International Seminar on Hydrology of Extremes

1-3 December, 1988
Roorkee (India)

LOW FLOW FOR MINIHYDRO POWER PLANTS

Piergiorgio Manciola

Stefano Casadei

Institute of Agricultural Hydraulics, University of Perugia
Borgo XX Giugno, 74—Perugia

SYNOPSIS

This paper is a contribution of a multidisciplinary research and suggests an estimation method of low flows, to individuate the best places of minihydro plants. In fact the low flows of a river define the period of low productivity and they qualify the technical and economic feasibility of minihydro plants.

Particularly the localization of these plants needs large territorial investigation and for this purpose it is necessary to evaluate the hydrological droughts for ungaged rivers.

The research suggests an estimation methodology of low flow based on the geomorphological and hydrological characteristics of a given basin, which can be evaluated by hydrogeological thematic maps.

The method required the preliminary analysis of 53 gauged basins of a region and the definition of a functional relationship between low flow (dependent variable) and hydro-geomorphological parameters (independent variables).

1.0 INTRODUCTION

Low flow have been investigated by different authors and particularly the aspects of interaction between surface, ground water and low flow regime of a basin [1,2,3,4,5].

For this problem a very important role has the value of a Base Flow Index (BFI) [8,9], derived by recorded flow hydrograph separation on ground water runoff and overland runoff.

An investigation of 53 gauged basins showed that the BFI has a high correlation with the hydrogeological characteristics of the basins. Then we assumed BFI as an indicator of the basin hydrogeology.

This hypothesis has been verified very well in the second part of this work when we found that BFI is the most important variable for total investigated basins.

The obtained results for discharge greater than 40 percentile, calculated by multiple regression equations, allowed to derive the lower line of duration curve for ungaged basins. It gives an evaluation of the hydrogeological regime of the river.

2.0 GAUGED SITES

The main characteristics of the 53 analyzed basins are reported in table 1. These basins have been chosen because they have a record years greater than 6 years and for them it is possible to define the hydrogeological characteristics (*).

The investigated area is equal to 50,000 Km^2 and the area of gauged basins is equal to 31,763 Km^2, about 2/3 of total.

The values of SAAR (Standard Annual Average Rainfall), BFI (Base Flow Index) and AREA (Basin Surface) are the independent variables which showed the best correlation with low flows.

Particularly BFI, which is calculated from annual recorded hydrograph, and its annual values have been found to be stable. The standard deviation is less than 5% [10].

The correlation between BFI and hydrogeological characteristics of gauged basins (see Tab.1) allowed to derive tab.2, where each geological complex is associated to a BFI average value. It can be accepted at a 5% significant level in according to t Student test of the date sample of every investigated basins.

The reliability of the results derived also by the consideration that BFI increases with the storage capacity of investigated geological complexes [6] which can be gauged in the following way:

- (1) complex of marine clay, (2) argillaceous flysch complex.

Areas where both surface runoff and evapotranspiration prevail over infiltration, percolation and aquifer capacity are consequently negligible.

- (4) Volcanic complex, (5) marly-calcarenitic complex.

Areas where the values of effective infiltration are comparable to those of runoff.

- (6) basin edge complex, (7) complex of slope deposits, (8) dolomitic complex, (9) complex of pelagic deposits, (10) complex of carbonate shelf, (11) carbonate shelf edge complex.

Areas where effective infiltration prevails over surface runoff.

(*) See "Hydrogeological scheme of Central Italy" [6,7], where it is possible to derive the effective infiltration of various complexes

Generally the BFI variability for each geological complex is small (see tab.2) and this derived by different elements, for example the thickness complex, presence of clastic deposits, spring captation and urban drainage.

3.0 UNGAUGED SITES

By means of daily discharge of 53 gauged basins the duration curve for each basin has been calculated.

The Q(P) discharge values have been expressed as a percentage of Average Daily Flow (ADF) in such a way to have an homogeneous comparison between basins with different flow regime.

Then we studied the multiple linear regression between Q(P)% and SAAR, BFI, AREA:

$$\sqrt{Q(P)\%} = a_0 + a_1 \sqrt{SAAR} + a_2 \sqrt{BFI} + a_3 \sqrt{AREA} \qquad (1)$$

The square root has been employed to eliminate negative value of Q(P)%.

The application field of equation (1) is for the Q(P)% value of percentage of time discharge exceeded $P(Q \geq Q_i) \geq 40\%$.

The obtained results suggested to divide the sample in two subsamples:

subsample A: AREA>100 Km^2 (Tab.3)
subsample B: AREA≤100 Km^2 (Tab.4)

For A Q(P)% showed a strong correlation only with BFI, consequently satisfactory results can be obtained by simplified equation:

$$\sqrt{Q(P)\%} = b_0 + b_1 \sqrt{BFI} + b_2\, BFI \qquad (2)$$

For B Q(P)% had a good correlation with BFI but also AREA parameter showed sometime a relevant weight.

Finally equation alike (1) is analyzed to derive the Q(P) values without the ADF component:

$$\sqrt{ADF} = a_0 + a_1 \sqrt{SAAR} + a_2 \sqrt{BFI} + a_3 \sqrt{AREA} \qquad (3)$$

The equations (1) and (3) have been applied to 51 basins and, then, they have been verified for the other two basins, considered as "ungauged" sites and with inputs only hydro-geomorphological parameters: SAAR, BFI and AREA.

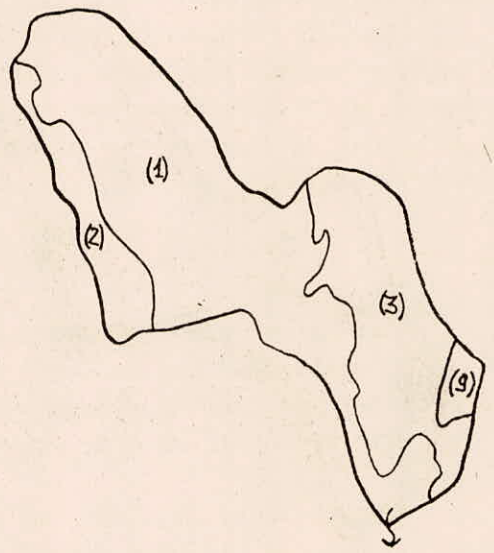
4.0 EXAMPLES

The examples studied regard two characteristic basins located along the Appenninic Ridge in Central Italy, a great basin on river Chiani at Morrano bridge and a little basin on river Velino at Posta village.

River Chiani at Morrano bridge

Characteristic data are: SAAR=962 mm., BFI=35 calculated from annual hydrograph and catchment area 422 Km^2.

Hydrogeological complex	BFI theoretic average
(1) Complex of marine clay (237 Km^2)	23
(2) Argillaceous flysch complex (47 Km^2)	32
(3) Arenaceous flysch complex (123 Km^2)	44
(9) Pelagic deposits (15 Km^2)	80



BFI estimated by weighted area mean is 32, with a simple difference from BFI calculated.

The results obtained by equations (1) and (3) with Tab.3 are:

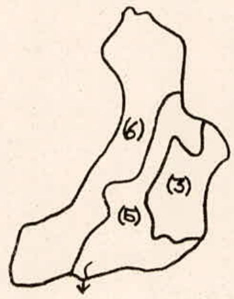
ADFest.=4.06 cumecs ADFobs.=4.50 cumecs Δ%=9.8

P %	Q(P)obs. cumecs	Q(P)est. cumecs	Δ %
40	2.30	1.94	15.6
50	1.58	1.32	16.5
60	1.04	0.89	14.4
70	0.65	0.58	10.7
80	0.38	0.38	0.0
90	0.23	0.28	-21.7
95	0.15	0.21	-40.0

River Velino at Posta village

Characteristic data are: SAAR=1017 mm, BFI=71 calculated from annual hydrograph and catchment area 95 Km^2.

Hydrogeological complex	BFI theoretic average
(3) Arenaceous flysch complex (24 Km^2)	44
(5) Marly-calcarenitic complex (27 Km^2)	76
(6) Basin edge complex (44 Km^2)	80



BFI estimated by weighted area mean is 70, with a very simple difference from BFI calculated.

The results obtained by equations (1) and (3) with Tab.4 are:

ADFest.=1.07 cumecs   ADFobs.=1.53 cumecs $\triangle$%=30

P %	Q(P)obs. cumecs	Q(P)est. cumecs	$\triangle$ %
40	1.32	0.96	27.3
50	1.07	0.83	22.4
60	0.91	0.73	19.8
70	0.76	0.62	18.4
80	0.66	0.50	24.2
90	0.54	0.38	29.6
95	0.46	0.30	34.7

The results of the examples are reported graphically in figures 1 and 2.

5.0 CONCLUSIONS

This paper suggests a mathematical model to derive an estimation of water resources of a region. Particularly we obtained the low flow evaluation for gauged and ungauged basins with an accuracy included on average between 10% and 25%. This accuracy can be considered acceptable to design a minihydro plant relating to its optimal regime.

Further developments could allow the optimization of the entire duration curve which can define completely the hydrological regime of a given basin. Moreover we are planning to extend the research to other regions with different hydrogeological characteristics in such a way we can have a confirmation of the goodness of the proposed methodology.

Tab.1 CHARACTERISTIC DATA OF STUDIED CATCHMENTS (I part)

N. -	river -	hydrometric station	years of record	SAAR mm	BFI obs.	AREA Km^2	hydrogeological complexes (tab. 2)
1	Tevere	S.Lucia	31	1013	44	934	(3)=100%
2	Tevere	P.te Felcino	34	973	43	2033	(3)=100%
3	Tevere	P.te Nuovo	37	980	51	4147	(3)=82% (9)=18
4	Chiani	P.te Morrano	37	962	35	422	(1)=56% (2)=11% (3)=29% (9)=4%
5	Chiascio	Torgiano	40	1038	59	1956	(3)=53% (9)=47%
6	Topino	Bettona	38	1014	64	1220	(3)=38% (9)=62%
7	Paglia	Orvieto	14	1015	30	1320	(1)=53% (2)=18% (3)=9% (4)=19% (9)=1%
8	Fiora	M. di Castro	10	940	59	818	(1)=10% (2)=20% (4)=70%
9	Marta	P.te Cartiera	26	945	92	273	(4)=52% natural lake area =48%
10	Mignone	Rota	11	1071	42	220	(2)=39% (4)=61%
11	Treia	Civ. Castellana	13	1018	76	497	(4)=100%
12	Aniene	Subiaco	44	1394	85	233	(10)=100%
13	Velino	Posta	19	1017	71	95	(3)=25% (5)=28% (6)=47%
14	Amaseno	Fossanova	12	1282	67	382	(4)=8% (10)=92%
15	Nera	Torre Orsina	46	1052	93	1445	(9)=100%
16	Orcia	Monte Amiata	21	815	25	580	(1)=77% (2)=23%
17	Albegna	Monte Merano	12	1151	28	192	(1)=56% (2)=34% (9)=10%
18	Chienti	P.te Giove	20	1327	80	110	(9)=100%
19	Chienti	Pieve Torina	23	1317	82	118	(9)=100%
20	Vibrata	Alba Adriatica	12	795	57	117	(1)=81% (3)=9% (5)=4% (6)=6%
21	Tordino	Teramo	34	1044	58	147	(3)=71% (5)=29%
22	Tavo	S.Pellegrino	34	1129	66	213	(3)=47% (6)=35% (10)=18%
23	Feltrino	S.Vito	25	847	28	50	(1)=100%
24	Trigno	Pesco Lanciano	15	1360	39	90	(2)=58% (5)=42%
25	Carpino	Carpinone	7	1175	78	72	(6)=100%
26	Rapido	S.Elia	14	1476	92	69	(7)=35% (8)=65%
27	Melfa	Picinisco	8	1346	82	42	(7)=14% (8)=76% (10)=10%

Tab.1 CHARACTERISTIC DATA OF STUDIED CATCHMENTS (II part)

N.	river	hydrometric station	years of record	SAAR mm	BFI obs.	AREA Km²	hydrogeological complex (tab. 2)
-	-						
28	Sacco	Ceccano	12	1330	39	923	(2)=11% (3)=11% (4)=49% (5)=2% (10)=27%
29	Cosa	Ceccano	12	1396	51	324	(3)=21% (10)=79%
30	Liri	Sora	24	1181	71	1329	(3)=25% (6)=2% (10)=68% (11)=5%
31	Giovenco	Pescina	11	850	82	139	(3)=17% (6)=13% (10)=34% (11)=36%
32	Rio Mollo	Settignano	6	1377	37	71	(3)=34% (7)=36% (11)=30%
33	Marta	Centr.Traponzo	34	910	72	851	(4)=100%
34	Candigliano	Acqualagna	9	1249	41	617	(3)=90% (9)=10%
35	Metauro	Barco di Bella.	20	1169	43	1045	(3)=90% (9)=10%
36	Esino	Moie	7	1133	55	791	(1)=20% (3)=29% (9)=51%
37	Potenza	Cannucciaro	29	1144	73	439	(3)=28% (9)=52%
38	Tenna	Amandola	25	1358	76	100	(3)=5% (5)=15% (6)=55% (9)=25%
39	Aso	Comunanza	16	1285	71	85	(3)=69% (5)=5% (6)=26%
40	Rio Arno	Ponte Rio Arno	36	1357	63	58	(3)=50% (5)=9% (6)=36% (8)=5%
41	Aterno	Treponti	29	1001	53	114	(3)=65% (5)=11% (6)=19% (8)=5%
42	Aterno	L'Aquila	23	1015	59	531	(3)=47% (5)=15% (8)=5% (10)=28% (11)=5%
43	Aterno	Molina	33	920	74	1303	(3)=23% (5)=12% (6)=30% (8)=5% (10)=27% (11)=3%
44	Tasso	Scanno	9	1221	77	80	(3)=15% (6)=40% (7)=25% (11)=20%
45	Sagittario	Villalago	29	1285	94	108	(3)=9% (6)=39% (7)=26% (11)=26%
46	Pescara	Maraone	35	914	93	2033	(3)=5% (6)=60% (7)=5% (10)=15% (11)=15%
47	Zittola	Montenero	36	1376	60	32	(2)=35% (5)=65%
48	Sangro	Opi	20	1610	47	130	(3)=33% (8)=12% (10)=28% (11)=27%
49	Aventino	Vicenne	13	882	78	201	(2)=46% (10)=54%
50	Biferno	Ripalimosani	14	1284	67	593	(3)=47% (6)=18% (10)=12% (11)=23%
51	Arno	Stia	26	1298	39	62	(3)=100%
52	Can. Chiana	P.te Ferrovia	30	825	33	1271	(1)=50% (3)=50%
53	Arno	Subiano	34	1271	43	738	(3)=100%

Tab. 2: BFI for various hydrogeological complexes

N.	hydrogeological complex	BFI	
		range	theoretic average
(1)	COMPLEX OF MARINE CLAY	16 - 30	23
(2)	ARGILLACEOUS FLYSCH COMPLEX	26 - 38	32
(3)	ARENACEOUS FLYSCH COMPLEX	34 - 54	44
(4)	VOLCANIC COMPLEX	55 - 75	65
(5)	MARLY-CALCARENITIC COMPLEX	72 - 80	76
(6)	BASIN EDGE COMPLEX	78 - 82	80
(7)	COMPLEX OF SLOPE DEPOSITS	81 - 85	83
(8)	DOLOMITIC COMPLEX	83 - 91	87
(9)	COMPLEX OF PELAGIC DEPOSITS	70 - 90	80
(10)	COMPLEX OF CARBONATE SHELF	80 - 88	84
(11)	CARBONATE SHELF EDGE COMPLEX	85 - 95	90

Tab. 3: a_i, regression coefficients and error in estimating of equations (1) and (3) for great basins

DURATION %	a_0 --	a_1 --	a_2 --	a_3 --	R -	s.e.
40	0.30567	0.04562	0.85062	0.00802	0.956	0.362
50	-1.42331	0.02824	1.02005	0.00974	0.970	0.353
60	-2.48781	0.00575	1.14567	0.00968	0.965	0.429
70	-3.36114	-0.01615	1.25613	0.01007	0.941	0.618
80	-3.14045	-0.05650	1.31633	0.00729	0.928	0.727
90	-0.47679	-0.14774	1.31319	-0.00266	0.927	0.755
95	-0.38704	-0.15590	1.28022	-0.00226	0.912	0.817
ADF	-3.87034	0.10213	0.06288	0.11417	0.938	0.522

Tab. 4: a_i , regression coefficients and error in estimating of equations (1) and (3) for little basins

DURATION %	a_0	a_1	a_2	a_3	R	s.e.
40	2.10505	-0.01615	0.88963	0.03431	0.960	0.344
50	-0.80221	-0.03360	1.09886	0.13720	0.961	0.429
60	-3.29659	-0.05369	1.28691	0.24037	0.956	0.539
70	-5.29048	-0.05586	1.37536	0.30770	0.958	0.568
80	-8.13366	-0.02220	1.39641	0.39344	0.947	0.683
90	-12.01316	0.03609	1.43296	0.47731	0.938	0.753
95	-15.10780	0.09569	1.45035	0.51670	0.929	0.835
ADF	-3.87034	0.10213	0.06288	0.11417	0.938	0.522

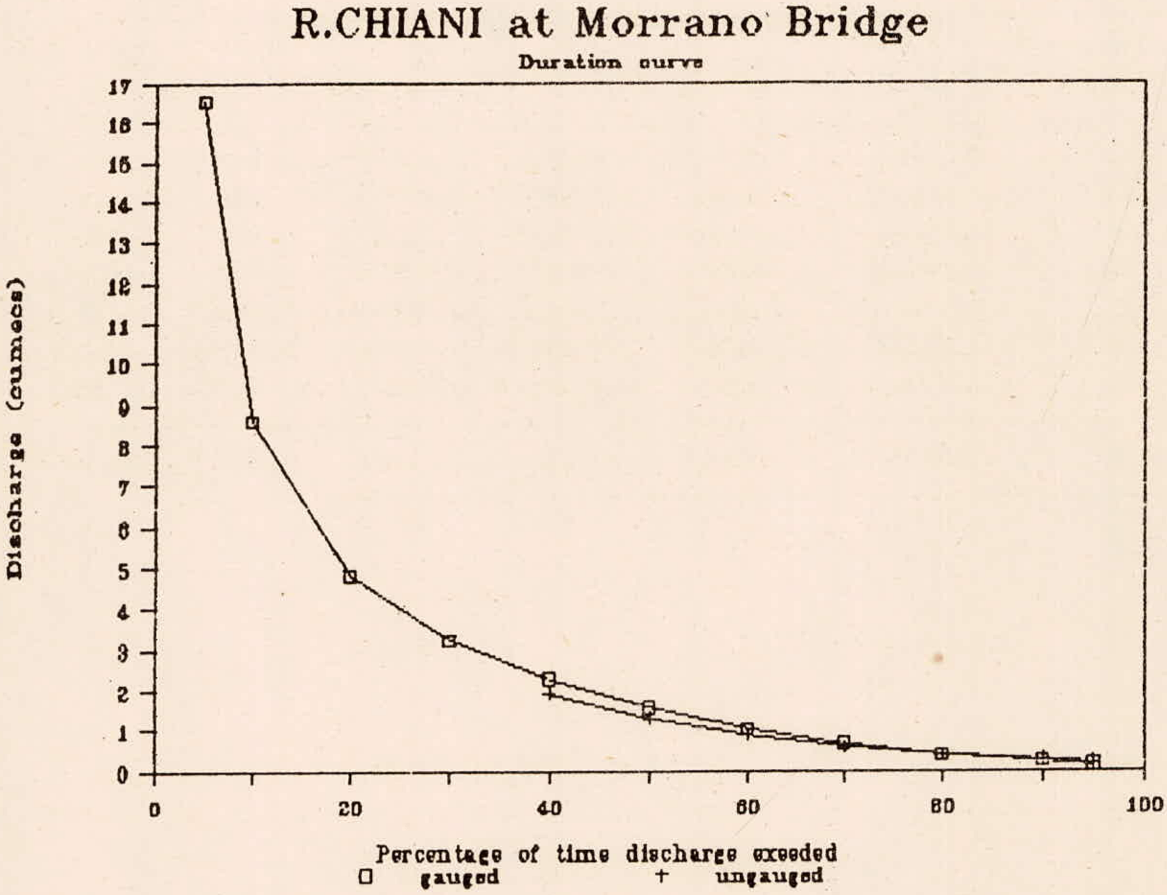
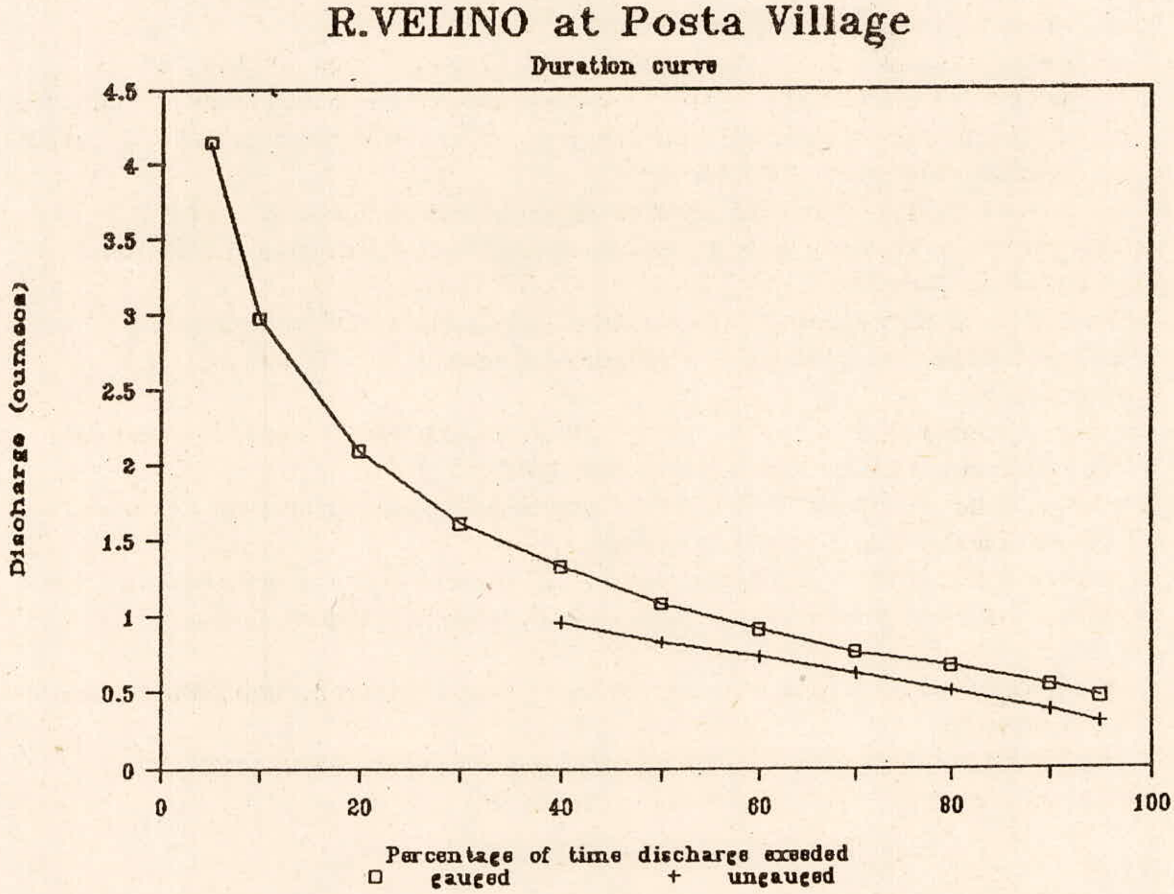

R.CHIANI at Morrano Bridge
Duration curve
Discharge (cumecs)
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
0
20
40
60
80
100
Percentage of time discharge exceded
□ gauged
+ ungauged

Figure 1



R.VELINO at Posta Village
Duration curve
Discharge (cumecs)
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
0
20
40
60
80
100
Percentage of time discharge exeeded
gauged
ungauged

Figure 2

REFERENCES

[1] Martin J.V. and Cunnane C. 1976 "Analysis and prediction of low-flow and drought volumes for selected Irish rivers" The Institution of Engineers of Ireland.

[2] Simmers I. 1975 "The use of regional hydrology concepts for spatial transation of stream data." The Institution of Civil Engineers. Introductory Paper to the Hydrological Group.

[3] Musiake K., Inokuti S., Takahasi Y. 1975 "Dependence of low-flow characteristics on basin geology in mountainous areas of Japan." Publication of Nx 117 de L'Association Internationale des Sciences Hydrologiques de Symposium de Tokio." 147,156

[4] Midgeley D.C. 1957 "Generalized drought sequence probabilities for storage draft frequency analysis." International Hydrology Symposium, Fort Collins, 443,450.

[5] Knisel W.G. 1963 " Base flow recession analyses for comparison of drainage basins and geology." Journal of Geophisical Research, 68,12, 3649-3653.

[6] Boni C., Bono P., Capelli C. 1987 "Hydrogeological Scheme of Central Italy. Hydrogeological Map scale 1:500.000".

[7] Boni C., Bono P., Capelli C. 1987 "Hydrogeological Scheme of Central Italy. Hydrology Map scale 1:500.000".

[8] Lvovitch M.I. 1972 "Hydrologic budget of continents and estimate of the balance of global fresh water resources." Soviet Hydrology, Nx 4. pp. 439-360.

[9] Institute of Hydrology Crowmarsh Giffort Wallingford, Oxon 1980 "Low Flow Studies".

[10] Tonini D. 1974 "Elementi di idrografia ed idrologia" Vol. I-II.