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The Impact of Extreme distribution of Rainfall on Flood Hydrograph Behavior in the Way Ruhu Sub-Watershed of Ambon City

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ABSTRACT
The Way Ruhu watershed is a densely populated area that is more dominant in the lower reaches of the Way Ruhu river. The area of Hative Kecil Village often experience flood. As a result of surface flow runoff, it causes the accumulation of runoff of the Way Ruhu Subwatershed. Rain discharge transformations are used in using the HEC-HMS model because this model can mimic flow behavior in watershed systems. Rainfall data is used from satellite data they are (TRMM), (CHIRPS), for frequency distribution analysis following the extreme value distribution pattern (GEV). Way Ruhu watershed is located in the Great Watershed of Way Batu Merah with an area of 15,727 Km^2 and is located in Sirimau District of Ambon City which is divided into three Subwatersheds from the results of the interpertation of the GIS Arc with a land use coefficient of 0.233 (SubDAS_3), 0.19 (SubDAS_2), 0.84 (SubDAS_1), CN, Ia and Lag time values are part of the input parameters of HEC HMS located in the Sub Watershed. From the simulation results of the Parameter model, calibration is carried out for the initial abstraction, Curve Number and Time Lag values. This is because these parameters are measurable watershed characteristic parameters that are intended to approach the model results according to actual conditions. From the results of optimizing the bias presentation of 11.40% and RMSE, the standard deviation is 0.2 and the Nash-Sutcliffe Efficiency (NSE) value is 0.976 which is the comparative value of the model to observations. To determine the occurrence of flood inundation, a comparison of Hydrograph / Outflow HEC-HMS SCS-CN method was modeled using HEC-RAS. 2-D river flood simulation resulted in an inundation area of 0.263 km2. For 1D in the upper reaches of the Way Ruhu river gives runoff from the existing conditions of the river as high as 1,410 m

Keywords: GEV, Way Ruhu, Time lag, Runoff

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I. INTRODUCTION

The large amount of land that has been converted into residential areas due to the population growth, causing a decrease in catchment areas, which will cause flooding. If the intensity of rain is high, the sedimentation rate increases, resulting in silting of the river, which causes overflow of water (*flooding*). The flow through the Way Ruhu watershed is a densely populated area that is more dominant in the lower reaches of the Way Ruhu river. Around the area of Hative Kecil Village often experience flood problems. Due to surface flow runoff, it causes runoff accumulation through land surface channels and converges in tributaries. The distribution of the time of occurrence of rain and the length of time of horizontal movement of surface runoff water, causing the formation of flood discharge hydrographs. Due to the transformation of rain, complex discharges cause changes in the watershed system and input characters. Quantitative analysis of watershed system outputs based on system inputs and characteristics can be performed with the HEC-HMS model.

The HEC-HMS model is one model that can mimic flow behavior in watershed systems. One way that is considered quite good for rain-flow analysis of watersheds is with a flood flow hydrograph. According to Sene flood hydrographs will be very useful for studying fluctuations in river volume and peak discharge times. With a flood hydrograph, the relationship between rain and river flow discharge will be obtained within a certain time span. For this reason, thing to be considered is that the hydrological analysis of existing rainfall data must be in accordance with the type of data distribution, and each type of distribution has special properties so that each hydrological data must be tested for suitability with the properties of each type of distribution. As a preliminary estimate, the corresponding type of distribution can be determined based on statistical parameters.

To avoid the adverse effects of rainfall and climate extreme events, it is important to pay attention to extreme values, given the inability of humans to avoid or exempt from the disasters that rainfall and climate phenomena can cause. One theory that specifically addresses extreme events is EVT (*Extreme Value Theory*), EVT pays attention to the information of extreme events based on extreme values obtained to form a distribution function of extreme values of rainfall and climate phenomena. In modeling the maximum value of a random variable, extreme value theory will resemble central limit theory in modeling the number of random variables. Based on this theory, it is known that asymptotically the extreme values of rainfall and climate will converge following the distribution of GEV (*Generalized Extreme Value*) is an extreme value in a certain period. Suppose we have a free random variable x1,x2,... xn each variable xi has the same distribution function which is F(x) then considered the maximum value Mn = max(Xl,X2,Xn)

$$F(x) = \begin{cases} \exp\left(-\left[1+\xi\left(\frac{x-\mu}{\sigma}\right)\right]^{\frac{1}{\xi}}\right), & \xi \neq 0 \\ \exp\left(-\exp\left[-\left(\frac{x-\mu}{\sigma}\right)\right]\right), & \xi = 0 \end{cases}$$

(1)

Where;
μ = location parameter
σ = scale parameter
ξ = shape parameter

The ξ shape parameter determines the characteristics of the spread end; if ξ < 0 then its hug function has a finite right end point and if ξ ≥ 0 its probability function will have an infinite right end point by Gomes and Guillou (2016) The distribution of compressed extreme values (The distribution of compressed extreme values is one of the distributions that can be used to assess maximum rainfall events), is a combination of three types of limited distributions for extreme values into a single form as derived by Fisher and Tippet. The three singular forms in question are the Gumbel distribution, the frechet .

$$G(x) = \exp\left\{-\exp\left[-\left(\frac{x-\mu}{\sigma}\right)\right]\right\}; -\infty < x < \infty$$

(2)

$$G(x) = \begin{cases} 0 & ; x > \mu \\ \exp\left\{-\left(\frac{x-\mu}{\sigma}\right)^{-a}\right\} & ; x > \mu \end{cases}$$

(3)

$$G(x) = \begin{cases} \exp\left\{-\left[\left(\frac{x-\mu}{\sigma}\right)\right]^{a}\right\} & ; x > \mu \\ 1 & ; x \geq \mu \end{cases}$$

(4)

Where μ is the location parameter, σ > 0 is the scale parameter ξ > 0 is the shape parameter (Stpehenson, 2003). The parametric form of GEV would lead to the Gumbel distribution for limit ξ = 0, the Frechet distribution if ξ > 0, and the weibull distribution if ξ = 0. The relationship of equation (1), (2) and the GEV distribution will be obtained after the parameters are determined as follows: for the Frechet distribution the parameters are determined to be ξ = > 0; σ > 0 and μ = a + b ; While the Weibull distribution parameters are determined to be. After knowing the extreme type of data used and assuming the distribution of the data, for example GEV, the next step is to estimate the parameters of the assumed distribution. The estimation method that is often used is maximum likelihood estimation (MLE). Suppose y1,... yn is n observations independent of the random variable Y1,...... Yn each GEV distribution with indeterminate parameter θ=(μ,σ,ξ). otherwise the data are assumed to be independent of each other, then: F(yi,.......ynIθ) = F(Y1Iθ).....f(YnIθ)1/a b/a.
This is called the likelihood function, often written I(θIy). Log from the likelihood function:

$$L(\theta|y) = K\prod_{i=1}^{n}\exp\left(-\left(1+\xi\,\frac{ti-\mu}{\sigma}\right)^{-1/\xi}\right)$$

(5)

$$\prod_{i-1}^{n}\frac{1}{\sigma}\left(1+\xi\,\frac{yi-\mu}{\sigma}\right)^{\frac{1}{\xi}-1}$$

(6)

HEC-HMS (Hydrologic Modelling System) is a software used to assist in simulating the hydrological cycle (*rainfall, evapotranspiration, infiltration, surface runoff and bottom flow*) of a catchment by describing its physical and meteorological properties. A simple schematic representation of the runoff process replicated in HEC-HMS. A wide selection of mathematical models for all hydrological components that conceptually represent watershed behavior are included in the program. The program uses separate models to represent each component of the runoff process such as models for calculating runoff volume, direct runoff /baseflow/channel flow models as well as alternative models to account for cumulative losses e.g.: loss models according to SCS and CN. Then, it calculates the volume of runoff by subtracting losses (infiltration, storage, interception, evaporation and others). HEC-RAS is a hydraulics model used for flow simulation with input parameters of the land use coefficient and characteristic parameters of rivers such as geometric and flow data. HEC-RAS provides different options for performing river analysis i.e. one-dimensional stable flow for water surface profile calculation, 1D and 2D stable flow simulation for moving flow, quasi-unstable flow for sediment transport calculation and water quality analysis.

II. Methodology

The selected data are appropriate customary data to analyze and replicate the actual hydrological and hydraulic situation. Furthermore, the quality of the data used for modeling directly affects the output, so the collected data must be filtered and processed before using it.

2.1 Research Location

The data required for hydrological modeling (HEC-HMS) are:

- Digital Elevation Model (DEM):
- Land use and land cover
- Rainfall Data
- Stream data

The Research Area is in the Batu Merah Way watershed for the Ruhu Way Sub Watershed. Limits are determined from the results of DEM analysis with the help of Arc GIS and Global Mapper software.

Fig 1. Way Ruhu Sub Watershed

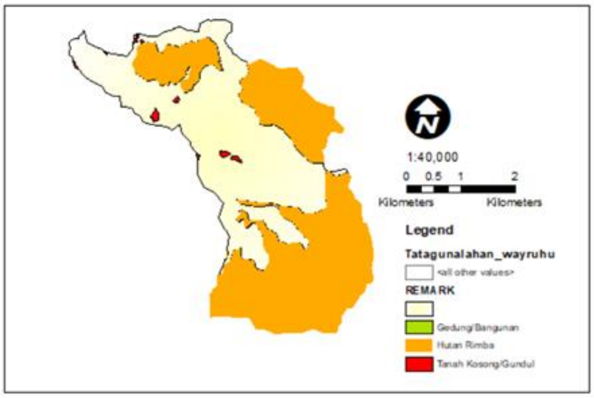
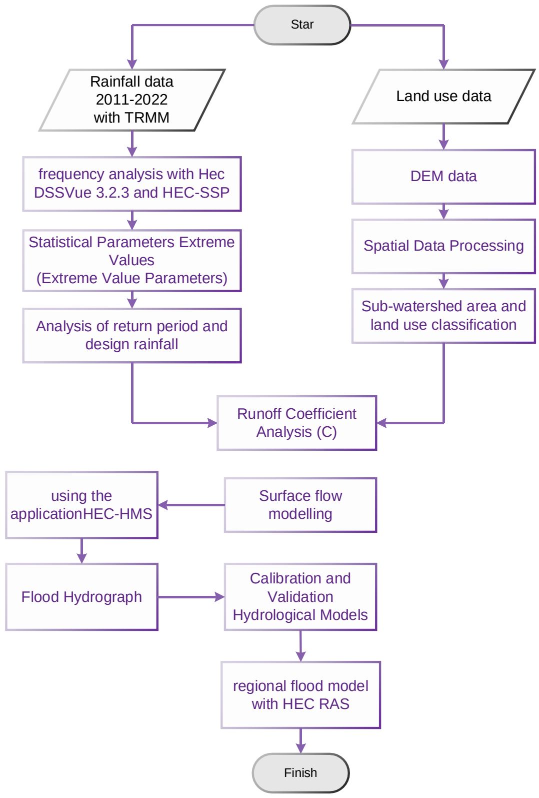


Fig 2. Flow chart distribution of extreme rainfall on flood hydrograph behavior



III. Discussion

3.1 Rainfall Plan

Regional Rainfall Analysis is the average rainfall taken from satellites in the form of TRMM (*Tropical Rainfall Measuring Mission*) data with data series from January 1, 2011 to November 30, 2022. In this study, satellite data was used for the amount of rainfall. The rainfall satellites used are Tropical Rainfall Measurement Mission (TRMM) 3B42, Climate Hazards Group InfraRed Precipitation with Station (CHIRPS), Analysis of rainfall frequency in this study using Hec DSSVue 3.2.3 and HEC-SSP encroachers. From the results of the frequency distribution analysis follows the extreme value distribution pattern (GEV).

Fig 3. Rainfall Data Graph according to CHIRPS 2011-2022

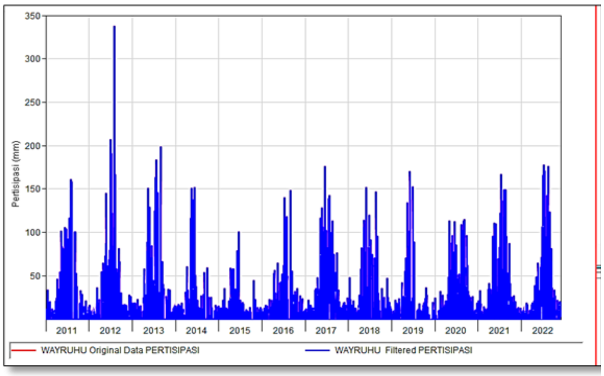
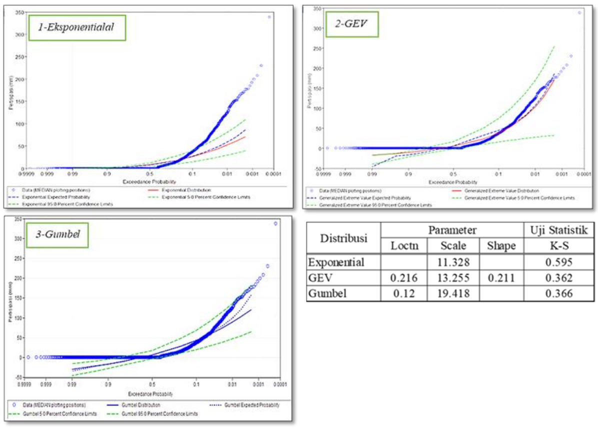


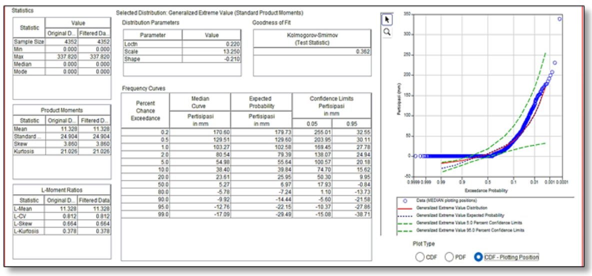
Fig 4. Frequency distribution graph results for 3 methods



Distribusi	Parameter			Uji Statistik
	Loctn	Scale	Shape	K-S
Exponential		11.328		0.595
GEV	0.216	13.255	0.211	0.362
Gumbel	0.12	19.418		0.366

From figure 2 above, it can be seen that the graph that tends to fall within the constraints of the opportunity curve is the distribution of the GEV model.

Fig 5. Parameter Graph Frequency distribution with GEV



The results of the planned rainfall calculation using the GEV method have relatively not too high rainfall from CHIRPS data of the highest rainfall of 337.82 mm and the lowest 0 mm with a total of 4352 recorded data (01/01/2011 – 30/11/2022). for statistical parameter tests using Kolmogorov-Simirnov yielded a test value of 0.362. From the results of the distribution test, the amount of planned rain value that will be used for the analysis of Hydration in River Watersheds and Hydraulics is a period of 50 years as seen in Table 1 below:

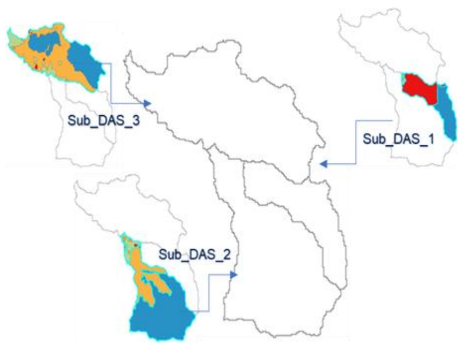
Table 1 Rainfall Plans

Return Periode	Mean	Cofidence Limits	
		0.05	0.95
5	23.61	50.32	9.95
10	38.4	74.69	15.63
20	54.98	100.56	20.18
50	80.54	138.05	24.94
100	103.27	169.37	27.79
200	129.51	203.89	30.12
500	170.6	254.95	32.55

3.2 General Conditions of the Research Area

Way Ruhu watershed is located in the Great Watershed of Way Batu Merah with an area of 15,727 km^2 and is located in Sirimau District of Ambon City which is located in 4 villages namely Batu Merah, Galala, Hative Kecil and Halong.

Fig 6. Way Ruhu Sub Watershed Section



3.3. Land use

The vegetation land cover factor is quite significant in reducing or increasing surface flow. Dense forests have a high level of land cover, so if rain falls on the rain area, this land cover factor slows down the speed of surface flow, and can even occur near zero speed.

Table 2 Land cover area

Land Use	Sub_watershead1		Sub_watershead 2		Sub_watershead 3	
	Area (Km2)	(%)	Area (Km2)	(%)	Area (Km2)	(%)
Fallow land	0.008	0.33	0.024	0.39	0.038	0.54
Forestry	1.177	48.13	4.138	67.64	2.872	40.27
shrubs	1.221	49.92	1.663	27.19	3.463	48.57
Residentail	0.040	1.62	0.292	4.78	0.757	10.62
Σ	2.445	100	6.117	100	7.131	100
Σ Wide Sub Watershead	15.693					

The CN value expresses the physical characteristics of the watershed as an influence of soil, hydrological conditions, land use and soil flexibility conditions (AMC). Determination of CN value by SCS-CN method, then what needs to be done is to combine land use with soil hydrology group (HSG). Determination of CN classification using the SCS-CN method of various land uses based on land use form factors, treatments or actions given and hydrological conditions. Determination of land use classification based on SCS-CN in Way Ruhu Sub Watershed shown in table 3 below;

Table 3 SCS CN values of way ruhu sub watershed

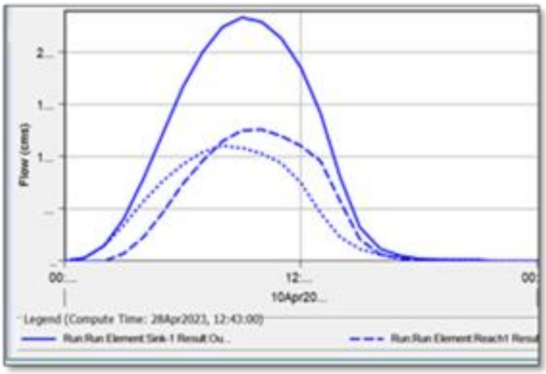
No	Land Use (Sub_DAS 1)	HSG (SCS_USDA)	CN (Table)	A (Km2)	Quality (%)	CN
[1]	[2]	[3]	[4]	[5]	[6]	[7]=[4]x[6]
1	Fallow land	B	71	0.008	0.003	0.236
2	Forestry	B	55	1.177	0.481	26.471
3	shrubs	B	58	1.221	0.499	28.952
4	Residentail	A	77	0.040	0.016	1.249
	Total			2.445	1.000	56.908

No	Land Use (Sub_DAS 2)	HSG (SCS_USDA)	CN (Table)	A (Km2)	Quality (%)	CN
[1]	[2]	[3]	[4]	[5]	[6]	[7]=[4]x[6]
1	Fallow land	B	71	0.024	0.004	0.280
2	Forestry	B	55	4.138	0.676	37.202
3	shrubs	B	58	1.663	0.272	15.768
4	Residentail	B	85	0.292	0.048	4.063
	Total			6.117	1.000	57.313

No	Land Use (Sub_DAS 3)	HSG (SCS_USDA)	CN (Table)	A (Km2)	Quality (%)	CN
[1]	[2]	[3]	[4]	[5]	[6]	[7]=[4]x[6]
1	Fallow land	B	71	0.038	0.006	0.445
2	Forestry	B	55	2.872	0.469	25.820
3	shrubs	B	58	3.463	0.566	32.838
4	Residentail	B	85	0.757	0.124	10.522
	Total			7.131	1.166	69.624

The HEC-HMS model is used for flood discharge analysis at the location of the "control point" The HEC-HMS model can provide hydrological simulations of daily flow peaks or for calculation of planned flood discharge from a watershed. In the HEC-HMS model raises the classical theory of unit hydrographs to be used in modeling, including SCS unit hydrographs, or we can develop other unit hydrographs using user define hydrograph facilities. The hydrograph flood model for the Way Ruhu Sub Watershed is arranged in three subbasin (*subwatershed*) and one sink (*outlet*) elements. The flow results of such model elements are determined with HEC-HMS, shown in Figure 7.

Fig 7. Way Ruhu Subwatershed Model Element Flow

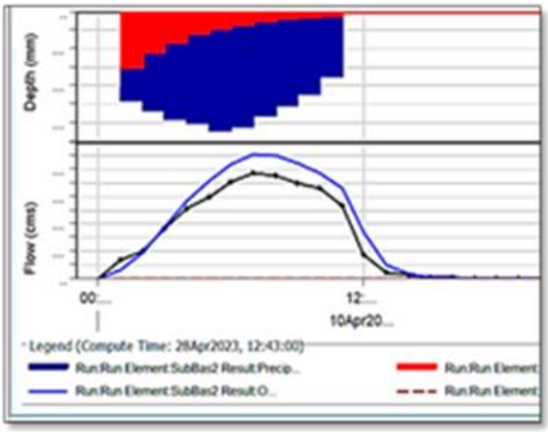


The initial parameters of other model elements are adjusted to the HEC-HMS calculation method. Predefined initial parameters are used as input data for the subbasin shown in Table 6. In addition to these initial parameters, additional parameters are also specified which include initial abstraction (*initial infiltration*, *losses*) which are calibrated subbasin parameters. Sub watershed calibrated in Sub DAS 2 While the sink is used as a parameter of the measured flood hydrograph at the same time as the model flood hydrograph shown in Figure 7.

Table 4 HEC-HMS input parameters

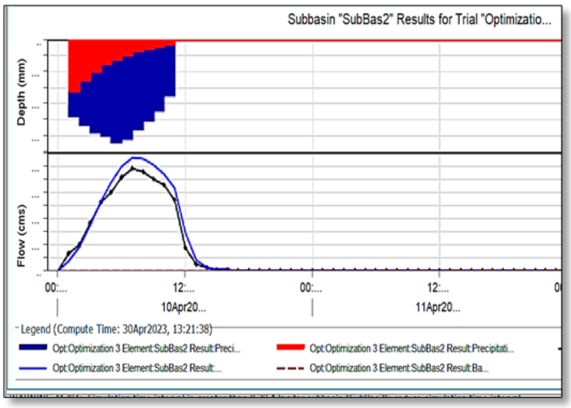
Year	L (m)		Y	CN	S	Ia	Tlag	C
2022	*SubWatershead_3*	4882.57	0.0139	69.62	110.81	22.16	108.46	23.38
	SubWatershead_2	2909.48	0.0536	57.31	189.18	37.84	52.84	19.07
	SubWatershead_1	669.41	0.0466	56.91	192.34	38.47	17.70	18.45

Fig 8 Before Kalibarisi in Sub Watershed 2 and Cumulative discharge in Sink_1



The parameters performed by calibration include initial abstraction, Curve Number and Time Lag. This is because these parameters are measurable watershed characteristic parameters that are intended to approach the model results according to actual conditions. From the results of optimizing the bias presentation of 11.40% and RMSE, the standard deviation is 0.2 and the Nash-Sutcliffe Efficiency (NSE) value is 0.976.which is the comparative value of the model to observations. From the results of calibration of the model and observations almost formed a peak of flow at the same time.

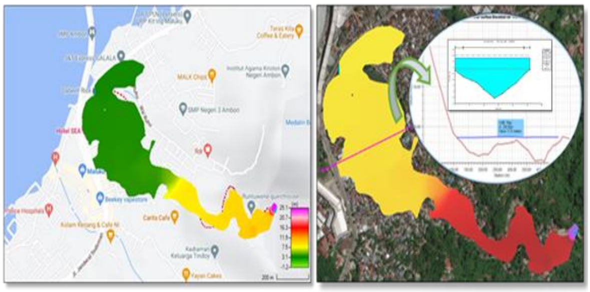
Fig 9. SubDAS-2 Calibration Results Parameters



3.4 Hydraulic Modeling Results / Flood Puddles

To determine the occurrence of flood inundation, a comparison of Hydrograph / Outflow HEC-HMS SCS-CN method was modeled using HEC-RAS. In order to determine the carrying capacity of the Way Ruhu river, a simulation was carried out using the Q50 year plan discharge based on the results of the unsteady flow simulation. Areas that are prioritized for inundation simulation are taken in densely populated areas around the downstream of the river. HEC-RAS-based 1-D and 2-D simulations were made to model the drainage capacity in each cross-section of the Way Ruhu River channel, while for 2D geometry models the area plus the influence of surface roughness values (*Manning values*) in surface flow calculations whose values are determined based on the type of land use.

Fig 10. 2D Model of Way Ruhu River flow and wide cross section of inundation plain



From the results of the 2-D river flood simulation by entering river parameters and land use coefficients, the area of inundation that occurred was 0.263 Km^2.

In the 1D cross section in the upper reaches of the Way Ruhu river gives an illustration in the section there is runoff from the existing conditions of the river as high as 1,410 meter.

IV. Conclusion

In the study area, rainfall data follows the distribution of GEV The flow model with HEC HMS was carried out on three Way Ruhu Sub Watersheds with Sub Watershed parameters and land use coefficients. The relationship between simulated discharge to observation discharge is quite significant with time at peak discharge by repeating optimization three times against initial abstraction, Curve Number and Time Lag From the results of optimization bias presentation 11.40% and RMSE, standard deviation 0.2 and Nash-Sutcliffe Efficiency (NSE) Value 0.976. 2-D Hydraulics Analysis is used to model inundation in the Way Ruhu Sub Watershed, the area modeled is downstream of Way Ruhu which has an impact on inundation / flooding, from the simulation results it was found that the area of inundation area was 0.263 Km^2.

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