58.5	0.171	1.24	1.38	1.48
102	RADONJA	TUŠILOVIĆ	1949. - 1973. (25)	3.55	24.4	0.227	1.36	1.67	1.99
103	GLINA	MALJEVAC	1953. - 1986. (34)	3.37	38.5	0.362	1.34	2.14	2.79
104	GLINA	VRANOVINA	1947. - 1998. (45)	14.1	146	0.498	1.88	2.81	4.24
105	GLINA	GLINA	1952. - 1998. (40)	18.3	178	0.445	1.63	2.46	3.41

3. Results

By applying the described methodology, regional relationships between the modular values and variation coefficients of maximum annual discharges for the 10, 100 and 1.000-year return periods in the Danube River basin in Croatia were defined. The obtained results are shown in figures 2, 3, 4 and 5.

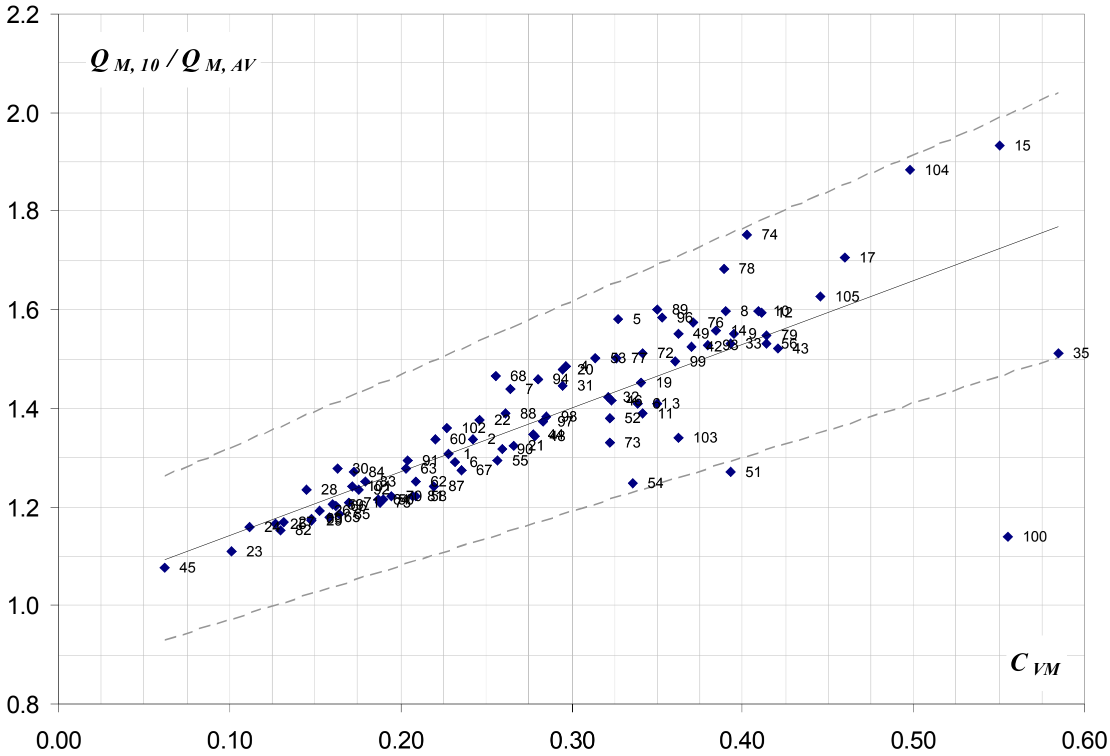

Figure 2. *Regional relationship between the modular values and variation coefficients of maximum annual discharges for the 10-year return periods in the Danube River basin in Croatia*

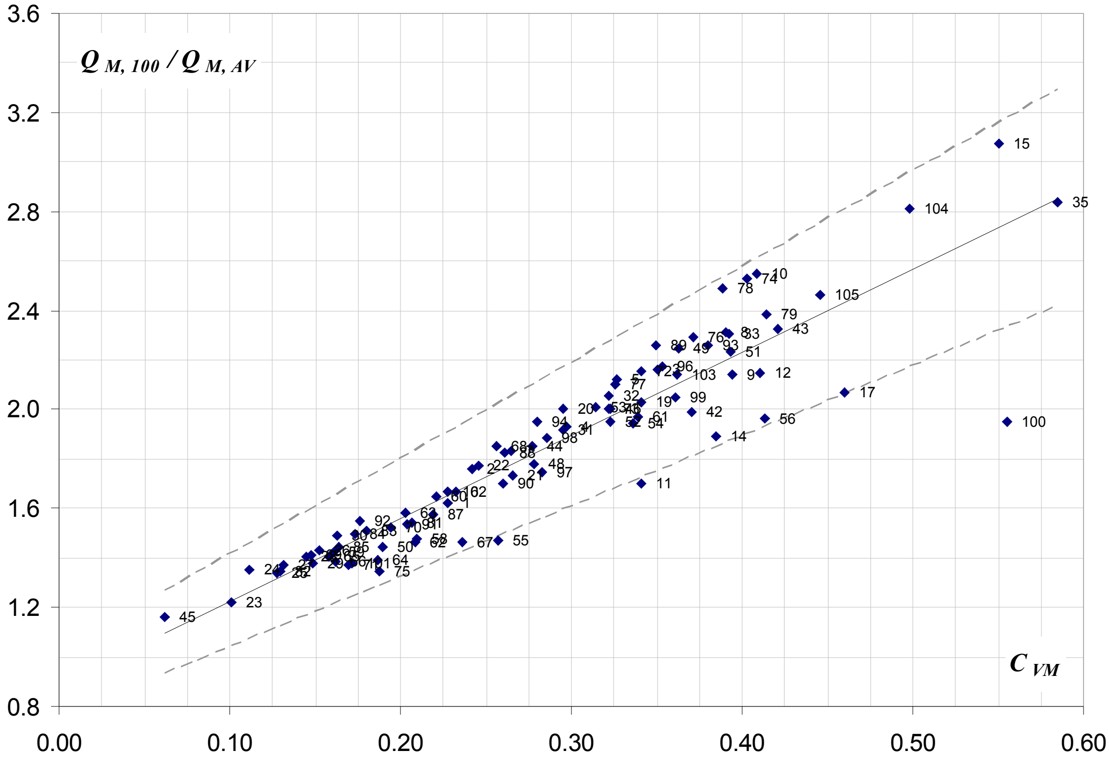

Figure 3. *Regional relationship between the modular values and variation coefficients of maximum annual discharges for the 100-year return periods in the Danube River basin in Croatia*

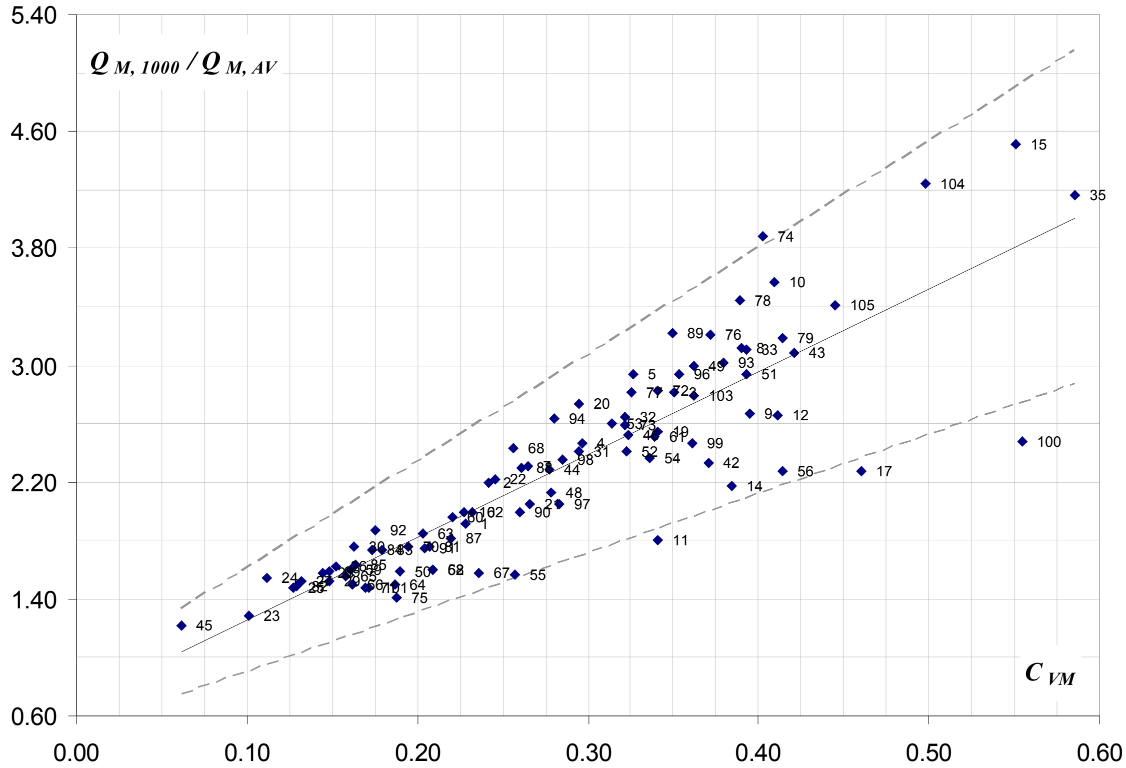

Figure 4. *Regional relationship between the modular values and variation coefficients of maximum annual discharges for the 1.000-year return periods in the Danube River basin in Croatia*

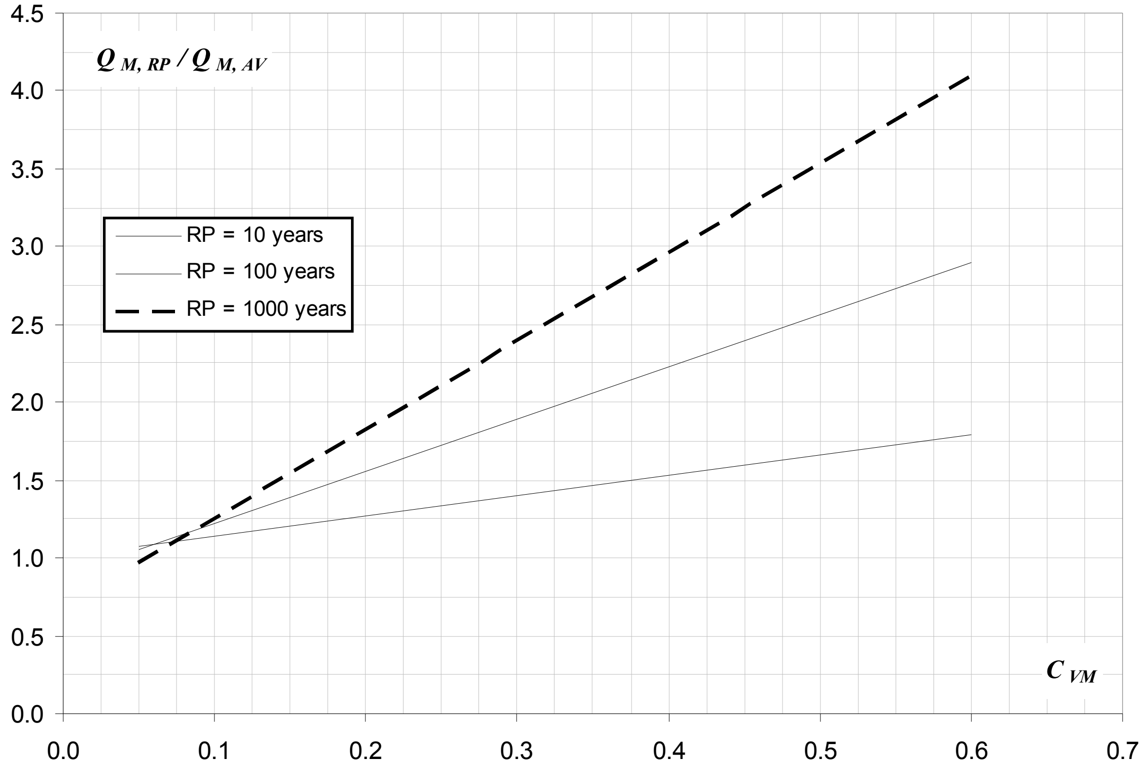

Figure 5. *Comparison of calculated regional relationships between the modular values and variation coefficients of maximum annual discharges in the Danube River basin in Croatia*

Table 2. Summary overview on calculated parameters of regional relationships

DISCHARGES	PARAMETERS OF REGIONAL RELATIONSHIPS			
	a_{RP}	**b_{RP}**	**r**	**σ (%)**
MAXIMUM ANNUAL FOR THE 10-YEARS RETURN PERIOD	1,29	1,015	0,81	15,1
MAXIMUM ANNUAL FOR THE 100-YEARS RETURN PERIOD	3,35	0.891	0,92	15,3
MAXIMUM ANNUAL FOR THE 1.000-YEARS RETURN PERIOD	5,69	0.684	0,92	28,4

Comparison of subject and some previously published relationships was performed and results are shown in figures 6, 7 and 8.

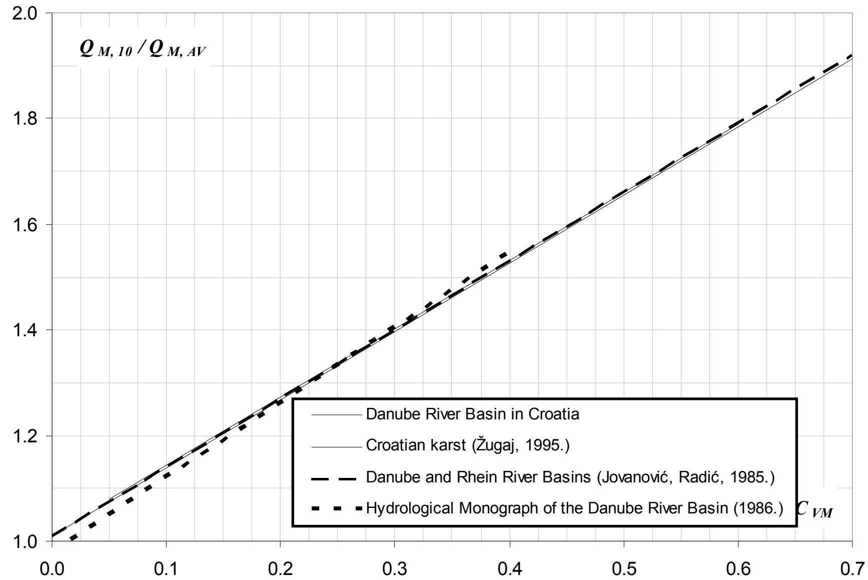

Figure 6. Comparison of regional relationship between the modular values and variation coefficients of maximum annual discharges for the 10-year return periods in the Danube River basin in Croatia with previously published relationships

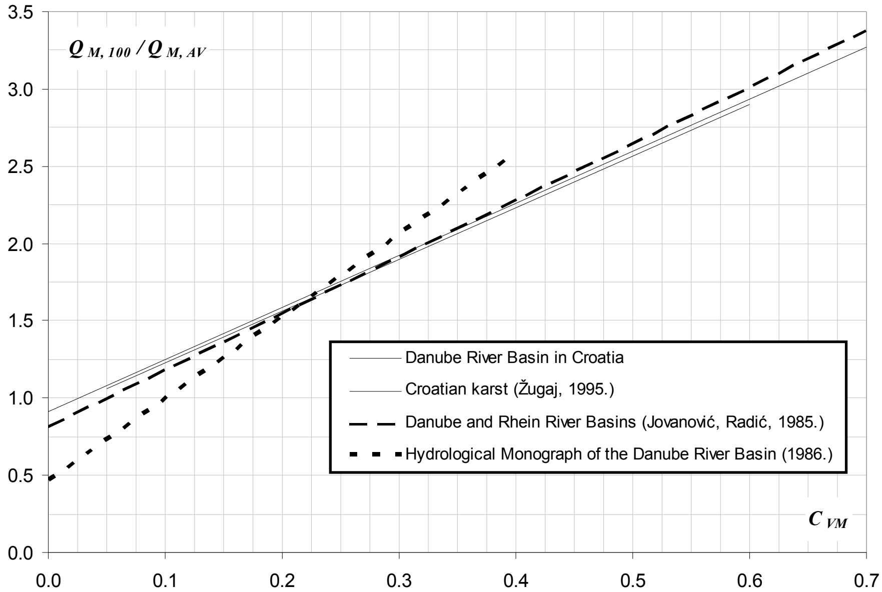

Figure 7. Comparison of regional relationship between the modular values and variation coefficients of maximum annual discharges for the 100-year return

periods in the Danube River basin in Croatia with previously published relationships

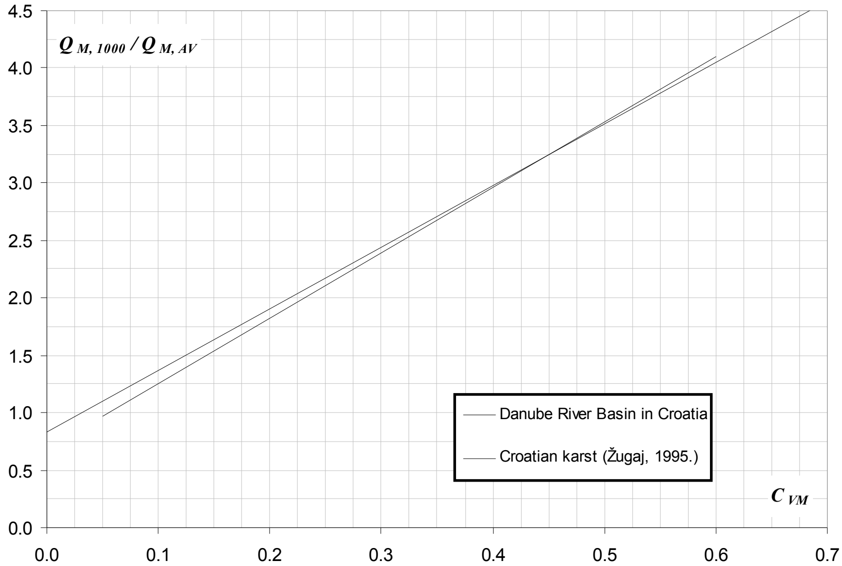

Figure 8. *Comparison of regional relationship between the modular values and variation coefficients of maximum annual discharges for the 1.000-year return periods in the Danube River basin in Croatia with previously published relationships*

4. Conclusion

The relationships presented in this paper were calculated on the basis of 90 available sufficiently long homogenous time series of observed discharges on gauging stations in the Danube River basin in Croatia. Because of high correlation coefficients (r) and confidence intervals (σ) of about ±15 %, relationships for 10 and 100-year return periods can be used in hydrological practice for estimations of maximum discharges in the cases when time series of measured discharges are insufficiently long for applying standard stochastic methods. Calculated relationship for 1.000-year return period has also high correlation coefficient (r = 0,92), but it is less reliable because of wider confidence interval (σ = ±28,4 %).

Presented relationships can be used for estimations of peak discharges on the basis of average maximum annual discharges, and variation coefficients of time series of maximum annual discharges. It is required that used time series of annual maximum discharges are homogenous and without significant trend, as well as that errors of their variation coefficients in accordance to Kritzky-Menkel's and UNESCO's tests are less than 10 %. For application of subject relationships, it is necessery to take into account their confidence intervals.

Calculated relationships for the Danube River basin in Croatia are very similar with previously published relationships for Croatian karst including Adriatic basins (Žugaj, 1995), and therefore can be applied for the whole Croatian territory.

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