HYDROLOGICAL ANALYSIS OF THE MAKASSAR-PARE CORRIDOR RAIL ELEVATED BRIDGE IN PANGKEP REGENCY SOUTH SULAWESI PROVINCE

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Abstract. Hydrological analysis is an important stage in the development of water resources. Determining hydrological quantities is actually not too difficult if the data for analysis purposes is available in sufficient quantity and quality. The method used for the analysis of the planned flood discharge depends on the amount of discharge data and rainfall data. Based on the analysis of discharge data and rain data. For planning the storage capacity of the river crossing the railway bridge, using the Nakayasu Synthetic Unit Hydrograph (HSS) Method, the river water level to the JEKA 2 structure is 13.38 m and the river water level to the tracks is 16.38 m so that the railroad tracks at Bridge 2 can be said to be safe against the river water level. Hydrological analysis is one part of a whole series in the planning of transportation structures such as roads, bridges and railway bridges including flood barrier embankments and so on.

1 Introduction

Hydrological analysis is an important stage in the development of water resources. Therefore the output of the hydrological analysis in general will determine the direction of the water resources strategy in a comprehensive and narrower manner. The amount will determine the dimensions and characteristics of the required infrastructure. Determining hydrological quantities is actually not too difficult if the data for analysis purposes is available in sufficient quantity and quality [1].

The classic problem in developing countries, including Indonesia, is that the availability of sufficient river flow data series is a separate problem, so the solution must be done by converting climate variables into flow variables [2].

The process of river flow originating from input variables in the form of climate data and physical characteristics of a watershed (DAS) is a very complex system that is often considered a "black box". There are 2 types of modeling that are commonly used to carry out this approach, namely the Data Driven Model and the Conceptual Model. The data driven model was formed without involving physical laws in the process of the occurrence of rain

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into a stream, but only based on the relationship between the outputs (river flow). The basic weakness of the data driven model is that it requires a long data series and the learning process, and it is very limited in its implementation both in terms of space and time dimensions [3]. The conceptual model reviews the physical process by which flow occurs according to the concept of the hydrological cycle, so that the resulting system of equations can be implemented more broadly. The need for climate and flow data series in the application of this model is only used to determine the value of the parameters so that it does not require a long series. On the basis of these reasons the conceptual model is relevant for application to watersheds in Indonesia [1].

So far many conceptual models have been developed, of course each has advantages and disadvantages because basically these models are developed according to the hydrological conditions of the local area. All models are basically developed from the same basic concept, namely the hydrological cycle. The basic thing that makes it happen is the way of interpreting the process starting from the occurrence of rain until it becomes a stream [2].

In planning the elevated bridge for the Makassar-Pare Corridor railway in Pangkep, data collection was carried out as a first step. The data is used as the basis for calculating stability and technical planning. From the rainfall data obtained, a hidological analysis was carried out which resulted in a planned flood discharge, which was then processed again to find the magnitude of the resulting flood routing used to determine the elevation of the spillway crest [4].

2 Method

2.1 General

The data needed to perform the calculations are secondary data, including: topographical maps, rain station location maps, and regional rainfall data.

Rainfall data is used to plan the amount of design rainfall and flood discharge for a certain return period to determine the right hydraulic design of a railway bridge building so that ideal structural handling is obtained. With the limitations mentioned above, hydrological analysis is a method for water balance/water balance in such a way that the planning and handling of problems on the railway body caused by the drainage system can be overcome. This calculation is in accordance with SNI 2415-2016 regarding the planned flood discharge. The stages of hydrological analysis are described as follows: 1) determining the length and area of the watershed; 2) determining the area around the stream; 3) distribution fit test; 4) determine the appropriate distribution; 5) determination of design rainfall; and 6) determination of design flood discharge.

2.2 Maximum Rainfall

The maximum rainfall is the rainfall that will be used to determine the design rainfall and bed flood discharge. When the return of the maximum discharge rainfall is > 20 years, the analysis can use distribution functions such as Normal distribution, Normal Log, Pearson Log and Gumbel.

Rainfall data were obtained from the Meteorology and Geophysics Station of Maros Regency, South Sulawesi Province as follows.

Table 1. Rainfall Data from the Maros Meteorological Agency Station

Tahun	Max (X_i)
2009	409
2010	351
2011	562
2012	326
2013	432
2014	435
2015	421
2016	461
2017	664
2018	596

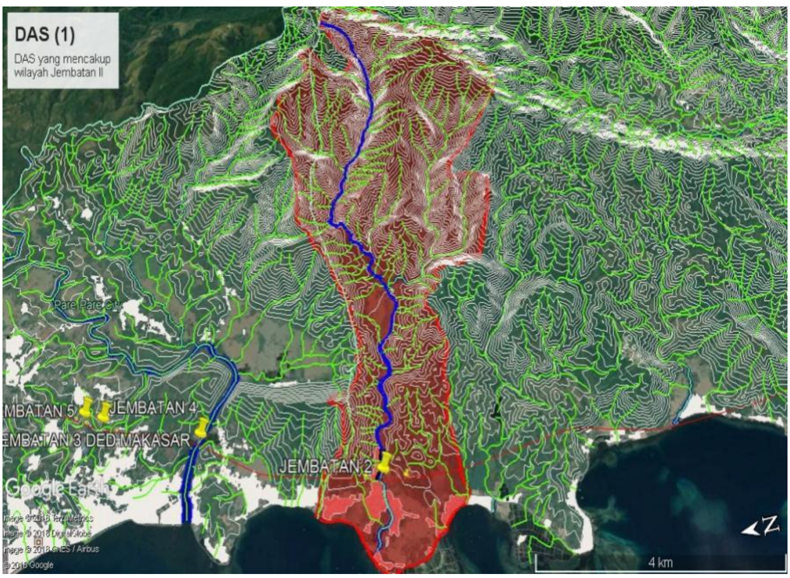

Fig. 1. Watershed 1

The watershed area (DAS) for the Makassar-Pare Corridor Railway Elevated Bridge in Pangkep II is described as follows:

Table 2. Area of the Bridge II River Basin

No.	Bridge Number	DAS	Luas DAS
1.	Bridge II	DAS (1)	32,4 Km^2

3 Results and Discussion

3.1 Hydrological Analysis for Planning Elevated Bridges

Hydrological analysis for planning elevated bridge areas includes two things, namely.
1. Inflow that fills the elevated bridge area.
2. Flood plan to determine capacity and spillway dimensions

The steps in hydrological analysis are:

1. Determine the watershed area (DAS) and its area
2. Determine the area of influence of rain gauge stations using the Thiessen Polygon Method
3. Determine the maximum rainfall each year from existing rainfall data.
4. Analyzing planned rainfall with a return period of T years
5. Calculate the design flood discharge based on the amount of planned rainfall
6. Calculating the main discharge for irrigation purposes and raw water
7. Calculate the need for water in the fields needed for the garden.

The main objective of hydrological analysis is to obtain a reliable discharge. several stages to obtain the mainstay discharge, namely by determining the average rainfall of the Watershed (DAS) and conducting a reliable discharge analysis.

In this study, the Thiessen Method is the method to be used in determining the average rainfall of the watershed. This method takes into account the weight of each station which represents the area around it. In an area within the watershed it is assumed that the rain is the same as that which occurs at the nearest station, so that the rain recorded at a station represents that area.

3.2 Hydrological Survey and Survey Planning

Hydrological survey work is needed to analyze the safety of the bridge design against the flood water level of the river below. In this study there are 6 bridges that cross the river, namely bridges 2, 3, 4, 5 and bridge 8. Therefore, it is necessary to carry out a hydrological analysis at the location of the bridge so that the design work carried out is appropriate for the surrounding hydrological conditions.

In this work, the calculation of the planned flood discharge is carried out using an empirical formula by relying on rainfall data obtained from the relevant agencies. The calculation method and analysis results will be presented in this chapter.

3.3 Analysis of Periodic Rainfall

3.3.1 Normal Distribution

To find out the amount of rainfall that is expected to repeat every t year is to use the following formula:

$$S_x = \sqrt{\frac{\sum (x_i - x_a)^2}{n-1}}$$

$$X_T = X_a + K_T \text{ x } S$$

where:
XT = Design rainfall with Normal Distribution (mm)
Xa = average rainfall (mm)
KT = Gauss Reduction Variable Value
S = Standard Deviation
Xi = Rainfall max
n = amount of data

3.3.2 The Normal Log Distribution Method

The amount of rainfall that s expected to repeat t years can be known through the following calculations :

$$S\,\text{Log}\ X = \sqrt{\frac{\sum\left(\text{Log}\ X - \text{Log}\ \overline{X}\right)^2}{n-1}} \quad \text{Log}\ X_T = \text{Log}\ Xa + \left(K_T \cdot S\,\text{Log}\ X\right)$$

where:
Log XT = Design rainfall with Log Normal Distribution (mm)
Log Xa = Average rainfall (mm)
KT = Gaussian Reducing Variable Value for log normal distribution
S Log X = Standard Deviation

3.3.3 The Normal Log Distribution Method

The amount of rainfall that is expected to repeat t years can be known thorough the following calculations :

$$K_T = \frac{Yt - Yn}{Sn}$$

$$S\,\text{Log}\ X = \sqrt{\frac{\sum\left(\text{Log}\ X - \text{Log}\ \overline{X}\right)^2}{n-1}}$$

$$X_T = Xa + \left(K_T \cdot S\right)$$

where:
XT = Design rainfall with Gumbel Distribution (mm)
Xa = average rainfall (mm)
KT = Variable value for the Gumbel Distribution
S = Standard deviation

3.4 Analysis of Periodic Rainfall

3.4.1 Recapitulation of Rainfall Distribution

Recapitulation of rainfall distribution is described as follows :

Table 3. Recapitulation of Rainfall Distribution Calculations

No	Periode Ulang (Tahun)	Jenis Distribusi			
		Normal (mm)	Log Normal (mm)	Log Person III (mm)	Gumbel (mm)
1	2	465,70	454,920	450,777	451,058
2	5	465,70	550,188	528,238	580,329
3	10	465,70	607,806	576,861	665,925
4	25	465,70	669,687	762,847	774,065
5	50	465,70	723,534	679,546	854,289

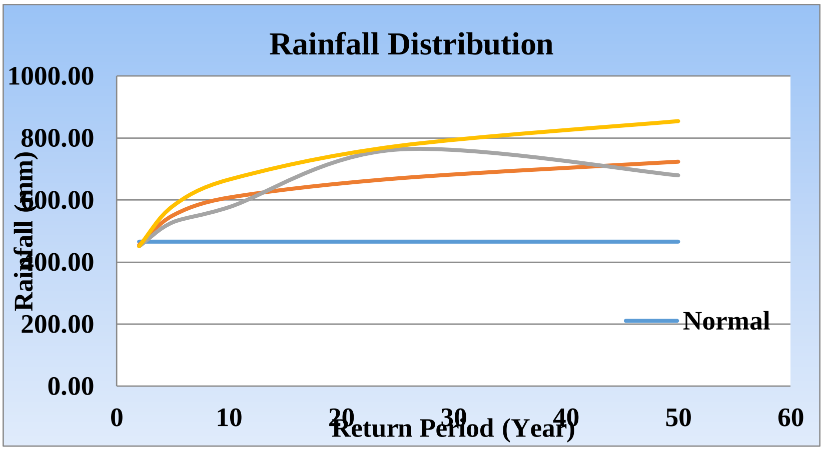

Fig. 2. Distribution of Rainfall

The recapitulation of the calculation of the distribution of rainfall up to 50 years for the Makassar-Pare Corridor Railway Elevated Bridge in Pangkep II is described as follows:

Table 4 Recapitulation of Rainfall Distribution Calculations Up to 50 Years

t	450,777	528,23848	576,8613031	762,8467236	679,54627
menit	It 2 Tahun	It 5 Tahun	It 10 Tahun	It 25 Tahun	It 50 Tahun
10	516,011	604,682	660,341	873,242	777,886
20	325,067	380,926	415,989	550,108	490,038
30	248,072	290,701	317,459	419,811	373,969
40	204,779	239,968	262,057	346,546	308,704
50	176,473	206,798	225,834	298,644	266,033
60	156,276	183,130	199,987	264,464	235,586
70	141,013	165,245	180,455	238,636	212,578
80	129,003	151,171	165,085	218,310	194,472
90	119,261	139,754	152,618	201,824	179,785
100	111,171	130,275	142,266	188,134	167,591
120	98,448	115,365	125,984	166,602	148,410
150	84,840	99,418	108,569	143,573	127,896
180	75,130	88,040	96,144	127,141	113,258
210	67,792	79,442	86,754	114,724	102,197
270	57,335	67,187	73,371	97,027	86,432
330	50,155	58,774	64,184	84,877	75,609
390	44,869	52,580	57,419	75,932	67,640
450	40,787	47,795	52,195	69,023	61,486
570	34,840	40,827	44,585	58,959	52,521
690	30,673	35,944	39,253	51,908	46,240
810	27,564	32,300	35,273	46,646	41,552
990	24,112	28,256	30,856	40,805	36,349
1170	21,571	25,278	27,604	36,504	32,518
1470	18,526	21,709	23,708	31,351	27,928
1770	16,369	19,181	20,947	27,700	24,676
2100	14,605	17,115	18,691	24,717	22,018
2460	13,143	15,402	16,819	22,242	19,813
2820	11,999	14,061	15,356	20,306	18,089
3000	11,514	13,493	14,735	19,486	17,358

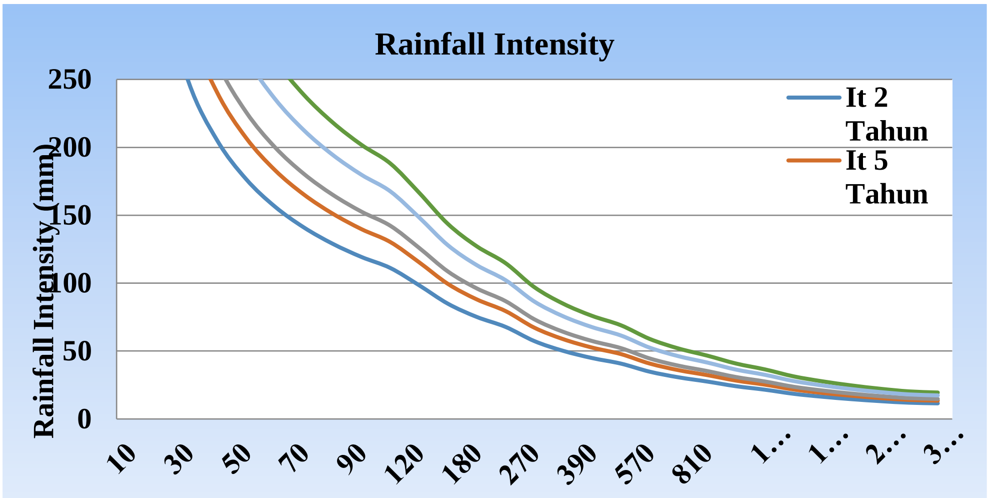

Fig. 3. Calculation of Rainfall Intensity for Up to 50 Years

3.4.2 Test of Probability Distribution

The compatibility test in the selection of the distribution function is tested by a suitability test using the test method and with certain confidence intervals using the following tests:

Testing the distribution function fit (goodness of fit) is the Chi-Square Method and the Kolmogorov-Smirnov Method. But these two methods are also tested whether these two methods are suitable for use in the rainfall data.

Use analytical method. The analytical method has unique properties for each probability distribution such as:

1. The Normal Distribution Has a distinctive characteristic, namely the asymmetrical value (skewness) is almost or equal to zero (Cs 0) with a kurtosis of 3
2. Log Normal Distribution It has distinctive properties, namely the asymmetric value (skewness) Cs 3 and a positive sign. Or with a Cs value approximately equal to three times the value of the coefficient of variation Cv.
3. The Gumbel distribution has a distinctive characteristic, namely its asymmetrical value (skewness) Cs 1.1396. Meanwhile, the kurtosis value of Ck is 5.4002.
4. Pearson III Log Distribution Does not have any unique properties that can be used to estimate this type of distribution.

So after passing these 3 tests, the most suitable uses the Log Pearson III distribution.

3.5 Calculation of Planned Flood Discharge

3.5.1 Nakayasu Synthetic Unit Hydrograph (HSS) Method

The method used for the analysis of the planned flood discharge depends on the amount of discharge data and rainfall data. For planning the storage capacity of rivers crossing the railway bridge, the method we propose to use is the Nakayasu Synthetic Unit Hydrograph Method (HSS), originating from Japan requiring several parameters in the analysis, including:

1. Time to Peak Magnitude, Tp.
2. The time lag from the point of gravity of the rain to the point of gravity of the hydrograph (Time Lag), tg.

3. Time Base of Hydrograph, TB.
4. The area of the drainage area (Cathcmen Area), A.
5. Length of the Longest Channel,
6. Run off Coefficient, C

The supporting formula used in the Nakayasu HSS analysis is as follows:

Lag time (time lag, tg):

tg = 0.4 + 0.058L for L > 15 km

tg = 0.21L0.7 for L < 15 km

Peak time and peak discharge of the synthesis unit hydrograph:

tp = tg + 0.8Tr

The time when the discharge is equal to 0.3 times the peak discharge:

t0,3 = α x tg

Peak time:

tp = tg + 0.8Tr

Synthesis unit hydrograph peak discharge:

$$Qp = \frac{1}{3,6} \times A \times R_0 \times \frac{1}{\left(0,3 \times t_p + t_{0.3}\right)} \times C$$

Information:

Tp	=	delay time (hours)
L	=	river length (m)
t0.3	=	time when discharge is equal to 0.3 times the peak discharge (hours)
1.5 t0.3	=	time when the discharge is equal to 0.32 times the peak discharge (hours)
a	=	coefficient, the value is between 1.5 - 3.0
tp	=	peak time (hours)
Qp	=	peak discharge (m3/sec)
A	=	DPS area (km2)
Tr	=	duration of rain (hours) = (0.5 x tg) to (1 x tg)
R0	=	rain depth unit (mm)
C	=	flow coefficient

Ascending curved section (0 < t < tp):

$$Q = Q_p \left(\frac{t}{t_p}\right)^{2.4}$$

Information:

Q = debit before reaching peak discharge (m3/sec)

t = time (hours

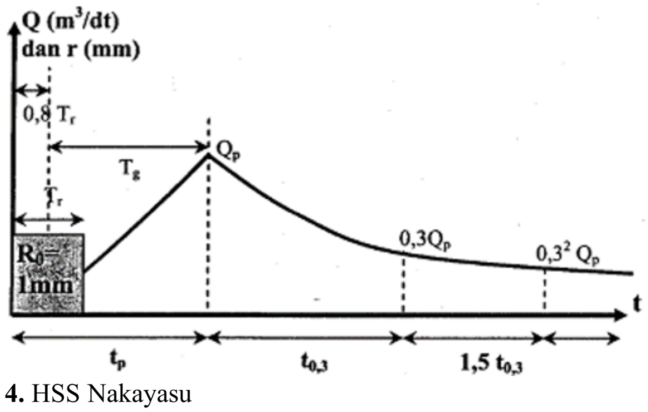

Fig. 4. HSS Nakayasu

Curved part down:

If $t_p < t < t_{0.3}$ $$Q = Q_p \times 0.3^{\frac{t-t_p}{t_{0.3}}}$$

If $t_{0.3} < t < 1.5t_{0.3}$ $$Q = Q_p \times 0.3^{\frac{t-t_p+1.5t_{0.3}}{1.5t_{0.3}}}$$

If $t > 1.5t_{0.3}$ $$Q = Q_p \times 0.3^{\frac{t-t_p+1.5t_{0.3}}{2t_{0.3}}}$$

3.5.2 Hydrology and Hydraulics Analysis on Bridge 2 (JEKA Pangkep)

Hydrological and hydraulics analysis on Bridge 2 (JEKA Pangkep) is described based on the Calculation of the Planned Discharge as follows:

Table 5. Watershed Land Use Zones in the Bridge Area 2

No	Zona Penggunaan Lahan	Koefisien Limpasan (C)	Luas Area (km²) (A)	C x A
1	Daerah Permukiman/Bangunan	0,4	2,5601	1,0240
2	Halaman, lahan tidak terpelihara dan sejenisnya	0,3	29,8399	8,9520
		Total	**32,4000**	**9,9760**
			C rata-rata	**0,3079**

The characteristics of watersheds (DAS) are as follows:
NB: data is taken from the highlands (upstream) of the river to the outlet, namely the bridge
Watershed area (A) = 32.4 km2
River length = 11.9 km
Run Off Coefficient (C) = 0.308
Slope (s) = 0.058

Table 6. Recapitulation of Hydrograph Calculation Results of Nakayasu Bridge 2 Return Period Up to 50 Years

Hour	Flood Debt				
	2 Year	5 Year	10 Year	25 Year	50 Year
0,00	0,47	0,47	0,47	0,47	0,47
0,50	17,63	20,58	22,43	5,95	26,33
1,00	91,03	106,59	116,36	29,39	136,99
1,50	240,10	281,28	307,13	77,00	361,72
1,90	424,17	496,98	542,68	135,78	639,20
...	...	...	...	...	...
26	0,85	0,92	0,96	0,59	1,05

27	0,77	0,82	0,85	0,57	0,92
28	0,70	0,74	0,77	0,54	0,82
29	0,65	0,68	0,70	0,53	0,74
30	0,61	0,63	0,65	0,51	0,68
31	0,58	0,60	0,61	0,50	0,63

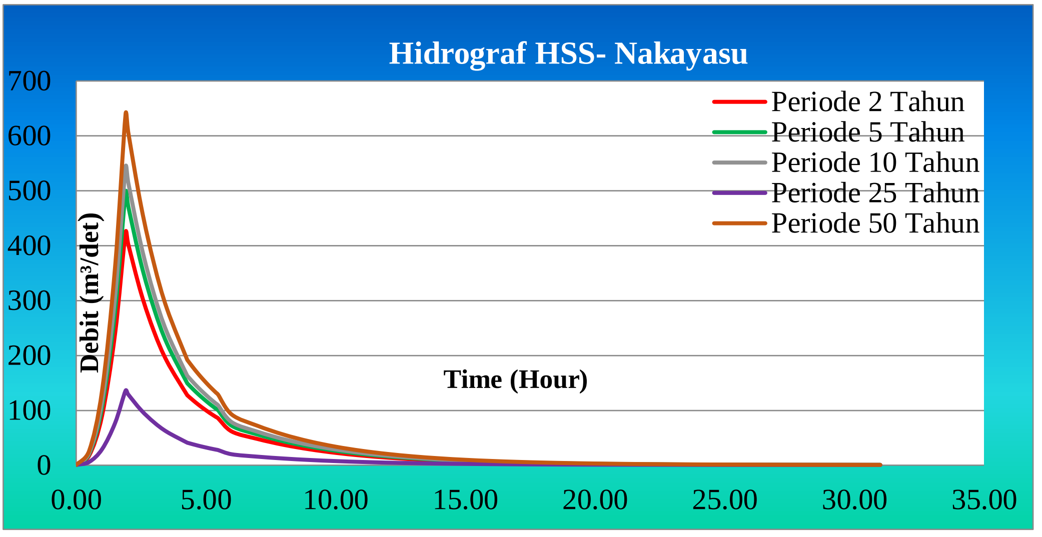

Fig. 5. Nakayasu Bridge II Hydrograph

The summary of peak discharge at various return periods of Bridge 2 (JEKA Pangkep) is illustrated based on the calculation of peak discharge at various return periods as follows

Table 7. Peak Discharge Summary at Various Return Periods

No.	Return Period (T) (Year)	Peak Debt (Qp) (m^3/Second)
1	2	424,17
2	5	496,98
3	10	542,68
4	25	135,78
5	50	639,20

3.5.3 Calculation of River Water Volume

The peak discharge for the 50-year return period = 639.2001 m^3/s, with a peak time of 1.90 hours, so:
V = 14.3 m/s
Q = A . V

3.5.4 Control of River Cross Section of Bridge Elevation 2

So, the water level of the river to the Bridge 2 KA structure is 13.38 m and the river water level to the tracks is 16.38 m so that the railroad tracks on Bridge 2 can be said to be safe against the river water level.

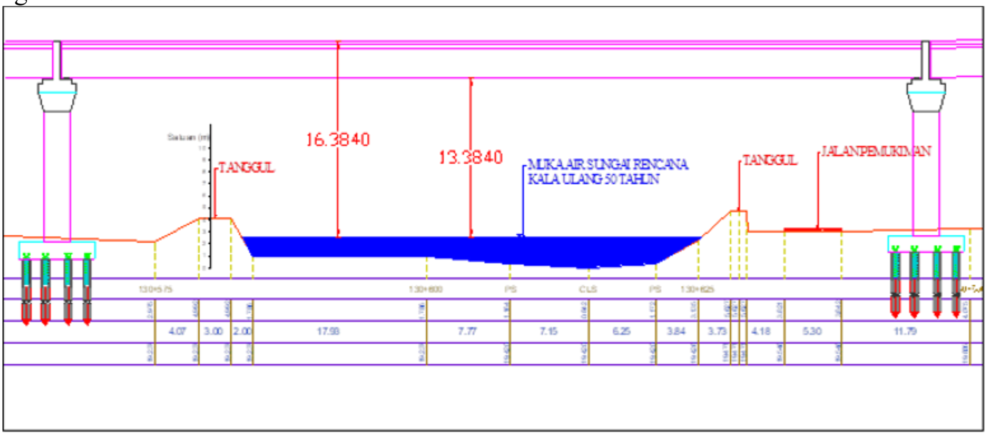

Fig. 6. Bridge River Water Discharge 2

Several research results that are relevant and strengthen the results of this analysis include research from [5] which shows that The planning of a railway bridge over the river is carried out by analyzing the hydraulic factors on the river in accordance with PM No. 60 of 2012 concerning Technical Requirements for Railway Lines. Hydrological and hydraulics analysis was carried out using the HSS Nakayasu method and the HEC-RAS v5.0.7 application program. This study aims to analyze the height of the flood water level based on hydraulic factors on the Way Tipo River and to design a guard height limit (freeboard) railway bridge based on the previously calculated water surface elevation results. Hydraulic analysis and high maintenance planning (freeboard) railway bridge (BH-102 KM. 53 + 778) on the Way Tipo Bekri River, Central Lampung Regency, resulting in flood discharge values for 50 and 100 year return periods of 742,281 m respectively3 /s and 854,431 m3 /s, the flood water level (MAB) is +45,38 m and +45,51 m, as well as the freeboard the length of the bridge is 1,32 m for the 50 year return period and 1,19 m for the 100 year return period in terms of the difference between the flood water level and the bottom girder of the bridge. It was concluded that freeboard the obtained railroad bridge meets the planning criteria, namely at least 1 meters from the bottom girder of the bridge to the flood water level; [6] which shows that Rainwater is one of the problems in the mining industry. Very high rainfall will cause the soil to be unable to accommodate rainwater, and result in water flowing thinly on the ground surface (run-off). The aim of this study was to compare the distribution of EJ. Gumbell, Pearson III log distribution, and Iway Kadya distribution to obtain the most suitable distribution for the rainfall data at hand. The Gumbell distribution has the highest planned rainfall value, while the Iway Kadya distribution has the lowest planned rainfall value, and the Log Pearson distribution has a planned rainfall value slightly above the Iway Kadya distribution. These three distributions can be used to determine planned rainfall, but the most suitable method to use is the gumbell method; and [7] shows that In making a numerical model, calibration is required and could use the Manning roughness coefficient as a parameter. The manning roughness coefficient can affect the condition of flows, one of which is the water level elevation. This research purposes to study the condition of the Lower Solo Bengawan River before the construction of the Karangnongko Barrage. The creation of a numerical model using 138 cross-sectional data of the river is carried out with the HEC-RAS program which is then flowed and includes variations of the Manning roughness coefficient between 0.022 - 0.030. Simulation results of unsteady-flow conditions using the HEC-RAS program for water level elevation shown that the numerical model with a manning roughness coefficient of 0.027 is the closest to the field with the value of RMSE is 0.068.

4 Conclusion

Hydrological analysis is one part of a whole series in the planning of transportation structures such as roads, bridges and railway bridges including flood barrier embankments and so on.

In this study, the Thiessen Method is the method to be used in determining the average rainfall of the watershed. This method takes into account the weight of each station which represents the area around it. In an area within the DAS it is assumed that the rain is the same as that which occurs at the nearest station, so that the rain recorded at a nearby station, so that the rain recorded at a station represents that area.

The information and values obtained in the hydrological analysis are important inputs for the subsequent analysis. The size and character of these buildings is very dependent on the purpose of construction and the information obtained from the hydrological analysis. Until clear information about hydrological properties and variables is known, it is almost impossible to carry out analysis to determine the various characteristics and characteristics of the flood. Likewise, basically water structures must be designed according to a correct standard, which is expected to produce a satisfactory design. The definition of satisfactory in this case is that the water must be able to function both structurally and functionally within the specified time.

In planning there are various factors that have a very big influence. These factors include: socio-economic factors, political and security factors, technical factors, and aesthetic factors. One aspect of the analysis that is expected to be produced to support the design of water structures is the determination of design variables, be it rain, flood or other hydrological elements. This is a rather complicated problem, because on the one hand adequate results are demanded, but on the other hand the means required for this are often inadequate. What is meant here is the availability of rain station data and information that has not been spread evenly, so that the analysis becomes shallow. To support such an analysis, it is necessary to understand the basic concepts and hydrology which are always related to one another in the calculation process. Because every change that is given or occurs in one of the hydrological elements, in general it is almost always followed by a change in response by other elements.

With the completion of the article on the results of this training, I would like to thank the Pihak Balai Pengelola Kereta Api (BPKA) Sulawesi Selatan Direktorat Jenderal Perkeretaapian Departemen Perhubungan and the Field Team of PT Citra Diecona Consulting Engineers Medan for their cooperation in collecting and processing field data Detailed Engineering Desain Bridge KA Antara Makassar-Parepare Lintas Makassar-Parepare (DED 402).

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