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Climate Changes and their Influence on the Design of Hydraulic Structures from Romania

During the last decades, the human being influenced environmentally the Earth, causing global environmental changes of such a size that have become global phenomena.
These changes include the climate, ozone layer depletion, biogeochemical cycles, hydrological cycle, and water resources, raising the ocean levels or thermohaline circulation.
The hydrological cycle and water resources changes have significant effects on the design of hydraulic structures, provided they are exploited in the presence or absence of major climatic factors, such as water, air, or soil.

Keywords: *hydrological cycle, water resources, theoretical probability curve*

1. Introduction

The hydraulic structure's design is done by taking into account their class of importance using specific design regulations and standards.

These are complemented by technical prescriptions necessary to follow-up the behavior of hydraulic structures during their operating period.

This paper try to present new design settlements of hydraulic structures, under the effects induced by hydrological regime and water resources of river basins, respectively what actions need to be adopted for having a safe operating of this type of structures during the time.

2. Establishing design prescriptions of hydraulic structures in accordance with climate change

The design of hydraulic structures is taking into account their class of importance by specific design standards and prescriptions.

According to these, engineers should take into account details regarding the future location of hydro technical works, under the conditions in which their operating behavior may change because the action of water, i.e. assumptions and design regulations.

These standards are complemented by technical prescriptions needed to follow-up the hydro technical constructions behavior during the operational period.

3. Amendments of prescriptions to the design of hydraulic installations

The design assumptions of transit and large water facilities through hydro technical works are determined by their class of importance and depend by the hydrological conditions of their location [1].

Maximum flow rates with different probabilities used to design and subsequent verification of these works can be determined by two methods, by using dates from measurements and lack thereof.

3.1. Existing data from measurements

These direct measurements of maximum flow carried out for a period of 20-40 years and include a complete cycle of dry, normal, and heavy rain years. The maximum flows recorded (with different probabilities according to their class of importance) are extracted from the curve of probability. However, these flows are affected by errors resulting from a poor number measurements respectively other causes induced by the rainfall regime.

Consequently, it is recommended that the maximum flow to be checked by similarity with other dates recorded to other hydrometric stations, located on the same the river or others with a similar hydrologic regime.

The maximum flow rates used to calculate the probability curve must meet two parameters:

- The flow sequences should be formed only by peak flood flows, and
- The maximum flow rates should have the same origin (pluvial or nival).

It is recommended the coefficient ***Cs*** = 2 ***Cv*** to maximum pluvial flows and ***Cs*** = 4 ***Cv*** for nival.

On the Romanian territory, the maximum flows resulted from rainfall are highest during the whole period of measurements, only in certain river basins where these flows are mixed pluvio – nival [2].

Consequently, engineers have concluded that to hydraulic works dimensioning is necessary to use maximum pluvial flows data measurements recorded. The most important issue that arises concerning the application of probability curves to calculating the maximum flows is the coincidence of theoretical and empirical probabilities from stemming security of this type of structures. The Romanian rivers have registered catastrophic floods that exceeded the 1/1000 years probability mentioned in the regulations. Generally, the theoretical probabilities determined by the analytical probability curves are closer to the actual probabilities determined for a number of years. However, should be take into consideration the fact that the formulas used to determine the empirical probabilities are giving ones within the maximum flows string, with values of probabilities based on the length of string. Consequently, the probabilities of historical maximum flows calculated with these formulas differ from the real ones.

Therefore, is necessary to choose the most suitable theoretical probability curve, which could allow to solving an issue frequently met in practice, namely the extrapolation of probabilities at the ends of the interval.

In this regard, can be used the theoretical Pearson III hydrologic hazard probability curve, which will be hereinafter, respectively the Gumbel probability distribution curve, the Gaussian probability curve, the Gauss - Laplace or the Gama probability curve.

In practice, it sometimes happens that the highest value of maximum flow rates to differ greatly than those incurred the curve, having other probability than the empirical one.

It is recommended to correct the empirical probability of these rates using a curve correction factor or recalculating the arithmetic mean $\overline{Q}_{max}$ and the coefficient of variation C_v, using specialized formulas from technical literature. For getting a better correction, the maximum flows result by calculating the hydrologic hazard probability to rivers where the data streams are short, therefore, it is recommended to increase the maximum flow value by using a safety correction coefficient, named ΔQ.

$$\Delta Q = Q_{max} \cdot a \cdot \frac{E_p}{\sqrt{n}} ,$$

Where a = 1 ... 2 and depending on the quality of measurements (real or doubtful ones);

n = number of measurements; Ep = the probable error determined by the diagram in according to p% and C_v (Figure. 1).

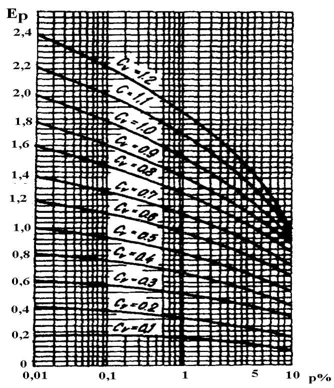

Figure 1. The Ep graph function

3.1.2. Evaluation of maximum flows with different probabilities using the empirical probability curve and the Pearson type III theoretical curve.

The Pearson type III curve distribution is an asymmetric curve, which depends by the positioning parameter f_0, and **a** respectively **d** variable. This curve is characterized by the fact that the origin of the coordinate axes is opposite [3].

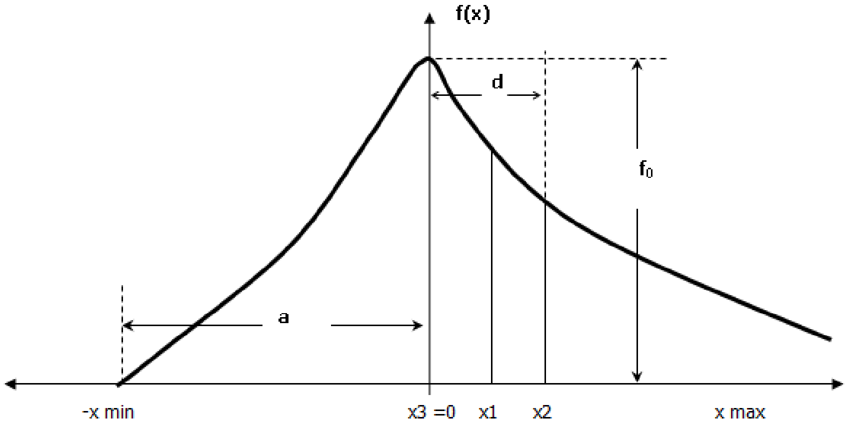

Figure 2. The Pearson type III theoretical distribution curve

The density of the curve is expressed by the formula:

$$f(x) = f_0 e^{-\frac{x}{d}} (1+\frac{x}{a})^{\frac{a}{d}},$$

where f_0 = the maximum ordinate; d = radial asymmetry; a = curve variability (distance between x_{min} and x_3), x = independent random variables represented by the Pearson type III theoretical curve.

Both, the distribution curve and the Pearson III probability curve depend by these three parameters. The distribution curve has a wide application in hydrology, adjusting fairly well the hydrological regime in Romania.

I conclude that the x_{max} variable (Figure 2) asymptotically tends to $+\infty$, just as a theoretical approximation of the physical phenomenon with no, any certainty that the x_{max} measured value is the highest possible one.

Providing few theoretical Pearson III distribution curve, which depend on these three parameters, we can solve a problem posed in hydrology, i.e., by choosing a curve in which to enroll the best in data obtained through observations and measurements with the condition that the first three moments of theoretical distribution to be equal to the first three percentage points calculated. The points I, II and III are namely: the arithmetic mean, the variation coefficient C_v and the asymmetry coefficient C_s.

In the case of continuous random variables, the probability of exceedance (probability that the random variable X to get greater values than a given value **x**), is expressed by formula:

$$p(x) = \int_x^\infty f(x)dx \ ,$$

Where ***p (x)*** = the probability of exceeding and ***f (x)*** = the density of the curve distribution.

For discrete random variables, the overflow probability shall be calculated according to the same formula, excepting the fact the integral is replaced by a sum.

To design, build and operating hydraulic works is necessary a knowledge of hydrological elements such as water flow, water level, water volumes, etc., with different probabilities in calculation and verification processes.

Having the statistical series X_i, $i=1, 2... n$, where $n > 20$ of hydrological observations and measurements, it may be drawn up an empirical probability curve by ordering downwards the hydrological data as a string ($X_i > X_{i+1}$).

This probability is calculated by using the Weibull's formula:

$$p_i = \frac{i}{n+1} 100 \ [\%] \ ,$$

Where: i = the number of the terms in string, and n = the total number of terms of the string.

The formula has a drawback that it provides approximate probability values at the ends of the range (only for n> 70 the approximations have low range).

The results are introduced to Table 1 and plotted as an empirical curve to a graph. The graph has the log or semi-logarithmic axis with the probability dates on the abscissa and the hydrological analysis dates on the ordinate (Figure 2).

Table 1. The elements of representation of the empirical probability curve

Year	The hydrological element analyzed, order descending $X_i (X_i > X_{i+1})$	Empirical probability $p_i = \frac{i}{n+1} 100$
0	1	2

The empirical probability curve achieved is particularly important into the practice because engineers can extract values of the hydrological sizes analyzed, with probabilities needed.

However, the application area of this probability curve is small one. In the most of the cases, this curve contains low amplitudes variations of the hydrological element studied, because of the short strings data used to the curve representation.

Thus, the extrapolating probability to the ends of the range can be solved by using the Pearson III theoretical probability curve.

The steps of calculating this theoretical curve are:

- The statistical string X_i is ordered descending ($X_i > X_{i+1}$), calculating the arithmetic mean by formula:

$$X_{med} = \frac{\sum_{i=1}^{n} X_i}{n},$$

- Also, is calculated the K_i coefficient and the C_v variation coefficient.

$$K_i = \frac{X_i}{X_{med}}$$

$$C_v = \sqrt{\frac{\sum_{i=1}^{n}(K_i - 1)^2}{n-1}}$$

- The asymmetry coefficient C_s is determined according to the variation coefficient C_v

$$C_s = \alpha \cdot C_v,$$

Where, the α coefficient values are approximated according to the size of the probability values calculated , namely:

- α = 0 for maximum levels;
- α = 1.5 for annual average flow river regime that impermanent;
- α = 2.0 for annual average flows, summer minimum, maximum spring;
- α = 3 to 3.5 for maximum rainfalls;
- α = 3.5 to 4.0 for small streams maximum flow.

When the data number n is very large one, the coefficient of asymmetry is calculated by using the formula:

Year	The hydrological element X_i ($X_i > X_{i+1}$)	Coefficients moduli $K_i = \frac{X_i}{X_{med}}$	(K_i-1)	$(K_i-1)^2$	$(K_i-1)^3$
0	1	2	3	4	5
. . . .	X_1 $X_{2.}$ . . X_n	K_1 K_2 . . K_n	(K_1-1) (K_2-1) . . (K_n-1)	$(K_1-1)^2$ $(K_2-1)^2$ . . $(K_n-1)^2$	$(K_1-1)^3$ $(K_2-1)^3$ . . $(K_n-1)^3$

Table 2. Intermediate calculations

$$C_s = \frac{\sum_{i=1}^{n}(K_1-1)^3}{n \cdot C_v^{\ 3}},$$

All date results are centralized into the Table 2.

The values with different probabilities are calculated by using the Foster - Rîbkin or the Krîţkii - Menkel table.

Foster and Rîbkin started from the premise that to the Pearson III distribution of variable K, the ordinates Ψ of probability curve are proportional with a coefficient $\boldsymbol{C_v = 1}$.

When $\boldsymbol{C_v \neq 1}$, then the K variable is calculated with formula:

$K = 1 + C_v\ \Psi$

The Foster-Rîbkin table is composed by the coefficient $\boldsymbol{C_v}$ (Table 3). It is used to calculate different values of probabilities, as follows:

- The values of asymmetry coefficient $\boldsymbol{C_s}$ are previously registered to the first column of Table 3.
- Corresponding to $\boldsymbol{C_s}$ values, the probabilities are calculated and introduced to the first line of the table.

Table 3. The Foster-Rîbkin probability rates for **α = 2** Deviations of ordinates

p% Cs	0,01	0,1	1	5	10	20	50	80	95	99	99,9
0,00	3,72	2,09	2,33	1,65	1,28	0,84	0,00	-0,84	-1,64	-2,33	-3,09
0,10	3,94	2,40	2,40	1,67	1,29	0,84	-0,02	-0,85	-1,62	-2,25	-2,95
0,20	4,15	3,38	2,47	1,70	1,20	0,83	-0,03	-0,85	-1,59	-2,18	-2,81
0,30	4,37	3,52	2,54	1,72	1,31	0,82	-0,05	-0,85	-1,56	-2,10	-2,67

p% Cs	0,01	0,1	1	5	10	20	50	80	95	99	99,9
0,40	4,60	3,67	2,62	1,75	1,32	0,82	-0,07	-0,86	-1,52	-2,03	-2,53
0,50	4,82	3,81	2,68	1,77	1,32	0,80	-0,08	-0,86	-1,49	-1,95	-2,40
0,60	5,05	3,96	2,76	1,80	1,33	0,80	-0,10	-0,86	-1,46	-1,88	-2,27
0,70	5,27	4,10	2,82	1,82	1,33	0,79	-0,12	-0,86	-1,42	-1,81	-2,14
0,80	5,50	4,24	2,89	1,84	1,34	0,78	-0,13	-0,86	-1,39	-1,73	-2,02
0,90	5,72	4,39	2,96	1,86	1,34	0,77	-0,15	-0,85	-1,35	-1,66	-1,90
1,00	5,96	4,53	3,02	1,88	1,34	0,76	-0,16	-0,85	-1,32	-1,59	-1,79
1,20	6,41	4,82	3,15	1,91	1,34	0,73	-0,20	-0,84	-1,24	-1,45	-1,58
1,40	6,87	5,10	3,27	1,94	1,34	0,70	-0,22	-0,83	-1,17	-1,32	-1,39
1,60	7,32	5,37	3,39	1,96	1,33	0,68	-0,25	-0,82	-1,09	-1,20	-1,24
1,80	7,77	5,64	3,50	1,98	1,32	0,64	-0,28	-0,80	-1,02	-1,09	-1,11
2,00	8,21	5,91	3,60	2,00	1,30	0,61	-0,31	-0,78	-0,95	-0,99	-1,00
2,20	-	6,20	3,70	2,01	1,28	0,58	-0,33	-0,75	-0,90	-0,90	-0,99
2,40	-	6,47	3,78	2,01	1,25	0,54	-0,35	-0,71	-0,82	-0,83	-0,83

Table 4. The Foster-Rîbkin table for calculating the theoretical probability curve

p%	0,01	0,1	1	2	5	10	20	50	80	95	99	99,9
Ψ												
Ψ ***Cv***												
$K=1+\Psi Cv$												
$Xp=K X_{med}$												

The Foster-Rîbkin table is only valid for $\alpha = 2$. The tables developed by Krîţkii - Menkel are based on the variable change $x = a\,\xi^b$, thus achieving the Pearson III probability curve for each report (Table 5, Table 6, Table 7 and Table 8).

Table 5. The Krîţkii - Menkel probability curve ordinate for $\alpha = 1$

p%	***Cv***										
	0,1	0,2	0,3	0,4	0,5	0,6	0,7	0,8	0,9	1,0	1,1
0,001	1,45	2,01	2,63	3,30	4,02	4,82	5,62	6,46	7,38	8,37	8,92
0,01	1,39	1,86	2,39	2,94	3,55	4,20	4,87	5,59	6,07	7,19	8,01
0,1	1,33	1,70	2,11	2,54	3,02	3,53	4,05	4,50	5,21	5,82	5,58
1	1,24	1,51	1,78	2,09	2,41	2,76	3,11	3,40	3,90	4,31	4,73
5	1,17	1,34	1,53	1,72	1,92	2,13	2,35	2,56	2,80	3,05	3,28
10	1,13	1,26	1,40	1,54	1,69	1,82	1,96	2,11	2,27	2,42	2,56
20	1,10	1,17	1,25	1,32	1,41	1,43	1,55	1,81	1,67	1,72	1,75
50	1,00	0,99	0,98	0,98	0,93	0,90	0,86	0,81	0,76	0,70	0,62
80	0,91	0,83	0,74	0,65	0,57	0,47	0,39	0,31	0,23	0,16	0,11
95	0,84	0,69	0,55	0,42	0,31	0,21	0,14	0,08	0,04	0,02	0,01
99	0,78	0,58	0,41	0,27	0,16	0,08	0,04	0,02	0,01	0,00	0,00
99,9	0,72	0,47	0,28	0,15	0,07	0,02	0,00	0,00	0,00	0,00	0,00

Table 6. – The Krîţkii - Menkel probability curve ordinate for α = 1, 5

p%	Cv									
	0,1	0,2	0,3	0,4	0,5	0,6	0,7	0,8	0,9	1,0
0,001	1,44	1,94	2,46	2,91	3,47	3,95	4,35	4,72	5,02	5,30
0,01	1,40	1,81	2,25	2,70	3,15	3,37	3,94	4,31	4,88	4,91
0,1	1,32	1,67	2,08	2,39	2,77	3,14	3,48	3,82	4,13	4,41
1,0	1,24	1,49	1,75	2,03	2,31	2,59	2,87	3,15	3,45	3,78
5,0	1,17	1,34	1,52	1,70	1,90	2,10	2,31	2,52	2,78	3,04
10	1,13	1,26	1,39	1,58	1,68	1,83	1,99	2,16	2,38	2,57
20	1,08	1,17	1,25	1,34	1,42	1,51	1,59	1,89	1,78	1,88
50	1,00	0,99	0,99	0,97	0,96	0,93	0,89	0,83	0,16	0,67
80	0,91	0,83	0,74	0,65	0,55	0,45	0,35	0,24	0,15	0,09
95	0,84	0,58	0,58	0,38	0,26	0,15	0,08	0,04	0,01	0,00
99	0,78	0,57	0,38	0,23	0,12	0,05	0,01	0,00	0,01	0,00
99,9	0,70	0,45	0,25	0,11	0,04	0,01	0,00	0,00	0,00	0,00

Table 7. – The Krîţkii - Menkel probability curve ordinate for α = 3

p%	Cv										
	0,1	0,2	0,3	0,4	0,5	0,6	0,7	0,8	0,9	1,0	1,1
0,001	1,58	2,50	3,82	5,6	8,10	11,00	14,26	17,6	20,6	24,00	27,5
0,01	1,51	2,20	3,15	4,36	5,90	7,70	9,57	11,4	13,5	18,60	21,6
0,1	1,38	1,87	2,53	3,29	4,20	5,07	8,05	7,02	8,12	9,25	10,4
1	1,25	1,58	1,94	2,34	2,17	3,17	3,59	4,91	4,43	4,90	5,35
5	1,17	1,35	1,55	1,75	1,93	2,11	2,28	2,45	2,60	2,77	2,92
10	1,11	1,26	1,38	1,51	1,61	1,72	1,82	1,90	2,00	2,05	2,12
20	1,08	1,15	1,21	1,26	1,31	1,34	1,37	1,40	1,41	1,42	1,43
50	0,99	0,98	0,95	0,92	0,89	0,85	0,82	0,76	0,75	0,71	0,67
80	0,91	0,83	0,75	0,68	0,61	0,55	0,50	0,45	0,40	0,36	0,31
95	0,85	0,72	0,61	0,52	0,44	0,37	0,32	0,26	0,22	0,16	0,15
99	0,80	0,64	0,52	0,42	0,34	0,27	0,22	0,17	0,14	0,11	0,08
99,9	0,75	0,56	0,43	0,33	0,25	0,19	0,14	0,10	0,09	0,05	0,04

Table 8. – The Krîţkii - Menkel probability curve ordinate for α = 4

p%	Cv										
	0,1	0,2	0,3	0,4	0,5	0,6	0,7	0,8	0,9	1,0	1,1
0,001	1,50	2,28	3,35	4,69	6,21	6,30	10,42	12,8	15,5	18,28	21,3
0,01	1,42	2,05	2,85	3,18	5,00	5,28	7,70	9,21	11,0	12,89	14,8
0,1	1,35	1,80	2,36	3,00	3,75	4,58	5,43	6,31	6,48	7,33	9,54
1	1,25	1,55	1,88	2,25	2,65	3,07	3,49	3,92	4,40	4,88	5,37
5	1,14	1,26	1,39	1,58	1,68	1,76	1,87	1,97	2,09	2,15	2,24
10	1,09	1,16	1,23	1,29	1,33	1,38	1,42	1,45	1,47	1,49	1,49
20	0,99	0,98	0,96	0,98	0,90	0,86	0,82	0,78	0,74	0,91	0,68
50	0,91	0,83	0,75	0,67	0,80	0,53	0,40	0,41	0,36	0,70	0,26
80	0,84	0,71	0,39	0,49	0,41	0,33	0,26	0,21	0,17	0,13	0,10
95	0,79	0,62	0,48	0,37	0,29	0,21	0,16	0,12	0,08	0,06	0,04
99	0,73	0,53	0,38	0,27	0,19	0,13	0,09	0,08	0,03	0,02	0,01
99,9	1,50	2,28	3,35	4,69	6,21	6,30	10,42	12,8	15,5	18,28	21,30

The calculation of the theoretical probability curve is done by using Table 9.

Having all these extracted values it can be calculated the hydrological probability for each element analyzed.

Table 9. Calculation of the theoretical probability curve by reference to the Krîţkii - Menkel tables

p%	0,001	0,01	0,1	1	5	10	20	50	80	90	99	99,9
K												
X_p=K X_{med}												

The theoretical probability curve is represented on the same empirical probability curve graphic. The abscissa represents the probability to logarithmic scale and the ordinate represents the hydrological size at normal scale, for α = 2 or logarithmic scale $\alpha \neq 2$.

It is considering the position of the theoretical probability curve compared to the empirical probability curve. If there are, differences between two curves need to make a fit of the theoretical probability curve using experimental date (the empirical probability curve) by changing the coefficients ***Cv*** and ***Cs*** or the α report.

Drawing up theoretical probability curve starts by taking the most probable value of the coefficient ***Cs*** i.e., ***Cs*** = ***2 Cv***. Need to be checked if the theoretical probability curve overlaps the empirical probability one, or not. If this happen, means the α coefficient was well chosen and the calculation is concluded.

If, however, these two curves have similar values on the average probability and at the ends do not overlap (usually this case happens very often) is given a new value to this coefficient. This case, the theoretical probability curve is recalculated until it will overlap the empirical one (Figure 3).

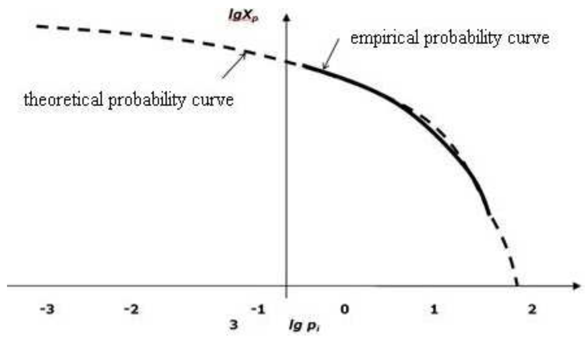

Figure 3. The Pearson III empirical probability curve

The change direction α coefficient depends by the position of these two curves, namely:

- Case the low probability curves area is <10% then α coefficient > 2.
- Case the theoretical probability curve is below the empirical one, then α coefficient.

3.2 Case of missing data from measurements

Case no any measurements and observations of the maximum flows are registered on the river, and then are necessary used mathematical models. These are based on the systemic perspective in hydrology, the rain extension process being represented by graphs. The rating of hydrological output depends on the river basin surface, corresponding to the cross section of river [5].

Usually, river basins are classified by their areas size ***F***, as follows: very small basins (***F*** ≤ 50...100 km^2) small basins (100 < ***F*** ≤ 500 km^2) medium basins (500 < ***F*** ≤ 1000 km^2) and large basins (***F*** > 1000 km^2).

3.2.1. Evaluation of maximum flow design for very small reservoirs

In practice, to this type of water reservoirs is necessary an evaluation of maximum flow rates on slopes and small rivers. The mathematical models used are actually simple formulas that provide a maximum flow rate size which depending on the input into the system, i.e. the rain intensity calculation respectively a series of physical and geographical elements of the river basin [6].

The models that take into account the main factors contributing to flood genesis are called genetic models. The most used model from is the method or the rational formula:

$$Q_{p\%}^{\max} = 16,7 \cdot \alpha \cdot I_{p\%} \cdot F \qquad (m^3/s)$$

Or

$$q_{p\%}^{\max} = 16,7 \cdot \alpha \cdot I_{p\%} \qquad (m^3/\ km^2\ s)$$

Where, $Q_{p\%}^{\max}$ and $q_{p\%}^{\max}$ represents the probability of the maximum flow rate exceeding, respectively the specific maximum flow rate with probability of exceedance, as flows set for section calculation; F = the reception basin area corresponding to section calculation (km^2); ɑ = coefficient of superficial leakage, Ip% = the intensity of rain calculation with temporal probability of exceedance, (mm / min); 16.7 = conversion factor of size.

3. Conclusions

The climate change is one of the most serious challenges of humanity, influencing the activities associated with the management of hydraulic structures.

The amplification of climate change induces additional problems both for in design as well as to the operational hydraulic structures. The design activity will be taking into account the design prescriptions and calculation efforts, such as flows having maximum levels with different probabilities of exceedance, flows with different levels of security, rainfall calculation, curve of maximum rainfall, maximum wind speeds with different probabilities or maximum / minimum design temperature. The operational activities of hydraulic works should reconsider the operating conditions of structures under the conditions in which the operating efforts are modified compared to those which taken into account the design (transit flows higher than those used to structure's design, additional water volumes which need to be stored or disposed safety). Under the conditions of climate change appears the necessity to modify the rainfalls calculation used to reach the maximum flow with different probabilities. The rainfalls graphs and their intensity calculations used to dimensioning the maximum flow must be updated by supplementing these values with less than 20%. In the last decade of years, were registered many crashes to hydraulic structures, particularly to structures of transit flows on rivers and (bridges, culverts, viaducts), to which the specialists have used rain calculation formulas which no longer correspond the current hydrological situation.

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