RIVER FLOW MODELING FOR HYDRO ELECTRIC POWER PLANT IN TALUDAA-GORONTALO WATERSHED

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Abstract: The operation of a Hydropower Plant in generating electricity is heavily influenced by the volume/discharge of water flowing in the river. In the concept of hydrological recycling, rainwater that falls in a catchment area/watershed will be processed into a runoff water flow and water seeping into the underground layer forms overland flow and baseflow. Water below ground level will rise as springs form streams.
The study performed a modeling technique to obtain the discharge value of watersheds in watershed areas as a function of rain in watersheds and watershed system parameters. Hydrological analysis uses HEC-HMS software with SCS-CN model with input parameter Curve Number (CN) as a number representing land use function, Initial abstraction (Ia) as much water seeps into the ground, Time Lag (TL) as the time it takes rainwater forms the discharge of the river. Hec-HMS process output is a time series of river discharge hydrographs based on rain data input. By calculating the river's mainstay discharge value using the Flow Duration Curve (FDC) method and the river head value can carefully determine the power value of the river's hydroelectric power plant.

Keyword: Modeling, rain, river flow, watershed, electric power

I. INTRODUCTION

The problem that is often encountered in the planning of a hydroelectric power plant is the incompatibility of the value of river flow discharge with the actual potential of the flow discharge in that river that can be fulfilled over time to be able to operate the power plant (Tsai *et al.*, 2016; Hussain *et al.*, 2019; Kordana *et al.*, 2019; Lyubimova *et al.*, 2020). Many planners only rely their project on the study of river discharge on the measurement of river cross-sectional area (A) and water flow velocity (V) as components to determine river discharge (Q) through the equation of Q = A x V m3/sec (Kusuma *et al.*, 2020). The value of river discharge can only provide the value of discharge at the time when the measurement is conducted. The climate change in the catchment area that occurs time after time or the value of river discharge over one year cannot be determined (Alisjahbana and Busch, 2017). As a result, the power plant that was built could not operate properly at certain times in which there was no rain at that time. Conversely, the power plant components can be damaged due to heavy rain with a long duration so that the volume of river water exceeds the capacity of the river weir or waterways to the powerhouse (Kabo-Bah *et al.*, 2016; Gokhale *et al.*, 2017). The occurrence of river flow discharges over time must be found out to assess whether the river flow meets the requirements for the minimum of the volume of water over time to turn the power plant turbine (Samora *et al.*, 2016; Ramadhani *et al.*, 2020).

Based on the concept of the hydrological cycle of rainwater that falls to the surface of the land, some will be infiltrated and others fill the curves of the surface of the ground, then flow to a lower place into rivers and finally into the sea. On the way to the sea, some will be evaporated. Some of the water that seeps to the ground will come out again into the river, called the interflow. Some will continue to go down and seep again into the groundwater that comes out little by little and enter the river as the groundwater flow, and so on (Rasmy *et al.*, 2019; Ekundayo, 2020). Because the hydrological cycle is a closed system, the water that enters is always the same as the one that comes out. This is known as the water balance (Linsley Jr *et al.*, 1975; Chow *et al.*, 1988; Soemarto, 1999). A river is a combined point of rain runoff that falls directly on a body of water, an intermediate flow, and a baseflow. The result of the river flow is the total output flow from the catchment area (Seyhan and Subagyo, 1990). This study generates a hydrograph that illustrates the occurrence of river flow over time through the Soil Conservation Service – Curve Number (SCS-CN) hydrological modeling technique which identifies the parameters of the catchment area, namely Curve Number (CN) that represents the function of land use, soil type, and initial moisture, Initial Abstraction (Ia) that represents water loss before the flow occurs which includes water that is stuck at the surface, water that is intercepted by vegetation, evaporation, and water that seeps into the ground (infiltration), and Time Lag (TL) that represents the time of peak rainfall events and peak flow discharge events.

II. METHODS

The type of this research was an exploratory study. The applied analysis was hydrological modeling to find out the energy or river flow discharge for power plants. Exploration was conducted to find out the actual condition of the catchment area in the field. The data collection of rainfall and river water level is conducted using ARR rain station data and AWLR data belonging to the Center of River Region II of Gorontalo that was installed at the location of the catchment area. The applied maps or satellite photos to analyze the area and condition of the catchment area are the Indonesian Geospatial Information Map belonging to the Geospatial Information Agency with a scale of 1:25,000 updated in 2019.

2.1. Hydrological Modeling with HEC-HMS

Hydrological modeling is a simplification from very complex elements and components to facilitate the understanding of hydrological phenomena. The hydrological model is a simple description of an actual hydrological system created to study the functions and responses of a catchment area from various inputs in that catchment area. Through the hydrological model, hydrological events can be studied which in turn can be used to predict the hydrological events that will occur. Hydrological modeling can describe the process of rain that falls in the catchment area and is processed in the system of the catchment area. It also produces a hydrograph output of the river flow discharge.

The Soil Conservation Service Model – Curve Number (SCS-CN) as a modeling technique approach in this study analyzes the occurrence of river flow discharge as a function of effective rain falling in the catchment area, land cover, land use, and antecedent moisture. In this model, the function of land use, soil type, and initial moisture is represented by the Curve Number (CN) parameter. The value of CN is determined by taking into account the antecedent moisture condition (AMC). The value of AMC can be determined simply by an approach based on the amount of rain that falls during 5 days before the CN calculation is conducted. To simulate the process of rain becoming flow in the catchment area, the Hydrologic Engineering Center – Hydrologic Modeling System (HEC-HMS) is used. The applied SCS-CN model equation is:

where is the accumulation of effective rainfall at time , is the accumulation of total rainfall at time , is the initial loss of rainwater before runoff occurs, is the maximum potential retention. The relationship between *Ia* and *S* is linear so that .

Value Curve Number (CN) of a watershed can be estimated as a function of land use, soil type and moisture before using tables SCS watershed and hydrological soil classification. For watersheds in which there are different types of soils and land use, the value is calculated as CN composites by using Equation:

where is CN composite total value to calculate the volume runoff with HEC-HMS, is Index DAS division who have use land and soil types is CN value for the distribution of watershed i, and is area of basin i.

Hydrological model (HEC-HMS) is designed to simulate the rainfall runoff in a watershed. HEC-HMS is designed for easy use in all geographic watershed. Components of HEC-HMS in a watershed shown by subbasin, reach, junction, source, diversion, reservoil and sink. Sub basin indicates the physical aspect of the total sub-watershed as rain, losses, total river flow and baseflow at the outlet sub basin. Reach marks on the calculation of the flow downstream of the outflow. Sourch indicates the artificial inflow input source. Diversion indicates the flow separation from the mainstream. Sink indicates the output of an artificial lake that does not have the output stream.

The area of catchment, the length of the main river, and land use were analyzed using the Indonesian Geospatial Information Map with ArcGIS software.

Analysis of simulated runoff prediction in other sub basin parameter analysis using SCS-CN models in HEC-HMS software as river runoff prediction models in Taludaa Basin. The parameter that changes is the value of CN, He, and Time lag is analyzed based on the characteristics of each sub basin.

2.2. Validation or Calibration Model

Calibration is a procedure to find out the values that are considered to be able to represent the actual situation based on input and output data from the hydrological modeling process. Calibration in the HEC-HMS program is carried out through the process of checking the suitability or output hydrograph comparison between the flow discharge from modeling results and the flow discharge from the measurement in the field at the same time. This process is carried out automatically and repeatedly with certain alterations in the HEC-HMS software. The calibration results can be accepted if the hydrograph of the flow discharge from the modeling is the same or close to the hydrograph of the flow discharge from the field measurement.

2.3 The Potential Energy of Water For Power Generation

The mainstay discharge or river flow discharge that can be fulfilled over time is used to turn a power plant turbine.

The analysis of mainstay discharge uses the Flow Duration Curve (FDC) method by illustrating a graph of the relationship curve between the discharge and the frequency of occurrence. The process of making FDC curves is by sorting the discharge data from the largest to the smallest on the Y-axis, and by making a ranking probability of the occurrence starting from 1 – 100% on the X-axis. Discharge probability for each presentation is calculated using the equation as follow (Soemarto, 1999):

where: is the probability of flow discharge, is the ranking position of data of flow discharge, is the total data. Determination of Mainstay River Discharge as shown in Fig. 1.

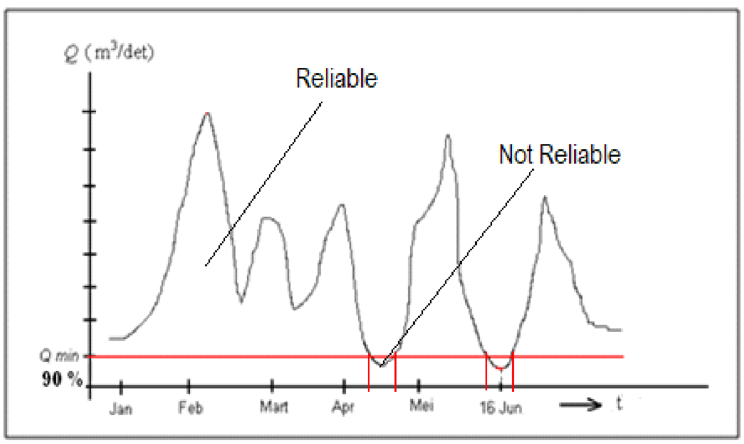


Figure 1. Determination of Mainstay River Discharge (Soemarto, 1999).

Discharge is the mainstay of the river flow is available throughout the year to be used for development projects of water resources. Discharge pledge can be searched by making the first line for the duration of the discharge-discharge equaled or exceeded, then we assign a frequency which is a flagship event in which, there is at least one failure. Mainstay based on frequency of occurrence (security, certainty) is formulated as follows:

where: is the number of observations and is thenumber of failures, the discharge more small than the discharge of the mainstay.

Discharge mainstay used for power plants amounted to 85-90%, which means that from the many rivers flow events throughout the year, must be met discharge range of 85-90% to be used for energy generation electricity. To know in detail the river flow by the time the incident is done by determining the value of the minimum discharge and maximum discharge flow hydrograph. Minimum discharge is the discharge with the smallest value available all the time as the river flow. Minimum discharge hydrograph is obtained by plotting the flow rate based on the time of the incident. With this process can be seen when the value of the smallest discharge/minimum in the river so as to use can be calculated capacity components/electrical generator that will be used by the potential of water resources. For details, determination of minimum discharge by river flow hydrograph events.

To get an adequate height water falls drains should be built in order to generate the appropriate volume of river flow for optimal turbine power plant. Obtaining high water fall (head) is based on the slope (slope) streams suitable field conditions. Elevation angle of slope of a stream can be obtained through field measurements using tools ukut theodolite, or through image interpretation to determine the value of altitude discharge measurement point and the altitude value in building micro-hydro power plant according to the assumption that the ideal distance can be obtained. The determination of the height of fall of water (head) is determined by subtracting the value of the height of the observation point and the point of building height values. Value added together with high altitude streams dammed river water after a high value falling water (Head).

In a hydroelectric power system, energy losses always occur when the potential energy, namely water, is converted into electrical energy. The amount of energy lost is influenced by several factors, namely:

- Rapid pipe losses/penstock
- Turbine efficiency
- Generator efficiency
- Civil construction efficiency

In the hydropower system analysis, the efficiency of hydroelectric power is usually set at 75%. Furthermore, the equation for determining the electric power that can be generated on the river flow is:

$$P=9{,}81 \times Q \times H \times \eta T \text{ (KW)}$$

where is the theoretically electric power (kilowatt), is the effective water falls height (m), is the water discharge (m^3s), and is the turbine efficiency.

III. RESULT AND DISCUSSION

3.1. The Conditions of The Study Area

The research area is Taludaa Watershed Bone Bolango Regency, Gorontalo Province as shown in Fig. 2.

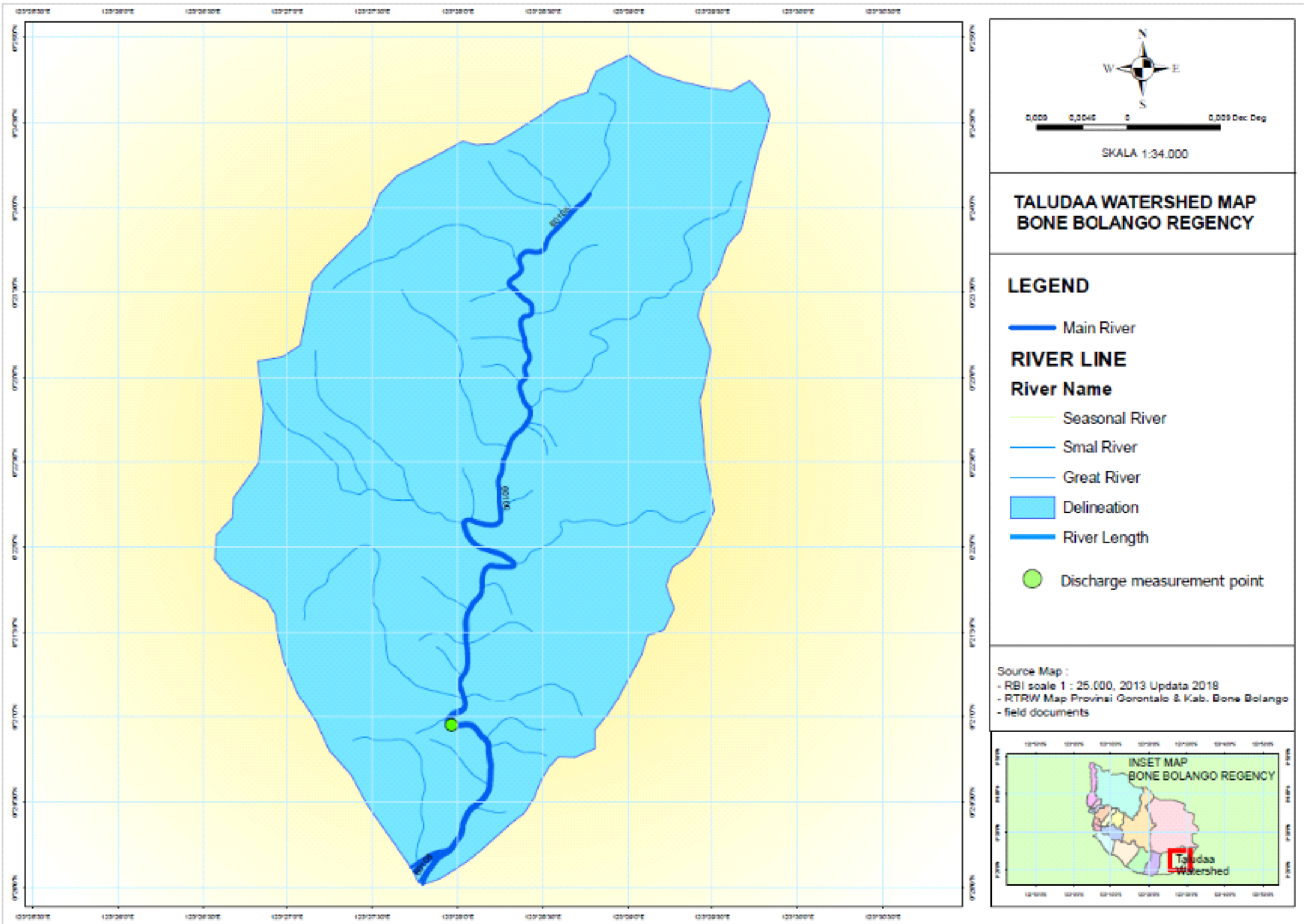


Figure 2. Taludaa Watershed Bone Bolango Regency, Gorontalo Province (ArcGis process results).

The Taludaa watershed area is 2,296.91 hectares, the length of the main river is 9,996 meters. The Taludaa watershed topography is a plateau with a slope of more than 30-45% and coarse textured. The condition of vegetation cover in the Taludaa watershed is dominated by high density vegetation of 81.97% of the Taludaa watershed area.

Land use in the Taludaa watershed consists of forest land use, residential land use, and dry agricultural land use. The land use in the Taludaa watershed is dominated by forests, amounting to 53.27% of the total area of the Taludaa watershed. The use of dry land agricultural land is 18.56%, for housing is 15.07% and the remaining 13.20% is another area of use. Settlements are in the downstream part of the watershed. Land use greatly influences the characteristics of the flood hydrograph, especially at the peak of the runoff.

3.2. Time Series Data

Taludaa Watershed using the external rain data obtained from the 2nd River Regional Hall of Sulawesi Gorontalo, namely rain data in June - September 2019 (rain data is presented in the appendix). For control specification (in HEC-HMS) river discharge data is analyzed using the "Curve Flow" method which is the relationship of water level height with river discharge resulting from field measurement. Taludaa River water and discharge level data pairs are presented in Table 1.

Table 1. data pairs of high-water levels and Taludaa river discharge

No	Date, Year	Water level(m)	Discharge (m^3/s)
1	06/9-2019, 16.35	0,40	2,30
2	06/28-2019, 16.53	0,41	2,31
3	06/30-2019, 17.15	0,41	2,31
4	07/01-2019, 17.00	0,39	2,29
5	07/22-2019, 15.00	0,40	2.31
6	07/24-2019, 16.00	0,53	4,08
7	08/05-2019, 09.00	0,61	6,51
8	08/17-2019, 14.00	0,89	13,50
9	08/20-2019, 17.00	1,11	24,63

By using the Microsoft excel software process, the debit data and the high-water level in the input by using scatter chart, curved line equations are obtained ($Y = aX^{2.235}$) (see Fig 3).

Based on the flow curve chart, the equation value is $Y= 18.84\ X^{2.24}$, with $R^2= 0.996$. The debit value of the river flow is obtained by entering a high-water level value that becomes variable X in the equation. Y is the debit value of the calculation result. Based on this process, river discharge value is obtained for control specification needs in HEC-HMS as a time series of river discharge data dated August 03, 04:00 – 20:00.

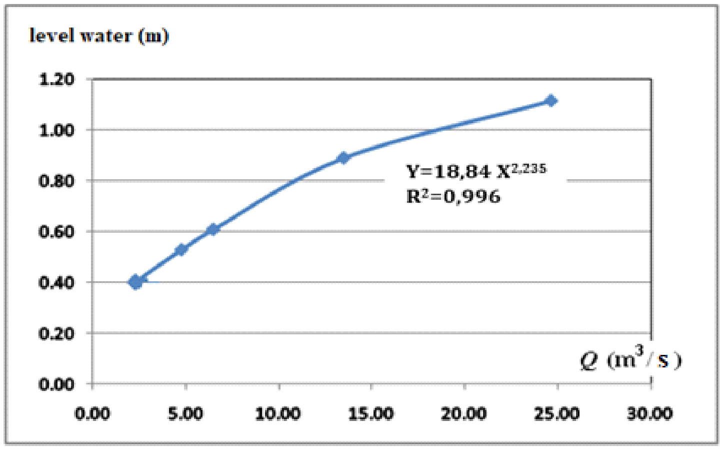


Figure 3. Curves of high-water levels with river discharge.

3.3. The Soil and Land use Classification in Determining the CN

There are three soil types occurred in the research area due to the soil map in the Sheet of Taludaa Bone Bolango with the scale 1:50.000. They are Alfisol, Inceptisol, and Mollisol. Furthermore, according to USDA soil texture classification, three textures exist are silty loam, loamy sand and sandy loam.

The CN – that is referred to SCS Table - is determined due to the land use map together with some adjustment that are found during the field observation as well as due to the hydrological soil group (HSG). However, the CN mapping of Taludaa Watershed area is referred to maps of land uses, land cover and hydrological soil group. In addition, based on the analysis of land use map together with vegetation coverage area, the derived information of land use types and its area as well as the vegetation cover density within Taludaa watershed that, are used for CN composite calculation in the sub watershed as its listed in Tab 2.

Table 2. The CN calculation of Taludaa Sub watershed

Land use type	Condition	Density (%)	spacious (km2)	Soil hydrology	CN	CN composite = 5 x 7
Settlement	70% impermeable	30%	3.68	C	70	257.6
Plantation	Ugly	50%	50.08	C	69	3,455.52
Agricultural farming	Ugly	< 25 %	267.65	C	75	20,073.75
Primary & secondary forest	Medium	30-70 %	4,212.80	B	60	252,768.00
			4,534.21			276,554.87
CN composite = 275,554.87/ 4,534.21= 60,77						

3.4. The results of the analysis CN SCS model

The results of the analysis SCS-CN Model with ArcGis software and calculations using equations as in the theoretical basis are divided into several components, namely: sub-basin, loss, transform, and baseflow. The sub-basin component is used to input the parameters of: the area of the catchment, the loss method, the transform method, and the baseflow method. In this process, the used loss method is the SCS Curve Number, the used transform method is the SCS Hydrograph Unit, and the used baseflow method is Recession. The values of the parameter input in the sub-basin component are presented in Tab 3.

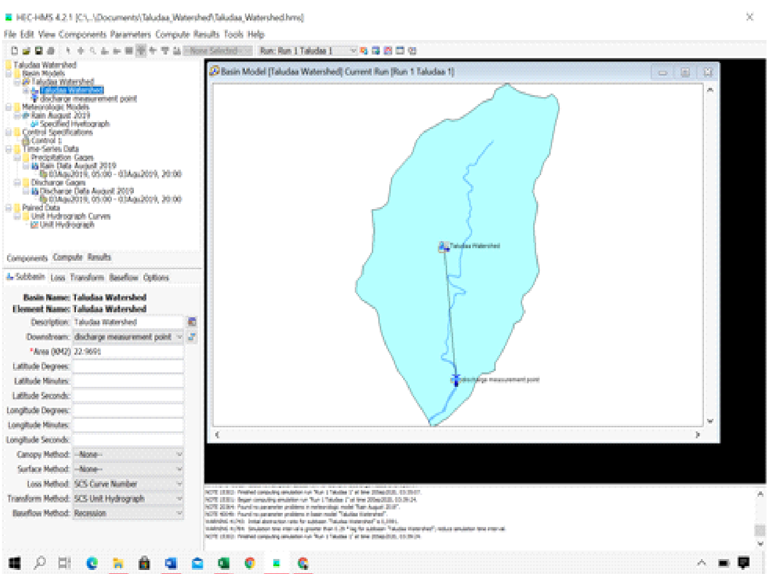
Table 3. The Results of Parameters from the Taludaa Watershed

Parameters of The Watershed Morphometry	Value
Area	44,38 Km^2
center of gravity	X=533,258.7636
	Y=51,252.9415
Gradient	18,3 %
Length of the main river	11,542 Km
Slope	0,065
The river segment height	Upstream = 850 (m)
	outlet = 100 (m)

Source: process results with ArcGis software

3.5. River Hydrological Modeling With HEC HMS

The hydrological modeling process of the Taludaa watershed using HEC HMS as shown in Figure 4.



Date	Time	Precip (mm)	Loss (mm)	Excess (mm)	Flow (M^3/s)
03-Aug-19	04:00	0.00	0.00	0.00	0.00
03-Aug-19	05:00	0.00	0.00	0.00	0.00
03-Aug-19	06:00	5.00	5.00	0.00	0.00
03-Aug-19	07:00	30.00	14.37	15.63	37.9
03-Aug-19	08:00	10.00	1.96	8.04	60.5
03-Aug-19	09:00	6.00	0.92	5.08	47.2
03-Aug-19	10:00	0.00	0.00	0.00	25.1
03-Aug-19	11:00	0.00	0.00	0.00	8.50
03-Aug-19	12:00	0.00	0.00	0.00	2.90
03-Aug-19	13:00	0.00	0.00	0.00	1.00
03-Aug-19	14:00	0.00	0.00	0.00	0.30
03-Aug-19	15:00	0.00	0.00	0.00	0.10
03-Aug-19	16:00	0.00	0.00	0.00	0.00
03-Aug-19	17:00	0.00	0.00	0.00	0.00
03-Aug-19	18:00	0.00	0.00	0.00	0.00
03-Aug-19	19:00	0.00	0.00	0.00	0.00
03-Aug-19	20:00	0.00	0.00	0.00	0.00

Figure 4. hydrological modeling of the Taludaa watershed in HEC HMS with time series gage precipitation and discharge on 03 Aug 2019.

the results of the HEC HMS process using the input of DAS parameters as in Table 3, obtained the comparison hydrograph results as shown in Fig. 5.

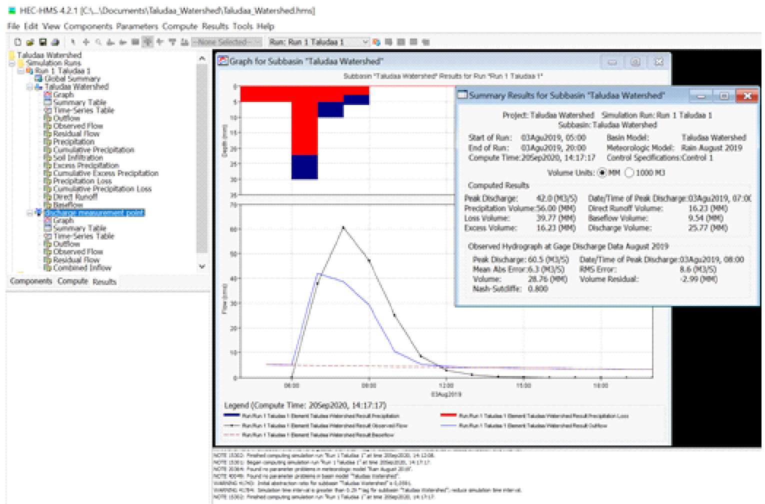


Figure 5. the results of the simulation process HEC-HMS hydrograph comparison of the outflow with the observed flow.

In figure 5, it appears that there is still a difference between the model hydrograph and the observation hydrograph, so it is necessary to calibrate.

The calibration process through optimization of watershed parameters, is done by changing the values of Initial abstraction, Curve Number, Recession Constant, and Initial Discharge.

The result of calibration process with HEC-HMS as figure 6, seen in figure number 5 of the modeling hydrograph is almost the same as the observation hydrograph with a difference in flow volume value = 6.63 mm and peak flow = -0.2 m^3/s. Based on the results of the calibration, the hydrological model in Taludaa Watershed is declared acceptable, with the value of the das parameter changes being Ia=18, TL=60, CN=40.63 and Rc=0.07.
To analyze river discharge time series, precipitation input gage rain data is changed with time series data on Taludaa region rain. The results of the hydrological model show the Taludaa river discharge hydrograph all the time with the June – September 2019 rain data time series, as shown in Fig. 7.

Time series of river discharge data resulting from the simulation process of hydrological models at Taludaa Watershed will be used to determine the river's flagship discharge using the Flow Duration Curve (FDC) method. The model simulation process discharge data is presented on the attachment.

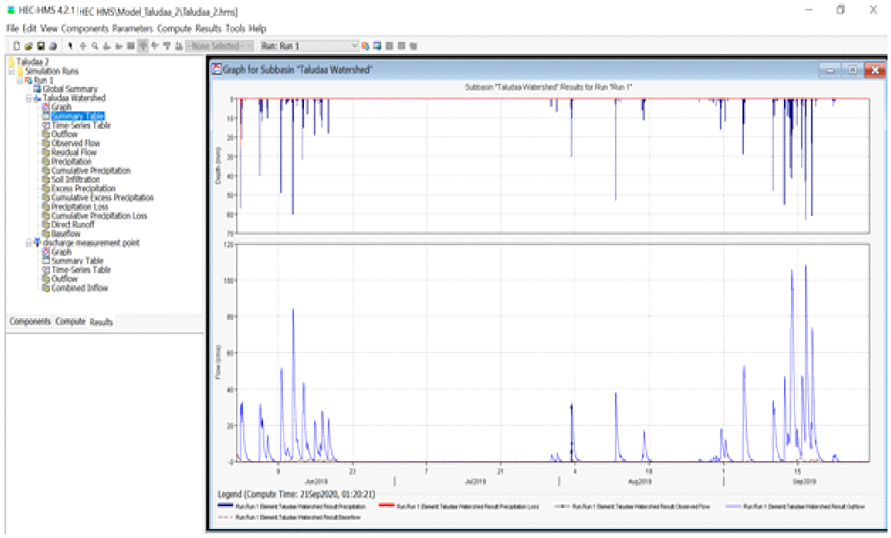


Figure 7. Taludaa River discharge hydrograph with June-September 2019 rain data time series, HEC- HMS process.

3.6. Determination Reliable River Discharge

To determine the mainstay river discharge using the flow duration curve (FDC) method by setting the frequency of achievement that is fulfilled as a river discharge potential of 90%. The results of river flow analysis using the FDC method, based on river discharge data from the simulation results of the HEC HMS model, obtained a reliable river discharge value of 10.1 m^3/s as shown in Fig. 8.

3.7. Potential Energy of Electric Power

The electrical power on Taludaa River can be estimated through the river discharge variables and the falling water height (head) values. The resulted electrical power is then due to the minimum discharge during the whole year that is used to set up the electric generator capacity. Through setting up the generator to its electrical power capacity, the electrical power is derived during the minimum discharge and once the discharge raising.

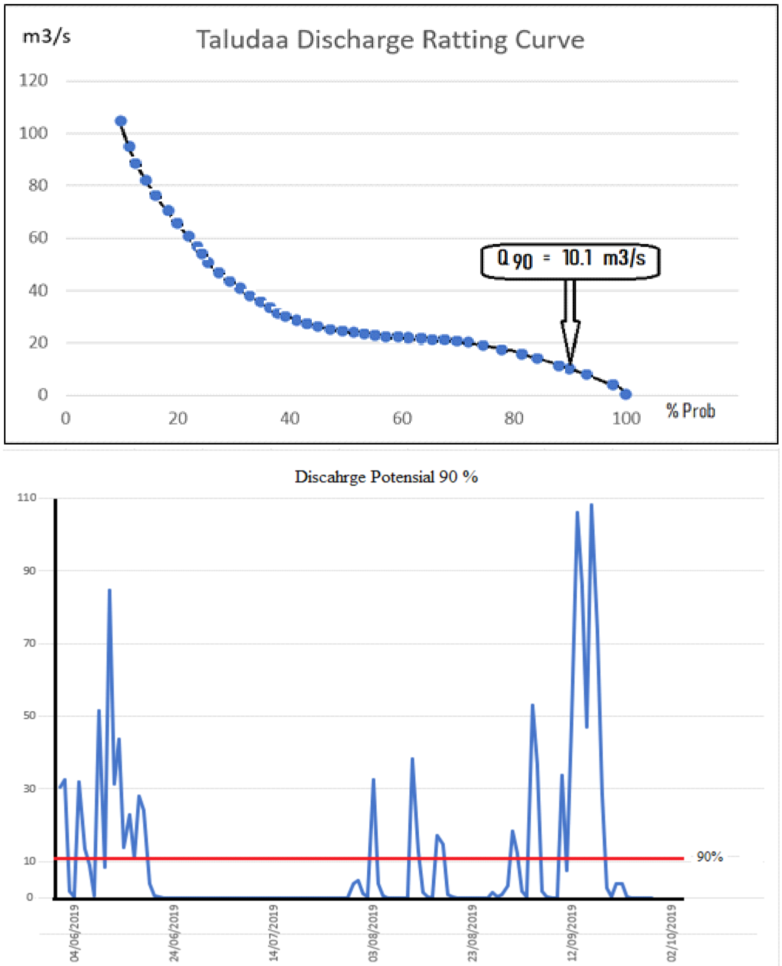


Figure 8. The results of reliable river discharge analysis using the FDC method,
And discharge hydrograph minimum reliable 90%

The height of the Taludaa river waterfall is estimated based on the morphometric conditions of the river was 3.25 m. If the turbine efficiency estimate is 75% then the electrical energy that can be obtained in the Taludaa River is:

$$P = 9.8 \times 10.1 \times 3.25 \times 75\ \% = 241.26\ \text{KW}$$

The micro scale of hydroelectric power plant is extendible through extending the falling water height (head). Therefore, the higher of the falling water, the greater power resulted by the micro scale of hydroelectric power plant power.

IV. CONCLUSIONS

Based on the previous results and discussions, following are some concluding remarks drawn in this study:

- The transformation of Soil Conservation Service – Curve Number (SCS-CN) model is the model applied to analyses river flow discharge in Taludaa Watershed. The maximum potential water retention (S) is bearded to derive the initial abstraction (Ia) or the water loss before runoff. The time gap between the rainfall peak and hydrograph peak is determined by Time Lag (TL). some results i.e. CN=40.63, Ia=18, Rc=0.07, and TL= 60 minutes.

- the application of river flow analysis models as a function of rain input and watershed system parameters, produces hydrographs of river discharge over time with a reliable river discharge 10.1 m^3/sec. electrical power generated in the flow of the river is 241.26 KW.
- The river flow discharge estimation with Conservation Service – Curve Number (SCS-CN) model is applicable for other rivers existed in the province of Gorontalo or other regions in general. The model analysis is applied to a small sub watershed; thus, the resulted model is then carried to analyses other rivers' flow within the watershed area. Precipitation data which is the rainfall in the area and the measured field discharge are the main components in the model analysis. Moreover, in order to gain the closest runoff so that is similar to the field condition, the watershed morphometry and its characteristics that are occupied as input parameters in the runoff analysis process are necessarily to be accurately analyzed.

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