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THE MODELING OF RAINFALL-RUNOFF OF DAS TOJO CENTRAL SULAWESI USING HEC-HMS SOFTWARE

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ABSTRACT
In the hydrological cycle, the rain falling on the ground surface in a watershed (DAS) then undergoes a process of evaporation, infiltration, and surface runoff. This conversion of rain into runoff surface can be used as a basis for calculating the discharge of the design flood. Analyzing flood design is one of the calculations in water resource planning. River flow discharge is an indicator of the output of a watershed system, especially in the process of converting rainfall into a surface flow. Flood discharge in a watershed is generally expressed as a hydrograph. One method that can be used to analyze the conversion of rain into flow is the HEC-HMS software. The purpose of this research is to determine the design of flood discharge and flow hydrograph of Tojo River using HEC-HMS software. In this article, the HEC-HMS model components used to analyze hydrographs are SCS CN for the runoff volume model and SCS UH for the direct runoff model. From the results of modeling using HEC-HMS, the peak flow discharge of the Tojo watershed in Central Sulawesi are 133.8 m3/s for a 2-year design flood, 239.8 m3/s for a 5-year design flood, 329.5 m3/s for 10-year design flood, 442.5 m3/s for 20-year design flood, 589.8 m3/s for 50-year design flood and 727.1 m3/s for 100-year design flood. Furthermore, the results of this study can be used for flood control planning and other water resource planning.

Keywords: Flood Design, Das Tojo, HEC-HMS

INTRODUCTION

One important aspect in understanding hydrology is an understanding of the drainage system in the Watershed or abbreviated as watershed (DAS) can be interpreted as a land area with ridges as a natural boundary and can stream the rainwater that falls in the system and then flows to a review point through the main river (1). DAS is the widening of an area that has contributed to the flow surface in the region (2). (3) the book of Applied Hydrology defines watershed (DAS) as an area that is limited by a series of hills or mountains, when rain falls on the area the water flows to a point of review or outlet.

In studying hydrology, we are first introduced to the hydrological cycle, where rain in the hydrological cycle is explained that when rain falls or falls on the surface of a watershed, it will undergo several processes such as evaporation, infiltration, and runoff (surface runoff) (4). This surface runoff is one indicator of the function of a watershed (DAS), where river flow discharge becomes a measurable parameter of the process of converting rain into the flow. The process of converting rainfall into flow is very complicated in a river drainage system (watershed) because many factors play a role in determining the characteristics of flow in a watershed, such as rainfall factors and watershed characteristics as a medium for transformation (5).

Watershed (DAS) characteristics that greatly affect the flow discharge, especially its morphometric characteristics include the size of the watershed (DAS) in this case the area of the watershed (A), the extent to which the main river flows (L), the gradient of the river slope (S) and

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others (6). The shape and size of the watershed (DAS), topographic conditions, soil type, and vegetation covering a catchment area are the characteristics that most affect the flow conditions in a watershed (DAS) (7). The number of factors that play a role in the process of converting rain into flow makes the calculation of flow discharge analytically difficult, so a hydrological model approach is an option for determining river flow discharge in a watershed (DAS) system. The analysis results of rain-flow modeling can be a basis for a consideration to evaluate the flow conditions in the river of the watershed (DAS) system (8).

Hydrological modeling has been developed by many software developers. One of them is HEC-HMS which provides quite good results when analyzing rainfall (9). Hydrologic Engineering Center - Hydrological Modeling System or better known as HEC-HMS is software with an open license (open source). HEC-HMS is software produced at the U.S. Army Corps of Engineers (USACE) engineering center. HEC-HMS can model complex hydrological systems in a watershed (DAS) through a simplification mechanism of the drainage area system. Researchers are interested in conducting a study to obtain peak flow discharge values as a result of rainfall-flow modeling analysis using HEC-HMS software in the Tojo watershed of Central Sulawesi.

MATERIALS AND METHODS

The Location of the Research

The object studied in this article is the Tojo watershed, which is located in two administrative areas. The Tojo watershed (DAS) is located in the administrative area of Tojo Una-una Regency and the administrative area of North Morowali Regency in Central Sulawesi Province as shown in Figure 1. The characteristics of the Tojo watershed (DAS) which are the main input data in this study are the watershed area and the length of the main river, with a value of 212.58 km2 Tojo watershed area and 28 km main river length (10). Furthermore, these watershed characteristics are used to determine the amount of flow that occurs in the Tojo River using HEC-HMS software.

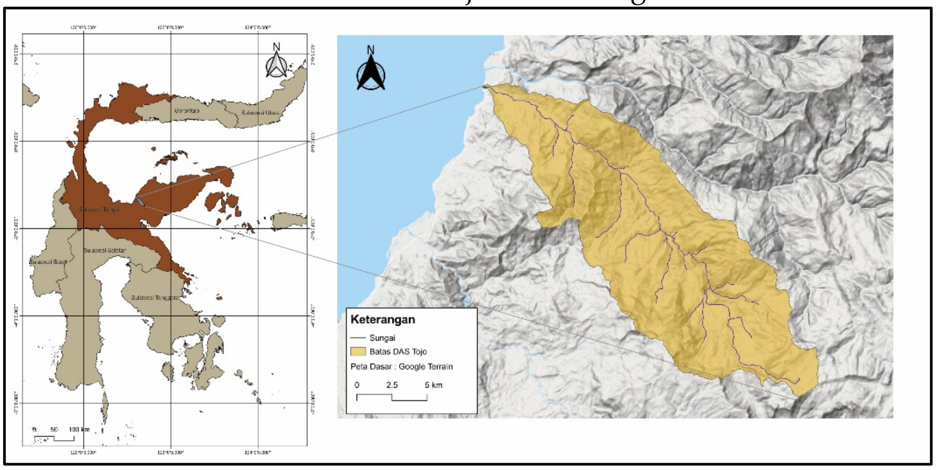

Figure 1. Tojo Watershed in Central Sulawesi Province

Data Collecting

The initial stages of the research began by collecting data that would be used for rainfall-flow analysis using HEC-HMS software. The data collected and used in the research include:

1. Daily rainfall data from 2011 to 2020 as the main input data for rainfall flow analysis. The data of rainfall used is spatial rainfall data obtained through the website: https://app.climateengine.com/climateEngine
2. The data of Land cover is used to know the land use in a watershed (DAS) that serves to calculate the value of Curve Number (CN). Land cover data used in this research is the land cover data acquired through the website of the Ministry of Environment. https://sigap.menlhk.go.id/sigap

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3. In addition to using land cover data, to obtain the value of the curve number (CN), soil hydrology group (HSG) data is required. Soil hydrology group (HSG) is a fundamental component to estimate the conversion of rainfall into flow in a watershed. The global HSG dataset used in this study has a spatial resolution of 250 m (11).

Data Analysis

The data that has been collected is then grouped based on the data type and analyzed using methods based on the type of each data. The methods used to analyze the data in this study include: 1. Frequency analysis, is a method used to analyze rainfall design, namely estimating the depth of rain for a certain rain period (12). The frequency analysis stage is also carried out to determine whether a series of data fits a certain data distribution or not (13). The initial stage of frequency analysis calculation is to calculate basic statistical parameters such as mean score (x ̅), standard deviation (Sd), coefficient of variance (Cv), coefficient of skewness (Cs), and kurtosis coefficient (Ck). The results of this basic statistical analysis are used to determine the frequency analysis method to be used based on the frequency analysis method on the determination table as shown in table 1. (3).

Table 1. Parameters for determining the type of rainfall distribution

No.	Type of Distribution	Term of Condition
1	Normal	$(\bar{x} \pm s)$ = 68,72% $(\bar{x} \pm s)$ = 68,72% $C_s \approx 0$ $C_k \approx 3$
2	Log Normal	$C_s = C_v{}^3 + 3C_v$ $C_k = C_v{}^8 + 6C_v{}^6 + 15C_v{}^4 + 16C_v{}^2 + 3$
3	Gumbel	C_s = 1,14 C_k = 5,4
4	Pearson III Log	Other than the values mentioned above

The equation for each type of distribution follows equation (1) through equation (4)

a. Normal

$$X_T = \bar{X} + K_T S \quad (1)$$

b. Log Normal, this method is calculated by changing the X score of the data with the logarithmic score of X (14), so that equation (1) becomes equation (2).

$$LogX_T = Log\bar{X} + K_T S_{logX} \quad (2)$$

c. Gumbel, the equation used in this method follows equation (1), but the KT frequency factor score is calculated using equation (3).

$$K_T = \frac{y_T - y_n}{s_n} \quad (3)$$

d. Log Pearson III, the equation for this method follows the log normal distribution equation as shown in equation (2). Meanwhile, the KT frequency factor value follows the pearson type III distribution frequency factor whose value varies depending on the coefficient of skewness (Cs) and the rainfall recurrence period or probability of occurrence.

The description of each parameter of the above equation as follows:

X_T = Estimated score expected to occur at return period T years
$\bar{X}$ = average score (in practice the average score of n sample data is used)
K_T = frequency factor of the normal distribution
S = standard deviation
y_T = *reduce variate* for return period T years
y_n = *reduce mean* for n data sample
s_n = *reduce standard deviation* for n data sample

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2. After obtaining the data of rainfall design using one of the selected methods, the frequency distribution scores of the data samples are then tested against the chance distribution function using the chi-square or Smirnov Kolmogorov method to determine whether the design rainfall is representative of the frequency distribution or not. Furthermore, certain return period rainfall is analyzed into hourly distributed rainfall using the mononobe method (15). The results of the mononobe rain intensity analysis are then used as input data in the HEC-HMS time series as the hyetograph value of the precipitation gauge.
3. Next, prepare the data representing subbasin (watershed) parameters such as watershed size, main river length and slope, curve number (CN), *initial abstraction* (Ia), concentration time (t_c), dan lag time (t_{lag}).

HEC-HMS

The HEC-HMS tool accommodates almost all of the physical parameters of the watershed in sub-sub models. The rain-flow simulation process carried out by HEC-HMS is based on the principle of the hydrological cycle, in which rain falling in a catchment water area will experience evaporation, and infiltration and end up at one review point as a discharge.

The accuracy of the rainfall stream analysis results using HEC-HMS software is determined by the available data and the method of analysis determined by the user. In HEC-HMS software, the amount of flow in a watershed is analyzed using the hydrograph principle. One of the methods used to calculate hydrographs is the Soil Conservation Services - Curve Number or known as the SCS-CN method. The SCS-CN method will analyze excess rainfall as a function of rain depth (P), soil surface type, and land use using equation (4).

$$P_e = \frac{(P-I_a)^2}{P-I_a+S} \quad (4)$$

Where:

P_e = *Precipitation excess* at time t
P = rain depth at time t
I_a = *Initial Abstraction*
S = *maximum potential retention*

The score of *maximum potential retention* (S) and watershed characteristics are associated with curve number (CN) parameter based on equation (5) (16)

$$S = \frac{25400}{CN} - 254 \quad (5)$$

Where:

S = *maximum potential retention* (mm)
CN = *curve number*

Based on some experimental analysis results on small watersheds, the Soil Conservation Service (SCS) developed an empirical relationship between Ia and S as equation (6).

$$I_a = 0{,}2\,S \quad (6)$$

The range of CN scores is between 100 and 30, where the CN value is 100 for waterlogged areas and the CN value is 30 for permeable soils with high infiltration rates (17). The CN value of a watershed is calculated based on several parameters such as land use, soil type, vegetation and soil moisture in the land cover. The CN value of each land use and soil hydrology group can be estimated based on tables published by SCS, and can be seen in the book Applied Hydrology (3). CN values for land use types and HSG types can be seen in Table 2.

Table 2. CN Value For Land Use Or Soil Type

Land cover type	Soil Hydrology Group			
	A	B	C	D
Land that has been planted				
conservation	72	81	88	91
No conservation	62	71	78	81
Grassland				

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Land cover type	Soil Hydrology Group			
	A	B	C	D
Poor cover condition	68	79	86	89
Good cover condition	39	61	74	80
Grassland: good condition	30	58	71	78
Forest: - Sparse plants poor cover	45	66	77	83
- good cover	25	55	70	77
Open fields, lawns, gold courses, cemeteries, etc.				
Good condition: grass covers 75% or more of the area	39	61	74	80
Medium condition: grass covers 50% - 75% of the area	49	69	79	84
Commercial and business areas (85% impermeable)	89	92	94	95
Industrial areas (72% Impermeable)	81	88	91	95
Residential				
Extensive % Impermeable				
1/8 acre or less 65	77	85	90	92
1/4 acre 38	61	75	83	87
1/3 acre 30	57	72	81	86
1/2 acre 25	54	70	80	85
1 acre 20	51	68	79	84
Parking lot, roof of house/ office/ building, car road (in the yard)	98	98	98	98
Pavement road with drainage	98	98	98	98
Gravel road	76	85	89	91
Dirt road	72	82	87	89

Each watershed is certainly not dominated by one land use and soil type but consists of several land uses or soil types, so the determination of CN values using composite CN can be calculated by equation (7).

$$CN_{composite} = \frac{\sum A_i CN_i}{\sum A_i} \quad (7)$$

In this study, the SCS UH model was also used to calculate direct runoff. The SCS direct runoff model used in HEC-HMS modeling is based on the principle of unit hydrograph calculation. The SCS direct runoff model also assumed that rainfall occurred evenly throughout the watershed. To obtain an overview of the hydrograph, the peak time is required, for which the SCS method uses equations (8) and (9) to calculate the peak time (17).

$$t_c = \frac{L^{0,8} \times \left(\left(\frac{1000}{CN} - 10\right) + 10\right)^{0,7}}{1900 \times Y^{0,5}} \quad (8)$$

$$t_{lag} = 0,6 \times t_c \quad (9)$$

Where: t_{lag} = lag time (hour); tc = concentration time (hour); L = river length (m) ; Y= average slope of DAS (%); CN = *curve number*

RESULTS AND DISCUSSIONS

The rain data used in this study is Climate Hazards Group InfraRed Precipitation with Station (CHIRPS) data. The use of this data has gone through considerations related to the availability of available data including the length of rain data. The difference in the amount of data analyzed has a significant effect on rainfall estimates at certain rain return periods, this causes significant deviations. The deviation of the results of the design rain analysis is getting smaller with the increasing length of rain data used in the analysis (18).

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CHIRPS rain data has a longer recording duration so it can be utilized in various calculations such as flood analysis (19). CHIRPS monthly rain data showed good linearity against Automatic Weather Station (AWS) observation data but produces an overestimated value with a bias of 6% (20). To analyze the design flood, the rainfall data used is the maximum rainfall data. The maximum rainfall data in the Tojo watershed can be seen in Table 3.

Table 3. Monthly maximum rainfall data for 2011-2020

Year	Monthly Maximum Rainfall (mm)											
	JAN	FEB	MAR	APR	MEI	JUN	JUL	AUG	SEP	OKT	NOV	DES
2011	14,94	8,24	18,17	32,14	31,80	94,97	37,51	15,69	56,90	15,22	10,56	15,99
2012	20,64	5,80	11,55	37,48	42,19	44,36	78,35	43,84	38,34	15,89	9,31	9,01
2013	2,09	11,38	39,04	22,49	35,48	46,62	41,90	30,36	35,48	22,36	21,67	8,29
2014	22,01	5,03	14,40	24,06	26,30	42,97	36,41	32,19	13,11	18,72	12,91	13,98
2015	12,97	7,09	10,04	31,19	22,78	40,05	36,10	9,95	10,63	32,69	11,49	13,00
2016	16,18	8,24	18,15	37,37	21,09	45,24	36,30	26,98	32,83	25,19	29,28	8,10
2017	14,83	5,44	15,97	46,94	34,50	65,85	62,63	26,83	72,26	33,59	13,65	8,38
2018	20,47	6,12	14,30	28,75	30,81	36,74	44,35	23,52	16,80	15,59	10,67	9,22
2019	14,71	4,40	18,14	38,70	21,64	52,48	42,50	11,32	52,56	21,65	10,08	9,39
2020	11,15	5,70	13,59	28,90	27,38	76,80	42,83	110,69	84,52	33,15	12,83	9,82

Source: Analysist Result, 2022

Furthermore, the data were analyzed using basic statistical methods to obtain the mean score (X_T=X ̅+K_T S), standard deviation (Sd), and coefficient of skewness (Cs). The calculation results obtained the mean score (X_T=X ̅+K_T S) = 1.7702, standard deviation (Sd) = 0.1596, and coefficient of skewness (Cs) = 0.6913. Furthermore, from this value, the KT value is determined based on the Log Pearson III distribution table for each return period and the coefficient of skewness (Cs). The results of the rainfall distribution analysis for periods of 2, 5, 10, 20, 50, and 100 years using the Log Pearson type III method can be seen in Table 4.

Table 4. Designated Rain for the method of Log Pearson Type III

Return Periode	P (%)	Cs	G	Log X	X (mm)
2	50	0,6913	-0,1145	1,7519	56,4835
5	20	0,6913	0,7909	1,8964	78,7802
10	10	0,6913	1,3326	1,9829	96,1319
20	5	0,6913	1,8592	2,0669	116,6593
50	2	0,6913	2,4028	2,1537	142,4533
100	1	0,6913	2,8180	2,2199	165,9322

Sumber: Analysist Result, 2022

The analysis is continued by testing the type of distribution chosen using the chi-square method to determine whether the distribution equation that has been chosen can represent a statistical distribution of the sample being analyzed. From the results of the chi-square analysis, the calculated chi-square result (x2count) = 1 and the critical chi-square score (x2critical) = 5.991, so that the distribution equation used can represent each sample analyzed. Furthermore, the results of the rainfall analysis plan are used to calculate the hourly rainfall intensity method using the Mononobe method. The results of the Mononobe method rain intensity analysis can be seen in table 5 and figure 2.

Table 5. Hourly Rain Intensity

Duration (Hour)	Return Period					
	2	**5**	**10**	**20**	**50**	**100**
	56,483	**78,780**	**96,132**	**116,659**	**142,453**	**165,932**
1	19,582	27,312	33,327	40,444	49,386	57,525
2	12,336	17,205	20,995	25,478	31,111	36,239
3	9,414	13,130	16,022	19,443	23,742	27,655
4	7,771	10,839	13,226	16,050	19,599	22,829
5	6,697	9,340	11,398	13,831	16,890	19,673

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Duration (Hour)	Return Period					
	2	**5**	**10**	**20**	**50**	**100**
	56,483	**78,780**	**96,132**	**116,659**	**142,453**	**165,932**
6	5,930	8,271	10,093	12,248	14,957	17,422
7	5,351	7,464	9,107	11,052	13,496	15,720
8	4,895	6,828	8,332	10,111	12,346	14,381

Sumber: Analysist Result, 2022

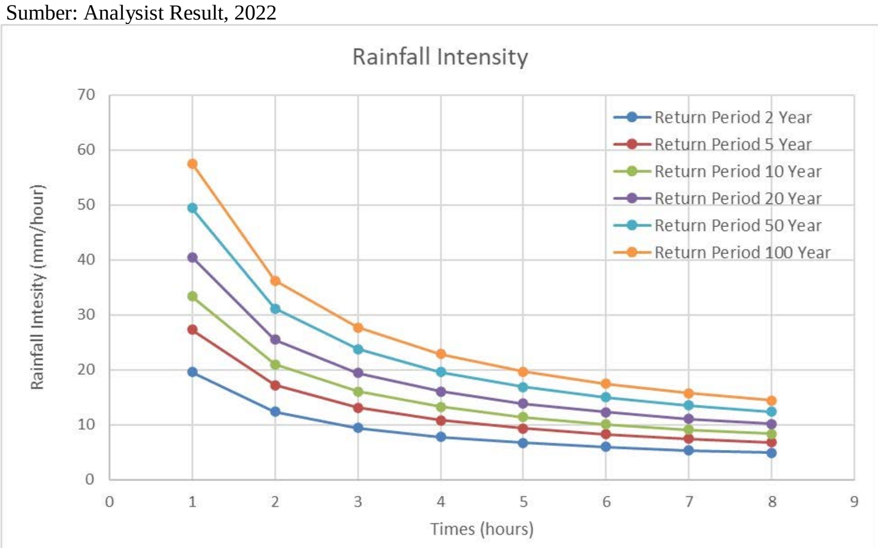

Figure 2. Graph of rainfall intensity based on rain return period (Analysis result, 2022)

The rain intensity values in Table 4 are then compiled in the form of a hyetogpraph using the alternating block method (ABM). Before analyzing the hydrograph using HEC-HMS, first the analysis of other watershed parameters such as curve number (CN), initial abstraction (Ia) and time lag. The watershed parameters used in this study can be seen in Table 6. The units used in each parameter adjust to the HEC-HMS units.

Table 6. Values of each input parameter of HEC-HMS in Tojo Watershed

Watershed Area (km^2)	L (ft)	Y (%)	CN	S (inch)	Ia (mm)	Imper vious (%)	Tlag (menit)
212,58	91,840	3,3	77,63	2,882	14,638	0,023	419,639

Source : Analysis Result, 2022

After obtaining the value of each HEC-HMS input parameter, modeling was then conducted. Modeling starts by inputting the value of each watershed parameter according to Table 5, rainfall time series data (precipitation gauge), meteorological model, and control. Furthermore, adding simulations for each return period of the design rainfall. The modeling results show that the design flood discharge for each return period of 2, 5, 10, 20, 50, and 100 years is 133.8 m3/s, 239.8 m3/s, 329.5 m3/s, 442.5 m3/s, 589.8 m3/s, 727.1 m3/s. The peak of the 2 and 5-year return period flood event occurs at hour 12, while the peak of the 10 to 100-year return period flood event occurs at hour 11 as shown in Figure 3.

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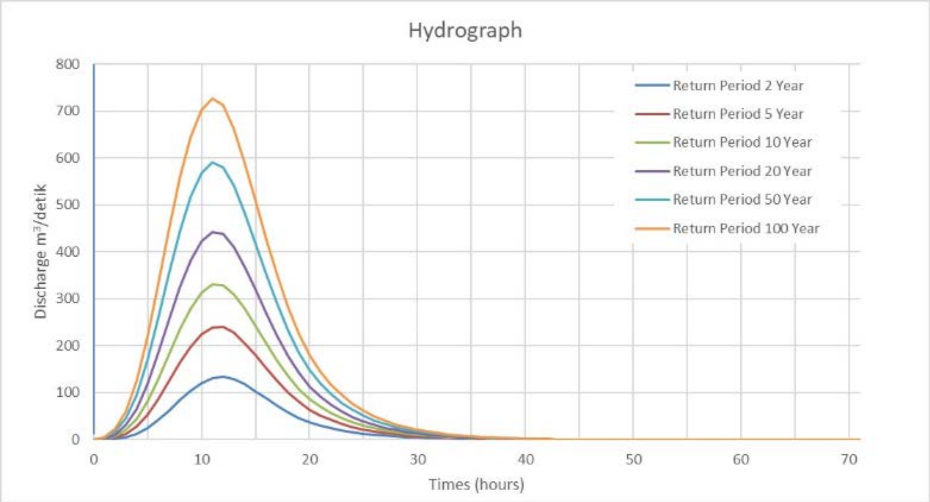

Figure 3. Hydrograph Flood Design of Tojo watershed using HEC-HMS (Analysis result, 2022)

The results of the design flood simulation using HEC-HMS are different from the results of previous research design flood analysis in the same watershed using the HSS ITB-1 method. The parameters that are assessed in HSS ITB-1 are watershed area (ADAS), main river length (L), and waiting time (Tp) analyzed using the Kirpich equation, HSS area is not dimensionless AHSS (21). The vastly different results are due to the parameters analyzed from these two methods being very different. The most sensitive parameter in the SCS CN method is the waiting time (Tp). The waiting time for the SCS CN method is calculated using the equation specified in the HEC-HMS Technical Reference Manual document. Meanwhile, for the ITB-1 method, the waiting time is analyzed using the Kirpich equation.

CONCLUSION

Based on the modeling results using HEC-HMS, the peak flow discharge of the Tojo watershed in Central Sulawesi Province is 133.8 m3/s for the 2-year design flood, 239.8 m3/s for the 5-year design flood, 329.5 m3/s for the 10-year design flood, 442.5 m3/s for the 20-year design flood, 589.8 m3/s for the 50-year design flood and 727.1 m3/s for the 100-year design flood. The peak of the 2- and 5-year return period flood occurs at hour 12, while the peak of the 10- to 100-year return period flood occurs at hour 11.

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