REDEFINITION OF FLOOD WATERS FOR THE KALIMANCI DAM

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1. Abstract

Definition of flood waters, their intensity and duration is the most important factor in defining the relevant flood waters for proportioning hydro-technical structures and protection against flood waters.

Due to changes of natural factors and changed conditions under the influence of anthropogenic factors taking place at already constructed hydrotechnical structures, redefinition of flood waters is an extremely important measure in forecasting floods and timely undertaking of corresponding activities for prevention or reduction of their consequences.

Presented in this paper are the results of the hydrological analysis of the Kalimanci dam basin carried out for the purpose of redefining flood waters. The analyses of the physical-geometrical characteristics of the drainage area carried out by use of DTM (**D**igital **T**errain **M**odel) and application of SWAT (**S**oil & **W**ater **A**ssessment **T**ool), a hydrological analysis module from the **G**eographic **I**nformation **S**oftware (GIS), are presented further in the text. Flood waters with different return periods will be redefined by use of statistic methods based on data from measurements of ″Bregalnica″ river flow (1961-2005) and ″Kamenichka Reka″ river flow (1986-2005). Shown further in the paper will be the results of the calculation of the maximum flood waters (MPF-**M**aximum **P**robable **F**lood waters) in the basin. MPF will be calculated by taking into account a series of data on maximum annual daily rainfall, measured at the dam itself, in the period 2005 to 2017. The results of these analyses will be presented in a tabular and graphic form.

Kaywords: hydrological analysis, watershed, flood, discharge, precipitation

2. Introduction

Water is an essential component of life on our planet. However, at the time of increased CO_2 emissions and global planetary environmental pollution, man faces the negative impacts of water. We are witnessing more frequent extreme meteorological and hydrological phenomena that result in enormous damage and loss of human lives. Under global warming effects, the conditions for the formation of natural hydrological phenomena have changed. Noticeable is the occurrence of non-characteristic high and low temperatures, heavy precipitations and increased humidity as well as periods without precipitations. These phenomena are manifested by extremely dry and extremely wet periods at previously uncharacteristic locations.

Floods as extreme events are the reason for the increased level and flow of water in river beds, lakes and seas. The appearance of flood water in nature is a natural phenomenon. It takes place due to an increased quantity of water in a given area within a relatively short period of time. In hydrotechnics and, generally, in construction, determination of flood waters with a certain return period is one of the key elements in design of such facilities.

Due to climate changes, but also due to anthropogenic activities in the catchment areas, conditions for formation of flood waves are changing. Therefore, redefinition of flood waters at already constructed hydrotechnical objects is necessary from the aspect of timely and precise forecasting of occurrence of flood waters and taking certain activities in order to prevent unwanted consequences.

In this paper, the subject of analysis is the catchment area of the Kalimanci dam and redefinition of flood waters.

The "Kalimanci" dam was built in 1969. It is located in the eastern part of the Republic of Macedonia, on "Bregalnica" river, northeast of the city of "Kochani", at 23 km from "Makedonska Kamenica". To the North, where "Kamenicka Reka" river empties into the water mirror of the "Kalimanci" reservoir, there starts the mining town of "Makedonska Kamenica". To the south, below the reservoir body, the hydroelectric power plant "Kalimanci" and "Istibanje" settlement were built. To the East, there stretches the "Kalimanci" field. Locations of "Kalimanci" dam is shown on Figure 1.

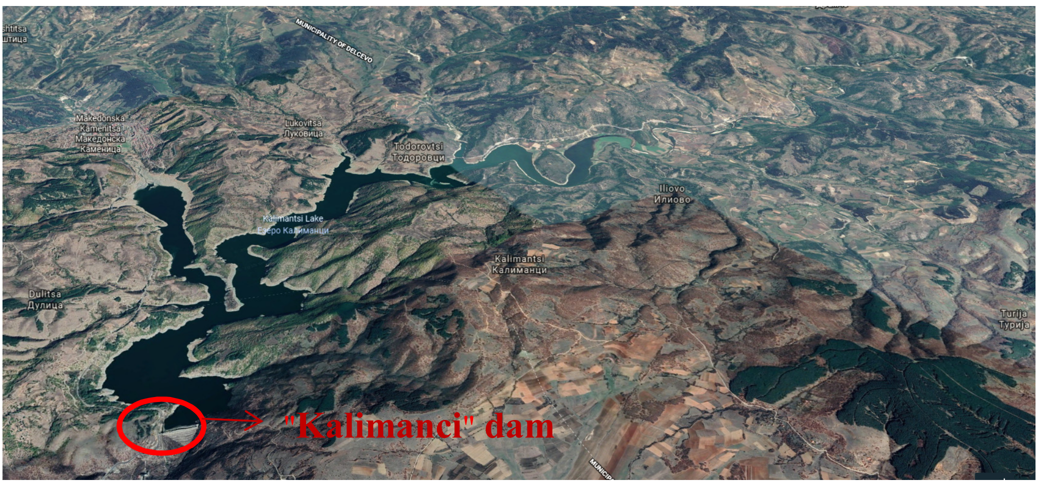


Figure 1 Locations of "Kalimanci" dam (Sourse: Google Earth)

The "Kalimanci" was built as an earthfill dam of a combined type constructed of a rock-shale fill, while its middle part is composed of a thin waterproof clay core and upstream and downstream filters. The height of the dam measured from the river terrace is 85 m, while its design height is 95 m. The dam length is 232 m, while the dam width is 10 m,

Figure 2. With the construction of the dam, the artificial "Kalimanci" lake was formed to accumulate the waters of "Bregalnica" and "Kamenicka Reka" rivers. The volume of the reservoir up to the overflow (515 mNV) is 115.6 million m^3, of which 113.8 million m^3 represents effective space.

Figure2 "Kalimanci" Dam (Sourse: Google Earth)

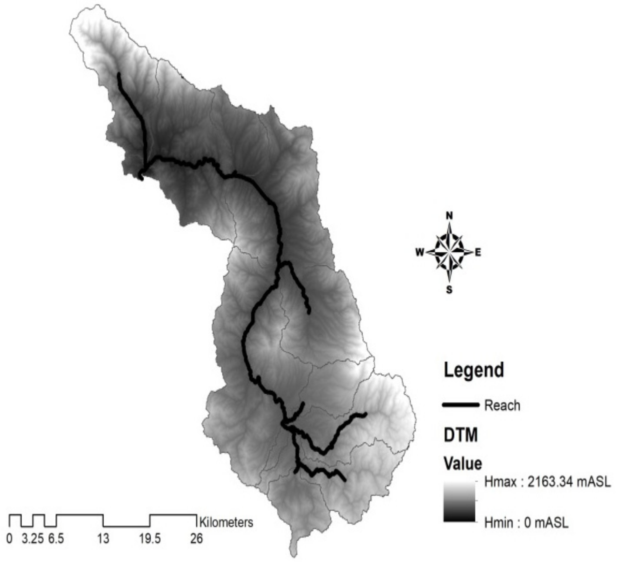
The purpose of the "Kalimanci" Dam is to accumulate water for irrigation of agricultural land with total area of 28 000 ha from "Kocansko Pole", "Vinichko Pole", "Shtipsko Pole" and "Ovce Pole", to produce electricity and flood protection.

2. Physical-geographical characteristics of the watershed

The determination of the physical geometric characteristics of the watershed was done by use of DTM (Digital Terrain Model) (30x30 m) and application of SWAT (**S**oil &**W**ater **A**ssessment **T**ool), hydrological analysis module from GIS (**G**eographic **I**nformation **S**oftware). To define the geometric characteristics of the watershed from the "Bregalnica" river to the "Kalimanci" dam, using the ArcSwat program, the DEM base of the Republic of Macedonia was used. Plotting of the watershed and definition of the size of the drainage basin on the "Bregalnica" river was done for the profile of the Kalimanci dam, with coordinates xy (631 529; 4648885). Output results through graph display of the watershed from "Bregalnica" river to the dam and separately for the "Kamenichka Reka" river are given in Figure 3 and Figure 4, respectivly.The geometric characteristics are shown in Table 1.

Table 1 The geometric characteristics of the watershed upstream the dam, watershed of "Bregalnica" and "Kamenicka reka" river

Wateshed	A [km^2]	H_{min} [mNV]	H_{max} [mNV]	dH	L_t [m]	L_s [m]	S_t [%]	S_s [%]
upstream the dam	1123	498	860	362	85,6	61,9	4,23	5,85
"Bregalnica" river	1007,3	498	860	362	62,6	41,8	5,78	7,42
"Kamenicka reka" river	115,7	506	1200	866	23	17	3,76	4,85



Figur 3 Watershed of the "Bregalnica" river

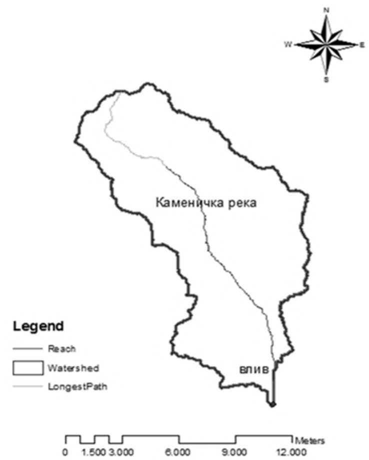


Figure 4 Watershed of the "Kamenicka reka" river

3 Use Land

Analysis of land use and representation of certain classes for the purpose of hydrological modeling of the drainage basin of the "Bregalnica" river, from its spring to the "Kalimanci" dam, was carried out by application of CORINE Layer Classification. The data were processed and interpreted using the GIS software modules, Table 2. The most common in the basin covering more than 832.18 km2 (74.1%) are the so called forests and semi-natural areas. Out of these, 799.04 km2 (71.2%) are under forests. The structure of the forests is dominated by coniferous, then broadleaf and small mixed forests. Grassland and grassland vegetation is present both in the transitional areas and in the higher parts of the watershed. In this group, the most present is the natural grass with approximately 33.05 km2 (2.9%) of the total surface of the basin and there is a negligible presence of rare vegetation of 0.1 km2 (0.01%). The agricultural areas with 263.35 km2 (23.45%) are fairly present in the basin and cover pastures of 120.04 km2 and dominant mixed agricultural areas, i.e., an agricultural area with natural vegetation of 143.31 km2 (12.80%). Within the basin, the so-called artificial surfaces (urban areas, industrial, commercial and transport facilities, then mines, landfills and construction sites) account for 27.47 km2 (2.45%) of the total surface of the basin. Urban areas are represented by 5.52 km2 (0.49%), industrial and commercial buildings cover 0.84 km2 and the most dominant are mines covering 21.11 km2 (1.88%). The scale of the network used (250x250 m) did not allow exact determination of the individual categories of the third level, such as roads, railways and alike that exist in the basin. For these reasons, no wetlands, muddy areas and water bodies were detected. Therefore, this analysis of presence of individual categories of land use should be taken only as indicative and for the needs of the hydrological analysis of the watershed. Figure 4 shows the sectoral presentation of presence of different categories of land.

Table 2 Category of Use land

Classe 1	Classe 2	second level		first level	
		[km²]	[%]	[km²]	[%]
artificial surfaces	urban areas	5.52	0.49		
	industrial, commercial and transport units	0.84	0.07		
	mine, dump and construction sites	21.11	1.88		
	artificial, non-agricultural vegetated areas	0.00	0.00	27.47	2.48
agricultural areas	arable land	0.00	0.00		
	permanent crops	0.00	0.00		
	pastures	120.04	10.7		
	heterogeneous agricultural areas	143.31	12.8	263.35	23.45
forests and semi-natural areas	forests	799.04	71.2		
	scrub and/or herbaceous vegetation associations	33.05	2.9		
	open spaces with little or no vegetation	0.09	0.01	832.18	74.10
wetlands	inland wetlands	0.00	0.00		
	maritime wetlands	0.00	0.00	0.00	0.00
water bodies	inland waters	0.00	0.00		
	marine waters	0.00	0.00	0.00	0.00
Nodata	Nodata	0.00	0.00	0.00	0.00
see and ocean	see and ocean	0.00	0.00	0.00	0.00
		1123.00	100	1123.00	100

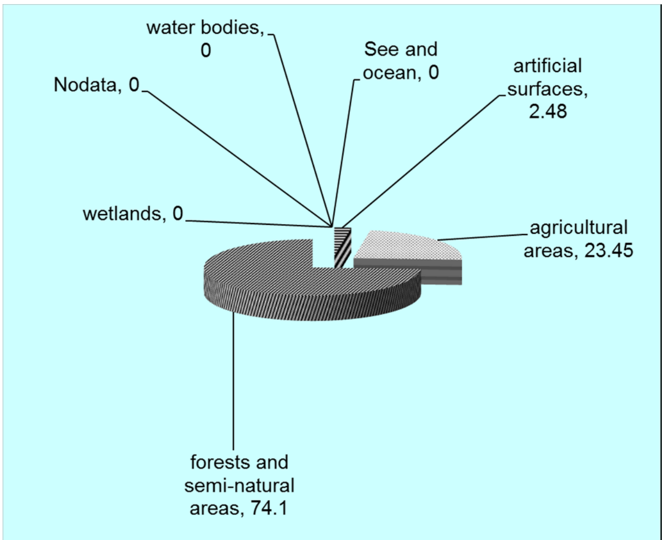


Figure 5 Categories of use land, sectoral presentation

4. **Redefining flood waters**

In order to determine the flood wave from the basin upstream the dam, the flood waters from the "Bregalnica" river and particularly the flood waters from the "Kamenichka Reka" river were analyzed since these are the two main rivers that flow directly into the reservoir.

To define the flood waters from "Bregalnica" river, a series of maximum annual flows at the measuring point of the dam profile was used. This series (1961-2005) was obtained in correlation with the series of maximum annual flows measured at the "Ochi Pale" measurement profile (source: UHMR).

A series of maximum annual flows (1986-2005) measured at the measuring profile in "Kamenica" was used to determine the flood wave from "Kamenichka Reka" river. The series of maximum annual flows of "Bregalnica" river and "Kamenichka Reka" river are shown in the form of hydrograms in Fig. 6 and 7.

All these data were statistically processed and the main statistic parameters (number of measured data (N), characteristic values of the sequence: average discharge (Q_{sr}), minimum (Q_{min}) and maximum discharge (Q_{max}), mean square deviation (σ), variation coefficient (C_v) and asymmetry coefficient (C_s)) were computed, Table 2. Statistical methods were used to determine the flood waters using three theoretical distribution functions (Gumbel, Pearson III-type and Log-Normal distribution[2], [3], [5])). To determine which distribution best adapts to the empirical probability of the array of measured data, the results obtained were tested. For this purpose, the (χ^2) test was applied. For the "Bregalnica" river, the best adapted was the Pearson III type distribution, while for the "Kamenichka Reka" river, the Gumbel distribution was best fitted. Lines of distribution of flood waters for "Bregalnica" river are shown in Figur 8 and lines of distribution of flood waters for "Kamenicka reka" river are shown in Figur 9. Hydrographs of a flood water with a different return period for "Bregalnica" river are shown in Figur 10 and hydrographs of a flood water with a different return period for " Kamenicka reka " river are shown in Figure 11.

Table 2 - - Statistic parametars for seria of data on maximum annual flows "Bregalnica" river and "Kamenicka Reka" river

discharge	**N**	**Q_{sr}**	**Q_{min}**	**Q_{max}**	**σ**	**C_v**	**C_s**
"Bregalnica" river	45	124,66	16,68	357,37	85,29	0,68	0,83
"Kamenicka reka" river	23	7,82	1,34	19,2	4,03	0,515	0,861

Table 3 – Flood waters calculate according to the three distribution functions for the "Bregalnica" river and "Kamenicka Reka"river

Return period T [years]	Probability p [%]	Bregalnica river			Kamenicka Reka river		
		Gumbel distribution	Log-Normal distribution	Pisrson-III-type distribution	Gumbel distribution	Log-Normal distribution	Pisrson-III-type distribution
10000	0,01	698,96	1834,87	710,58	34,96	57,64	31,84
1000	0,1	545,83	1119,63	558,77	27,72	40,32	26,08
100	1	392,29	606,23	403,55	20,47	25,87	19,99
20	5	283,85	352,65	290,12	15,34	17,48	15,40
5	20	186,06	184,96	185,21	10,72	10,96	10,88
2	50	110,69	94,71	105,90	7,16	6,75	7,17

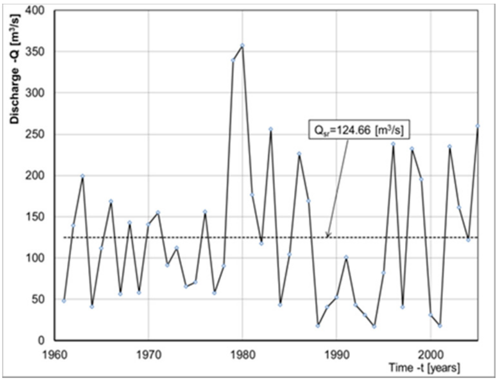


Figure 6 Hydrogram on maximum annual flows in "Bregalnica" river (1961-2005)

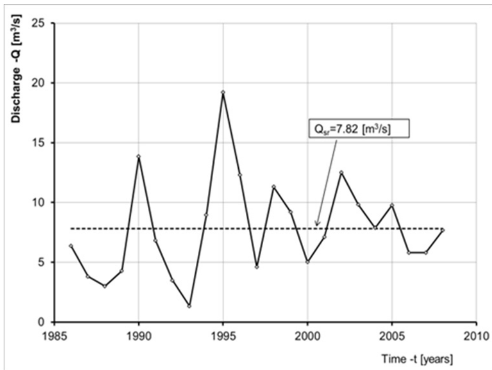


Figure 7 Hydrogram on maximum annual flows in "Kamenicka Reka" river (1986-2005)

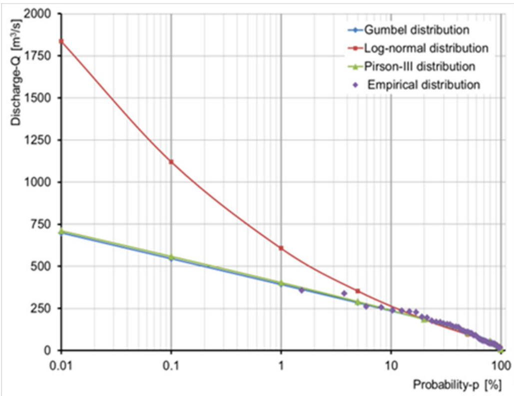


Figure 9 Lines of distribution on flood waters in the "Bregalnica" river

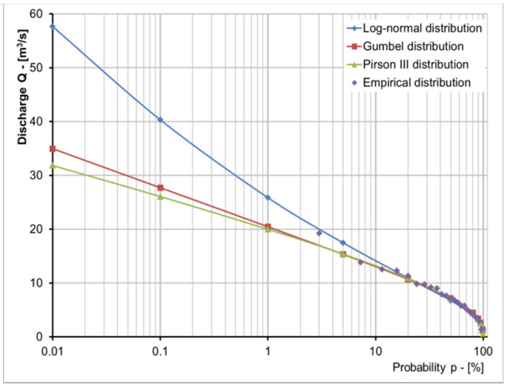


Figure 10 Lines of distribution on flood waters in the "Kamenicka reka" river

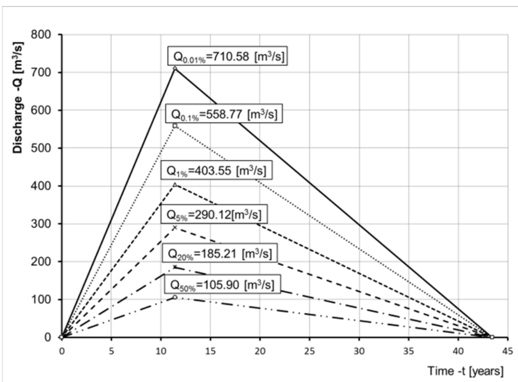


Figure 11 Hydrographs of a flood water with a different return period for "Bregalnica" river

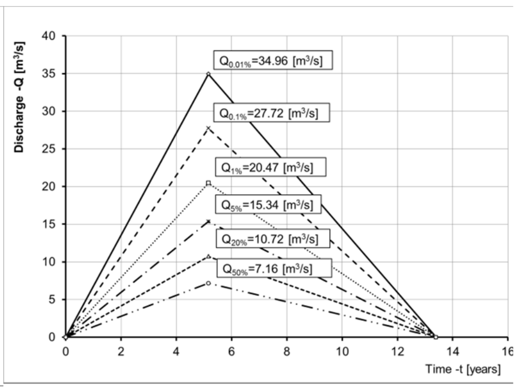


Figure 12 Hydrographs of a flood water with a different return period for "Kamenicka reka" river

5. Maximum Probable Flood (MPF)

A widely accepted practice in hydro-engineering was proportioning of spillways of large dams (dams higher than 15 m) by consideration of flood waters with a probability of occurrence of 0.01% (i.e., a return period of T = 10000 years) for bulk dams and 0.1 % (T = 1000 years) for concrete dams. More recently, this rule has been accepted and applied in our country and has been subjected to an extensive revision. Namely, from the statistics made by ICOLD (International Commission of Large Dams) regarding collapsed dams and reasons for their collapse, one can see that the most common reason for failure of large dams (even for 34% of the total registered collapsed large dams) is overflowing of the dam crown, which is mainly due to the low capacity and the insufficient throughput of the evacuation facilities (overpass). Due to this, in recent times and worldwide, an obligation has been introduced to design the spillway facilities of all major dams and dams of greater significance by consideration of the Maximum Probable Flood (MPF). This obligation is not only consistently observed in a large number of countries, but already built dams are subjected to revision, as well.

According to the U.S. Corps of Engineers, the Maximum Probable Flood (MPF) is the flood wave that can be expected as a consequence of the most unfavorable combination of critical meteorological and hydrological conditions in the analyzed basin. A dominant role in the formation of the MPF have the meteorological conditions combined with the hydrological state of the watershed (the previous humidity conditions of the soil that depend on the geological structure of the terrain). The physical geographical characteristics of the considered basin are practically unchangeable and do not have a dominant role in the formation of the MPF. Deterministic or parametric methods are used to determine the MPF. Used as an input in these methods are the probable maximum 24-hour precipitations (PMP_{24}-Maximum Probable Precipitation) at the geographical point of the basin where the measurement is carried out and at the average height of the layer of the probable maximum 24 –hour precipitations ($PMP_{24,\,A}$) in the basin.

Due to incomplete data and substrates (air humidity, wind, map of PMP), an alternative way of determining the probable maximum precipitation or a statistical empirical method prepared by the US meteorologist David Hershfild, [1],will be used to determine the maximum flood wave (MPF) for the "Kalimanci" dam basin. The procedure itself is simple, easy and fast and gives satisfactory results. This method used data in seria of maximum annual daily rainfall in the watershed for the period from 2005 to 2017 measured at the dam itself. The statistics for this seria (P_n) and the seria without the highest value (P_{n-1}) are shown in Table 4.

Table 4 - Statistical parametars for seria of data on maximum annual daily rainfall (2005-2017)

	N	P_{sr}	P_{min}	P_{max}	σ	C_v	C_s
P_n	13	40.45	25.1	55.2	8.57	0.21	0.23
P_{n-1}	12	39.22	25.1	54.0	7.54	0.19	0.13

To calculate the 24-hour maximum precipitations, the corrected values $Pcor=Pn\cdot f1\cdot f2=43{,}33$ (mm/den) and $\sigma_{cor}=f_3\cdot f_4\cdot\sigma_n=10.84$ are used, where: $f_1=1.04$, $f_2=1.03$, $f_3=1.1$, factors that depend on the length of the array, and $f_4=1.15$, the factor in function of the (σ_{n-1}/σ_n) relationship and the length of the array. $PMP=P_{cor}+k_{max}\cdot\sigma_{cor}=203.05$ (mm/24h), where $k_{max}=15$ is the generalized probability of the maximization factor and depends on P_{cor}, [1]. Since precipitation values are read at fixed time intervals, every day at 7 a.m., the observed values represent 24-hour precipitation. PMP_{24} is obtained if PMP is increased by 13%, namely: PMP_{24}=1.13PMP=237.89 (mm/24h).

PMP_{24} represents precipitation at a point, but for a basin, it is corrected by a reduction factor that decreases with the increase of the catchment area, i.e., f_6=f(A, t_k). For the basin upstream the Kalimanci dam covering an area of A=1123 km^2, with rain duration t_k=8.22h [?], f_6=0.755, while: $PMP_{24,A}=f_6 \cdot PMP_{24}$=179.6 (mm/24h). The maximum probable flood waters (MPF) are calculated according to the empirical formula: $Q_{max}=MPF=(PMPe \cdot A)/T_b$=1458.87 m^3/s where: $P_e=(PMP_{24,A}-0.2d)\ 2/(PMP_{24,A}+0.8d)$ = 101.51 mm, d- humidity deficit, which is in function of CN, which, on the other hand, is in direct relation with the categories of land use within the basin. For the basin upstream the "Kalimanci" dam, it is CN = 73, [2]. T_b = 43.41 h.

6. Conclusions

Definition of flood waters with different return periods, early warning about their arrival, as well as undertaking activities in order to safely accept them and prevent adverse consequences, is extremely important for the security of the populated areas downstream the dams. For high quality analyses and calculations, it is necessary to have adequate hydrological data (data on measured flows at appropriate hydrological measuring stations, measured precipitation data on the entire drainage area, etc.). In order to provide these data, it is necessary to establish an effective monitoring network and to maintain, develop and improve it according to the recommendations of the World Meteorological Organization (WMO).

In this paper, using statistical and statistical-empirical methods, based on available data, the flood waters and the Maximum Probable Flood for the "Kalimanci" dam basin have been defined/redefined.

Using statistical data and based on data from measurements of flows, the flood waters with different return periods have been defined for "Bregalnica" river and "Kamenichka Reka" river up to the profile of the "Kalimanci" dam. From the conducted analyses, it can be concluded that the "Kalimanci" lake is dominantly influenced by the surface waters that come from the "Bregalnica" river basin in respect to the surface waters coming from the "Kamenichka Reka" river basin. The flood wave from the "Bregalnica" river, i.e., the maximum flood water from the "Bregalnica" river basin upstream the profile of "Kalimanci" dam arrives in the lake for 11.42 hours, while that from "Kamenichka" river arrives in the lake in 5.16 hours.

According to these analyses, the Maximum Probable Flood (MPF) is 1458,87 m^3/s or almost twice the wave with a return period of 10,000 years (710,58 for the "Bregalnica" river basin and 34,96 m^3/s for the "Kamenichka Reka" river basin).

For further analyses aimed at checking the capacity of the facilities within the frames of the Kalimanci dam regarding acceptance of flood waters and safety of the downstream populated places against flooding, the maximum probable flood waters are recommended to be used.

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