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ANALYSIS OF TIME OSCILLATIONS OF WATER ON LAKE MODRIC AS A MULTI-PURPOSE RESERVOIR

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SUMMARY

The major task of multi-purpose reservoir „Modrac" operation is to decide how much water should be released now and how much should be retained for future use given some available and/or forecasted information at the beginning of the current time period. In practice, reservoir operators usually follow rule curves, which stipulate the actions that should be taken conditioned on the current state of the system. Through construction of the dam Modrac in 1964, the reservoir of the same name was formed. Its primary objectives were the provision of technological water for industries in the Tuzla region and mitigation of downstream floods as well as recreation and other purposes. The multi-purpose reservoir Modrac is currently a drinking water source for the municipality Tuzla. In order to better manage of the multi-purpose reservoir „Modrac", certain analyzes are presented in this paper.

This paper presents an analysis of annual precipitation, mean annual inflows in the catchment area of the multi-purpose reservoir „Modrac" for the period 1967 - 2016. In this paper there are presented statistical datas on the maximum amount of precipitation for the dry season period (May to October) for different return periods, for different distribution curves, as well as the maximum amount of precipitation for the wet season (November to April) for different return periods for different curves distribution.

This paper provides information on the movement of precipitation changes in the catchment area of multi-purpose reservoir "Modrac" for the period from 1967. – 2016.

Keywords: *reservoir „Modrac", annual rainfall, precipitation, dry period, wet period*

INTRODUCTION

The current way of producing energy is the main "culprit" for human activity caused by climate change, while the water regime, with all its consequences, the first major "victim". High waters are increasing and occurring more and more often, while low water and drought reduced last longer [1].

Multi-purpose reservoir "Modrac" is formed in 1964 with the construction of a dam in the gorge Modrac. It is formed by the rivers Spreča and Turija with its river tributaries. The total catchment area in the profile of the dam is approximately 1189 km^2, which accounts for over 60% of the entire river basin to prevent this. Of the total area of the basin, river Spreča occupies 832 km^2, river Turija occupies 240 km^2, while the rest of the basin belongs to the immediate basin reservoirs 117 km^2 [2].

For the dimension of normal backflow 200.00 (m.a.s.l.) reservoir provides, on average, 2,30 m^3/sec of raw water and 4,70 m^3/sec as hydro biological minimum for the river Spreča, looking downstream from the dam (projected state) [2].

Multi-purpose reservoir “Modrac” solves several hydrologic and extremely economic aspects as supply of population, industry and thermal capacity of Tuzla and Lukavac with technological water, dilution of wastewater discharges Tuzla and Kladanj industry, the increase of flow of Spreča river downstream of the reservoir during the summer, electricity production in a small hydropower, mitigates high water flood flows with retention influence of reservoir and prevent or significantly reduce flooding in the river valley Spreča downstream of the reservoir.

However, the actual amount of water in the reservoir may vary over the short term depending on rainfall and other conditions [3].

Flood control dams store all or a portion of the flood waters in the reservoir, particularly during peak floods, and then release the water slowly [4].

According to the Law on the Protection of accumulation "Modrac" uses of reservoir “Modrac”, in order of priority, are [2]:
- the provision of water for the population,
- the provision of water for industry,
- protection from flooding downstream of the dam,
- the provision of hydro biological minimum for river Spreča, downstream of the reservoir,
- development of tourism, recreation and water sports, in accordance with the Law,
- the production of electricity on small hydroelectric using excess water in the profile Modrac.

According to the latest geodetic and hydrographic measurements reservoir "Modrac" has the following morphometric characteristics [5]:
- total area of the reservoir “Modrac” is 16,69 km^2,
- total volume of water in reservoir “Modrac” is 102.759.629,92 m^3,
- useful volume of water in reservoir “Modrac” is 66.522.627,23 m^3,
- maximum depth of the reservoir Modrac is 14.94 m (bed elevation),
- the average depth of the reservoir “Modrac” is 5.32 m,
- maximum width of the reservoir “Modrac” is 2.411,17 m,

The Modrac dam is multi-armored reinforced concrete with 11 counterframes, with the following basic characteristics, Figure 1:
- construction height of dam H = 33.35 m;
- dam length in crown L = 205,0 m;
- level of the upper edge of the structure of the dam 205,00 m.a.s.l.;
- designed level of maximum downfall 203,00 m.a.s.l.;
- level overflow fields of the dam - angle of normal slowdown 200,00 m.a.s.l.;
- minimum operating level: 194,00 m.a.s.l.;
- the four bottom outlets (number: 2, 6, 7 and 8). The maximum capacity (maximum shutter openness) of the basic drains is about 80.00 m^3/s [6].

The emergence of high water is extreme hydrological phenomena defined by an unusually high water level, flow or volume of water at a certain place at a certain time period. Causes and consequences of flooding is usually not be predicted, but can be mitigated. The consequences of floods vulnerability of human lives and material goods, huge damage, involvement of a large number of people and resources in the field, social insecurity of the population, etc [1].

Figure 2 shows digital orthophoto image of multi-purpose reservoir „Modrac“ where are visible enormous amounts of sediments at the coastline of lake Modrac [6].

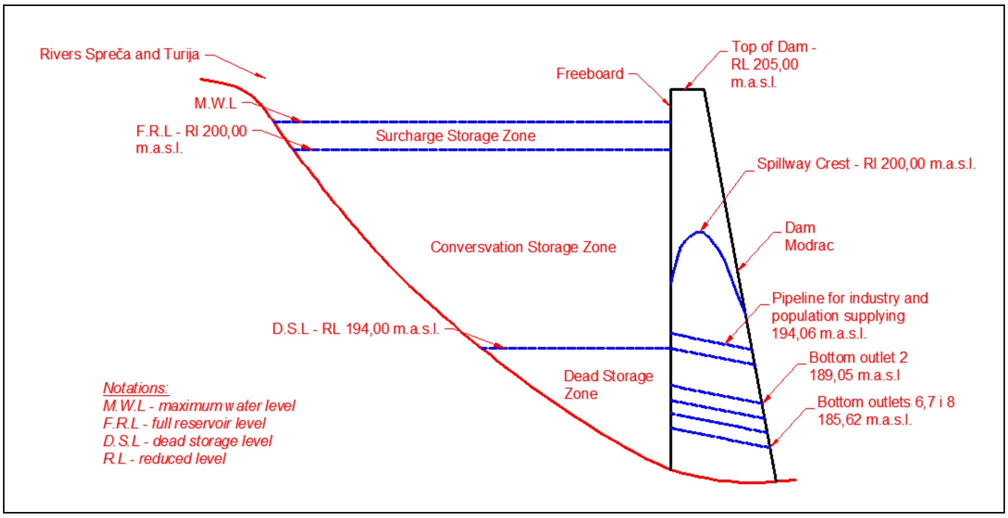

Figure 1. Charateristics of dam „Modrac“

Figure 2. Digital orthophoto image of multi-purpose reservoir “Modrac”

Climate changes are having a major impact on the amount of water in the multi-purpose reservoir as well as the appearance of large flood waves. One of the key elements for monitoring climate changes is temperature changes. Even slight changes in temperature affect the distribution of precipitation throughout the year, and the amount of precipitation [7].

This paper provides information on the movement of precipitation changes in the catchment area of multi-purpose reservoir “Modrac” for the period from 1967. – 2016.

Due to climate change in the period from the formation of the multi- purpose reservoir „Modrac“ to the present day all major flood waves have been recorded. In Table 1 of 1965, April 1985, July 1986, May 1987, June 2001, March 2006, May/June 2010 and May 2014 [8].

The discharge volume is controlled over the flow curve at the Modrac downstream station.

The amount of discharges is regulated by the bottom outlets and spillway facilities and depends on the level of water in the reservoir. Since the amount of discharge is limited by the appearance of large flood waves, there is a rise in the water level in the reservoir (accumulation charge), and thus absorbs part of the volume of the flood wave, ie it makes the reduction of the maximum flow. The reduction of maximum flow downstream ranges from 16 to 55% depending on the size of the water wave and the state of the reservoir Modrac level [8].

Table 1. Review of the characteristics of registered flood waves

Time to appear of flood wave	Maximum level H	Inflow Q_{inf}	Outflow Q_{out}	Retention of reservoir	Rainfall
	(m.a.s.l.)	(m^3/s)	(m^3/s)	%	(mm)
14.4. – 24.4. 1985.	201,09	406,50	201,10	50,53	81,16
15. 25.7. 1986.	200,74	272,10	154,90	43,07	117,57
3.5- 13.5 1987.	201,60	730,00	331,45	54,60	112,30
17.6. – 27.6. 2001.	202,12	619,10	466,36	24,56	60,20
29.5. – 8.6. 2010.	201,18	411,11	252,54	38,57	92,60
14. – 23.5. 2014.	203,42	1602,00	1137,00	29,00	213,90

The hydrographs of flood waves are determined on the basis of the natural flow into the reservoir. The hydrograph of outflows is determined by the discharge through the discharge facilitiess on the dam Modrac [9].

PRECIPITATION CHANGES

In addition, to determine the trend of changes in precipitation for a sequence of years from 1967. to 2016., the following figure shows the maximum annual precipitation values. From the Figure 3 it is visible that maximum value of precipitation (1434 l/m^2) has occured in 2014. All precipitation datas are measured climatological station „Modrac“ (K.S. Modrac) which is located at dam Modrac.

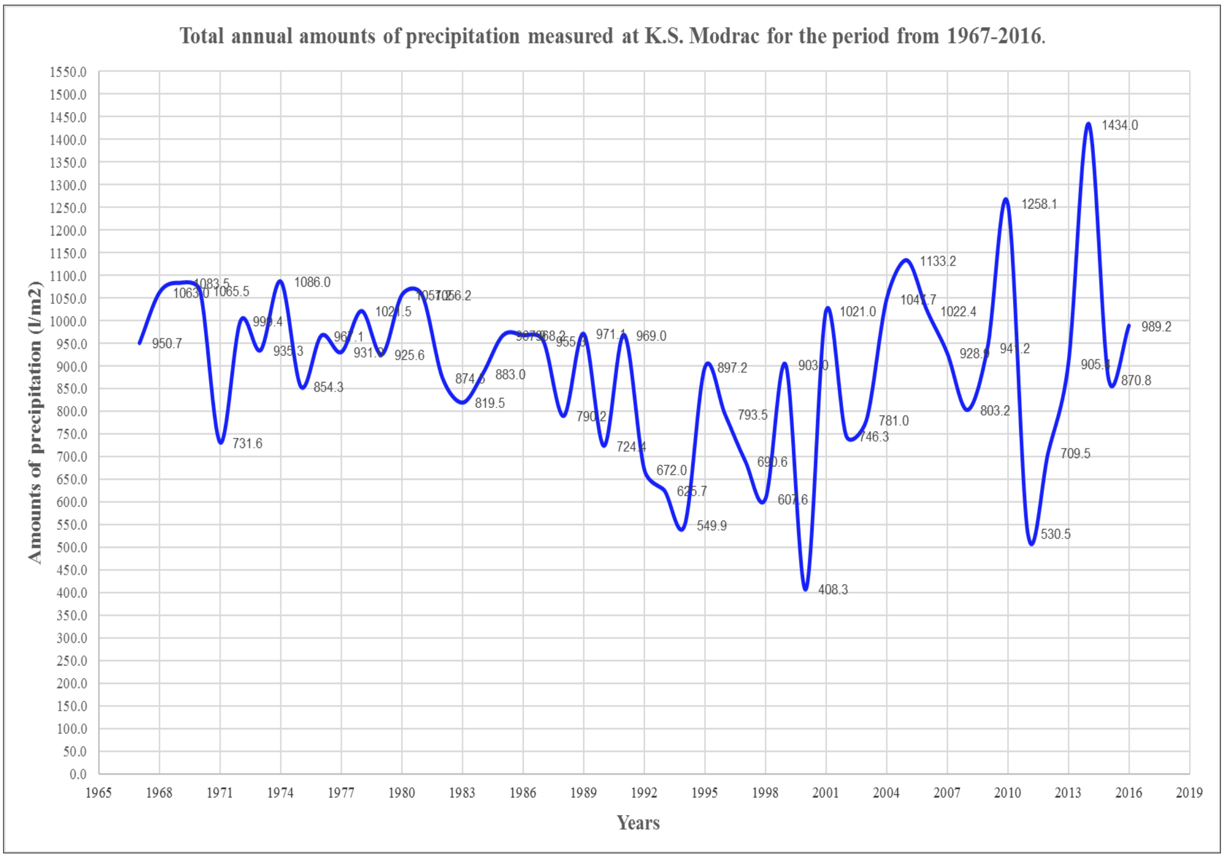

Figure 3. Total annual amounts of precipitation measurer at K.S. Modrac for the period from 1967 – 2016.

STATISTICAL PROCESSING AND PROBABILITY OF OCCURRENCE

Basics of statistical processing

For a reliable analysis of the behavior of a hydrological process, it is necessary to collect as much hydrological and meteorological data as possible (rain, water, flow, etc.). From this it follows that hydrological processing and analysis are based on a large number of data, ie on large samples of random hydrometeorological variables. In this case, under hydrometeorological processing and analysis, we mean a procedure by which large numerical random variable variables that point to sample behavior are determined from the large sample. The most commonly used numerical characteristics of the samples will be mentioned below. The arithmetic medium or commonly referred to as the mean is the most typical number in the set of values, which does not mean that the mean value itself must be one of the random variable X values.

The calculation of the maximum amount of rainfall by using statistical methods represents the procedure for determining the relevant distribution function based on input data obtained by hydrometeorological observations and measurements. The distribution function represents the way in which the frequency of members of a given entity is distributed according to the values of the variables they represent. The following table shows the calculation of the large waters using statistical methods and probability of occurrence of the Modrac accumulation deposits [10].

For the calculation of the maximum amount of precipitation, there was a 50 - year observation of the amount of rainfall on the Modrac dam profile (1967 - 2016).

Based on the presented series of maximum annual precipitation values in the Modrac reservoir reservoir, the calculation of the maximum values of these precipitation by statistical method was performed.

Empirical function of probability

The maximum annual precipitation is divided by the size and the empirical probability of occurrence of each individual member is defined. In the case analyzed, probability of occurrence by Chegodaev was adopted [11]:

$$P.P. = \frac{N+0,4}{m-0,3}$$

where:
P.P. – return period
N – number of row members,
m – number of members in a row

Thus, the probability of the occurrence of the first member (maximum annual precipitation) in the considered sequence is:

$$p = \frac{m-0,3}{N+0,4} = \frac{1\text{-}0,3}{50+0,4} = 0{,}0138=1{,}38\%$$

Probability of occurence of the second memeber is:

$$p = \frac{m-0,3}{N+0,4} = \frac{2\text{-}0,3}{50+0,4} = 0{,}0337=3{,}37\%$$

Determination of basic statistical parameters for a wet period (November – April)

Before approaching the calculation of the maximum annual precipitations of different return periods according to the distribution curves, it is necessary to determine the basic statistical parameters from the analyzed statistical set of data, namely: arithmetic mean, standard deviation σ, coefficient of variation c_v and asymmetric coefficient c_s .

The following values have been obtained:

1. arithmetic mean: $\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i = 121{,}29$

   where:
   n – number of row members
   x_i – i, member of the string

2. standard deviation: $\sigma = \sqrt{\frac{\sum_{i=1}^{n}((X_I - \bar{X})^2}{n}} = 31{,}17$

3. coefficient of variation: $C_v = \frac{\sigma}{\bar{X}} = \frac{31{,}169}{121{,}292} = 0{,}257$

4. koeficijent asimetrije: $c_s = \frac{m_3}{\sigma^3} = \frac{7666{,}56}{31{,}17^3} = 0{,}253$

   where:
   m_3 – third-order moment:
   $m_3 = \frac{1}{n}\sum_{i=1}^{n}(x_i - \bar{x})^3 = 7666{,}56$

Calculating the relative mean square deviations of the statistical parameters (error estimates), it was concluded that the mean deviations are not large. In the examples that occur in hydrometeorology, asymmetry according to this classification is usually medium, and very often large. It is not an exceptional case that the asymmetric coefficient reaches a value of 2, 3 and more (in our case c_s = 0.253 which means that the asymmetricity is small).

Determination of basic statistical parameters for a dry period (May - October)

The following values have been obtained:

1. arithmetic mean: $\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i = 139{,}522$

   where:
   n – number of row members
   x_i – i, member of the string

2. standard deviation: $\sigma = \sqrt{\frac{\sum_{i=1}^{n}((X_I - \bar{X})^2}{n}} = 54{,}78$

3. coefficient of variation: $C_v = \frac{\sigma}{\bar{X}} = \frac{54{,}78}{139{,}522} = 0{,}392$

4. asymmetric coefficient: $c_s = \frac{m_3}{\sigma^3} = \frac{161014{,}00}{54{,}78^3} = 0{,}979$

   where:
   m_3 – third-order moment
   $m_3 = \frac{1}{n}\sum_{i=1}^{n}(x_i - \bar{x})^3 = 161014{,}00$

Calculating the relative mean square deviations of the statistical parameters (error estimates), it was concluded that the mean deviations are not large. In the examples that occur in hydrometeorology, asymmetry according to this classification is usually medium, and very often large. It is not an exceptional case that the asymmetric coefficient reaches a value of 2, 3 and more (in our case c_s = 0.979 which means that the asymmetricity is medium).

Calculation of precipitations with different probability of occurence by selecting several theoretical distribution functions

The calculation of the precipitations, ie their estimation, was performed using the usual unbalanced distribution curves (Gumbel, Pearson 3, Galton) for comparison and Gauss symmetrical distribution.

<u>Gaussian distribution</u>

Amounts of precipitation for a different probabilities of occurence are derived from the expression:

$$P_{max} = \bar{x} + z \cdot \sigma$$

<u>Gumbel distribution</u>

Amounts of precipitation for a different probabilities of occurence are derived from the expression:

$$P_{max} = P_m + z \cdot \frac{1}{a}$$

where

P_m – mod of Gumbel's curve: $P_m = \bar{x} - 0{,}577\frac{1}{a}$

$\frac{1}{a}$ - parameter of Gumbel's distribution: $\frac{1}{a} = 0{,}78 \cdot \sigma$

<u>Pearson 3 distribution</u>

Amounts of precipitation for a different probabilities of occurence are derived from the expression:

$$P_{max} = (c_v \cdot \varphi + 1) \cdot \bar{x}$$

where

j – represents function defined as: j = f (c_s, p); the values of function j for different probabilities of occurrence p and different asymmetric coefficients c_s are determined from Foster - Ribkin's tables

<u>Log normal (Galton) distribution</u>

In this distribution, the logarithmic transformation of the random variables is applied, so distribution tags and their sizes are as follows:

1. logarithm for maximum rainfalls: $p = log P_{max}$
2. arithmetic mean of the logarithms of the row log P_{max} : $\bar{p} = \frac{1}{n}\sum_{i=1}^{n} p$
3. standard deviation of logarithms: $\bar{\sigma} = \pm\sqrt{\frac{\sum_{i=1}^{n}(p-\bar{p})^2}{n}}$

The values of the logs of the maximum amount of rainfall for different probability of occurrence are obtained according to the expression:

$$p_{max} = \bar{p} + z \cdot \bar{\sigma}$$

Values of the maximum amount of rainfalls of various probability of occurrences are obtained by anti - logging the values of the maximum rainfall logarithms, ie from the expression:

$$P_{max} = 10^{p_{max}}$$

The following table (Table 2.) summarizes the maximum rainfall values for different return periods for wet period (November – April) obtained by selecting different distribution curves.

Table 2. Maximum rainfall values for different return periods for wet period (November – April) obtained by selecting different distribution curves.

Return period (years)	Probability of occurence p (%)	Gauss (l/m^2)	Gumbel (l/m^2)	Pearson 3 (l/m^2)	Galton (l/m^2)
1000	0.1	217.61	277.45	421.67	993.12
200	0.5	201.40	240.98	361.75	693.43
100	1	193.61	219.10	331.01	583.45
50	2	185.19	202.32	302.62	484.17
25	4	175.84	185.06	270.30	393.55
10	10	161.19	161.97	225.36	284.45
5	20	147.47	143.73	185.15	209.89
2	50	121.29	116.26	114.98	117.49

The following table (Table 3.) summarizes the maximum rainfall values for different return periods for dry period (May – October) obtained by selecting different distribution curves.

Table 3. Maximum rainfall values for different return periods for dry period (May – October) obtained by selecting different distribution curves.

Return period (years)	Probability of occurence p (%)	Gauss (l/m^2)	Gumbel (l/m^2)	Pearson 3 (l/m^2)	Galton (l/m^2)
1000	0.1	308.80	414.46	485.05	1088.93
200	0.5	280.31	350.26	416.13	760.33
100	1	266.61	311.75	380.76	639.73
50	2	251.82	282.21	348.11	530.88
25	4	235.39	251.83	310.93	431.52
10	10	209.64	211.17	259.23	311.89
5	20	185.54	179.07	212.98	230.14
2	50	139.52	130.70	132.27	128.82

Figure 4. shows maximum ammounts of precipitation for a wet period (November - April) for different return periods, for different distribution curves. The analyzed period represents 50 yearly series of precipitation from 1967. to 2016.

Figure 5. shows maximum ammounts of precipitation for a dry period (May - October) for different return periods, for different distribution curves. The analyzed period represents 50 yearly series of precipitation from 1967. to 2016.

CONCLUSION

Analysis of maximum rainfall values shows that global climate change also reflects in the catchment area of multi-purpose resevoir „Modrac“ [11].

Figure 2., shows maximum total annual amounts of precipitation measured at K.S. Modrac for the period from 1967 – 2016., and it can be concluded that maximum annual amounts of precipitation occured in 2014 (1434 l/m^2).

Figures 3. and 4. shows maximum amounts of precipitation for a wet period (November – April) and dry period (May-October) for different return periods, for different curves of distribution.

From these two pictures it can be concluded that maximum amounts of precipitation for different return periods, for different curves of distribution are bigger for dry period because the practice through history is that the biggest flood waves have occured in May and June (Table 1 and 2).

Statistical analysis of maximum values of rainfall data for different return periods in this paper are of special importance for the prediction of flood waves and the determination of the actual volume of reservoir, which determines the degree of safety of the dam.

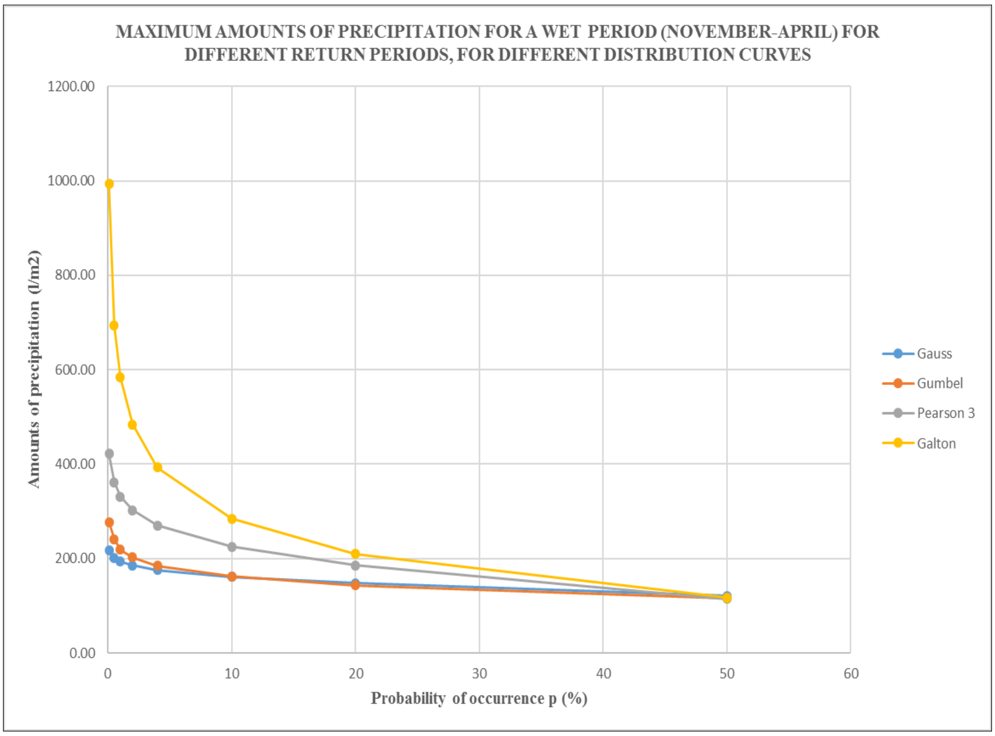

Figure 4. Maximum amounts of precipitation for a wet period (November-April) for different return periods, for different curves of distribution

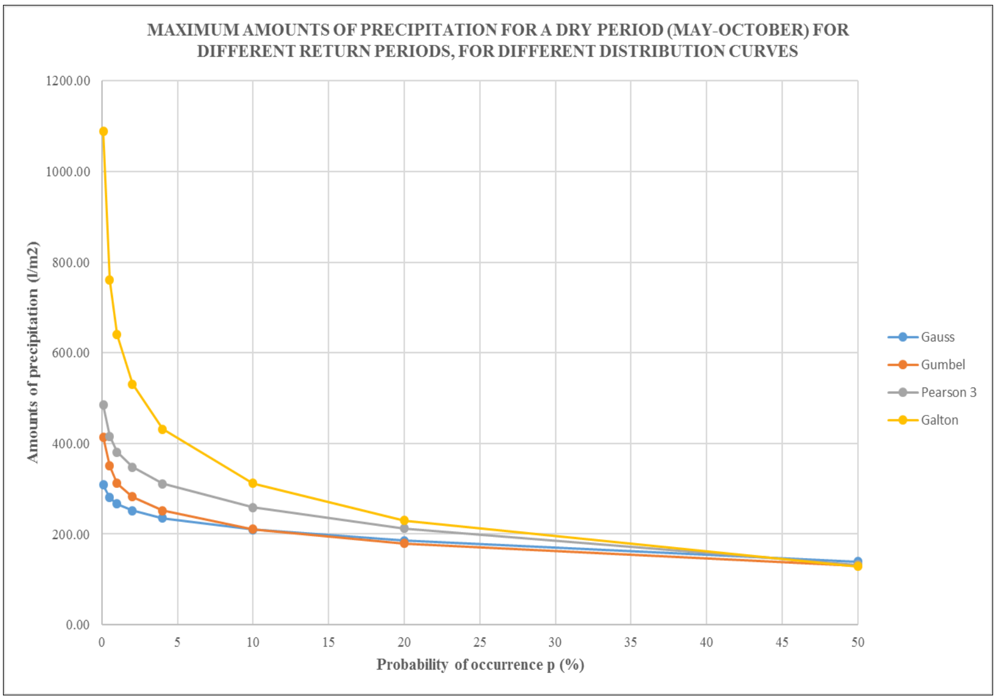

Figure 5. Maximum amounts of precipitation for a dry period (May-October) for different return periods, for different curves of distribution

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