# HEC-HMS MODELING OF TALOMO RIVER BASIN USING SYNTHETIC APERTURE RADAR

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**KEYWORDS:** Synthetic Aperture Radar, River basin modeling, HEC-HMS Modeling, Automated Water Level Station (AWLS), Rainfall Intensity-Duration Frequency (RIDF)

**ABSTRACT:** The best hydrological model is the one which gives results close to reality with the use of least parameters and model complexity. However, it is important to note that models are mainly used for predicting system behavior and understanding various hydrological processes. In this paper, the Talomo river basin model was generated using Synthetic Aperture Radar (SAR) data as input to HEC-HMS Model. The objective of this study is to generate a rainfall-runoff model of Talomo Watershed; specifically, this aims (i) to generate Talomo basin model using SAR; (ii) to calibrate the rainfall-runoff model; (iii) to compare observed flow against the outflow from the calibrated model; and (iv) to perform sensitivity analysis using Rainfall Intensity-Duration Frequency (RIDF). The result shows that the generated Talomo river basin HEC-HMS model consisted of 71 sub basins, 35 reaches, and 35 junctions. Adjusted values of model parameters such as initial abstraction, curve number, time of concentration, storage coefficient, recession constant, and ratio to peak were generated using the built-in search method of HEC-HMS. After comparing the observed and simulated flow values, the calibrated model attained good performance rating based on Root Mean Square Error (RMSE). The model also demonstrated change in the behavior of the runoff for 5, 25, and 100-year RIDF.

## 1. INTRODUCTION

About 20 typhoons visit the Philippines yearly. These have consistently resulted in widespread flood, deaths, and destruction across the country which ultimately set back progress and national development. This era of a changing environment is a harbinger of worse situations that are to come. Typhoons and floods are expected to increase in number and intensity, exposing island-states like the Philippines to further vulnerability (DREAM, 2012).

The Federal Emergency Management Agency (FEMA) of the United States emphasized the benefits of having hydrological models to create accurate flood maps. These benefits are the following: (i) reduced loss of life, (ii) reduced loss of property, (iii) reduced loss of business, (iv) preservation of natural functions of floodplains, and (v) resource deployment (Federal Emergency Management Agency, 2009). With the given benefits of having accurate hydrological models, people residing in or near the flood prone area will be informed ahead of time. Though flooding cannot be prevented, the awareness of communities especially those residing in the flood prone areas is an essential tool for preparation and mitigation of possible casualty and damages.

In the study of Zhang (2005), he emphasized on the hydrological models which are important and necessary tools for water and environmental resources management. The later believes that the demands from society on the predictive capabilities of such models are becoming higher and higher, leading to the need of enhancing new theories.

The main objective of this paper is to generate a rainfall-runoff model for Talomo Watershed; specifically, (i) to generate Talomo basin model using SAR data; (ii) to calibrate the rainfall-runoff model; (iii) to compare observed flow against the outflow from the calibrated model; and (iv) to perform sensitivity analysis using Rainfall Intensity-Duration Frequency (RIDF). The hydrologic computer model HEC-HMS (U. S. Army Corps of Engineers, Hydrologic Engineering Center – Hydrologic Modeling System, Version 2.2.1) was used to perform the rainfall-runoff analysis. HEC-HMS is a physically based storm event simulation model capable of simulating runoff from various land uses and soil types, combining subbasin hydrographs, and routing flow through storage and conveyance facilities (Dietz, 2003).

## 2. METHODOLOGY

Using Synthetic Aperture Radar (SAR) and the river centerline, subbasins and river channels of Talomo watershed were generated using the GeoHMS toolbar in ArcMap, thus obtaining Talomo Basin Model. This basin model is then calibrated using HEC-HMS and hydrometric data that was previously gathered to produce the corrected rainfall runoff model. In this process, parameters like Initial Abstraction, Curve Number, Time of Concentration, Initial Discharge, Ratio to Peak, Slope, and Manning's n are adjusted, then the observed flow against the outflow from the calibrated model were compared using Pearson R, RMSE, NSE, PBIAS and RSR.. This process is iteratively done until the performance rating of the model attains at least a satisfactory rating or a higher rating. After calibration, hypothetical scenarios are then simulated to conduct sensitivity analysis (Fig.1).

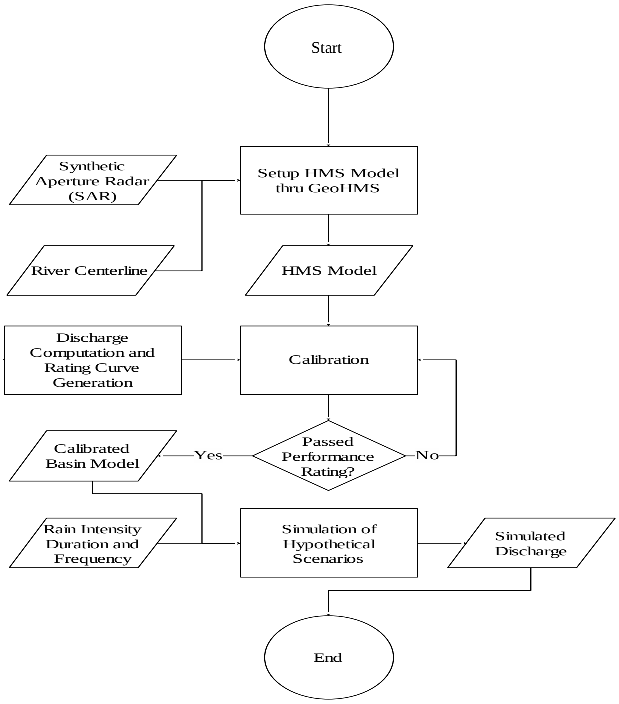


Figure 1: Methodology of HEC-HMS Modeling for Talomo River Basin

## 3. RESULTS AND DISCUSSIONS

Presented in this part are the following: (i) generated Talomo basin model using SAR; (ii) calibrated rainfall-runoff model; (iii) Comparison of observed flow against the outflow from the calibrated model; and (iv) sensitivity analysis using Rainfall Intensity-Duration Frequency (RIDF).

### 3.1 Generated Talomo Basin Model Using SAR Data

#### 3.1.1 Preprocessing of the Basin Model using HEC-GeoHMS

The feathered DEM and the river centerline were loaded in ArcMap 10.2.2. Under the HEC-GeoHMS toolbar were five major processes that will use the prevailing data and produce another sets of records, these are: (i) Terrain Preprocessing, which processes, analyzes, and derives the drainage network of the terrain; (ii) Project Setup, which extracts the terrain information of Talomo; (iii) Stream and Subbasin Characteristics, which extracts the topographic characteristics of streams and subbasins of Talomo watershed, (iv) Hydrologic Parameters Estimation, which assists in estimating the curve number of the Talomo watershed with the help of the available soil data and CN lookup table, and (v) Hydrologic Modeling System, which develops the hydrologic inputs for HEC-HMS (DREAM, 2011).

#### 3.1.2 Generating the Basin Model

Using HEC-HMS, hydrologic inputs that were previously generated using HEC-GeoHMS and ArcMap 10.2.2 were imported. After importing, creation of Meteorological Model, as well as Control Specification and Time Series Data for Precipitation and Discharge Gases were done. The values for Initial Abstraction under Curve Number Loss were solved using equation 1 where the value for the curve number can be derived from the generated attributes table of the preprocessed basin model. With the attributes table of the preprocessed basin model, values for Time of

Concentration and Storage Coefficient were also obtained. Under the Baseflow Recession, the Initial Discharge Column was populated with values using equation 2 while the Ratio to Peek column has a constant value of 0.5 and Recession Constant column has 1. For the Muskingum Cunge Channel Routing, the column for Width, Side-Slope, and Manning's n were populated with 30, 45, and the computed manning of Talomo River respectively. After supplying all the necessary data, calibration was set to start (DREAM, 2011).

$$IA = 0.05 \times \left( \left( \frac{25400}{CURVE\ NUMBER} \right) - 254 \right) \quad [1]$$

$$Initial\ Discharge = \frac{Area\ of\ the\ Specific\ Subbasin \times Baseflow}{Total\ Area\ of\ the\ Watershed} \quad [2]$$

The generated Talomo basin model consisted of 71 subbasins, 35 reaches, and 35 junctions. This basin model is illustrated in Figure 2. The Talomo river basins were identified based on soil and land cover characteristics of the area. The soil shape file was taken on 2004 from the Bureau of Soils; this is under the Department of Environment and Natural Resources Management. The soil map of the Talomo River Basin was used for the estimation of the CN parameter. The land cover shape file is from the National Mapping and Resource information Authority (NAMRIA). The Talomo river basin model was generated using Synthetic Aperture Radar (SAR). Precipitation was taken from Department of Science and Technology (DOST) rain gauges. Finally, it was calibrated using data from the Mahayahay Bridge and Nanaga Bridge Automated Water Level Station (AWLS).

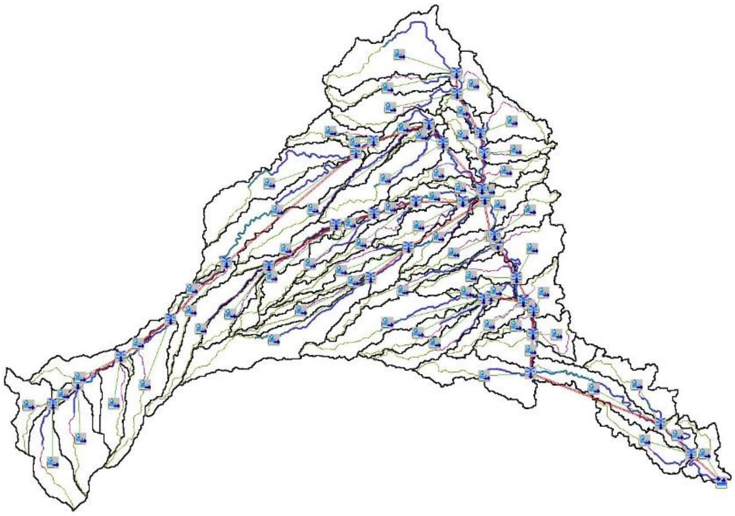

Figure 2: Generated Talomo Basin Model Using SAR

### 3.2 Calibrated Rainfall-Runoff Model

During the calibration, different configurations of model parameters were made which resulted to different behaviors of the hydrograph. The trial-and error method was initially used in the manual calibration of the model such as multiplying the values of subbasins by a factor for a specific parameter. In this method, it was observed that adjusting the initial abstraction ( Ia = 0.05*S) has an inverse correlation to the magnitude of the hydrograph. When the amount of precipitation absorbed by the watershed before the surface runoff increases, the simulated river outflow decreases. The curve number (CN) which must have Land Cover and Soil Type shapefile estimates the rainfall excess of the subbasin that gives positive correlation to the magnitude of the hydrograph. As it is lowered, the river outflow increases. The time of concentration (TC) used the Kirpich method for grassy Earth (Mountain) and uses the equation 3 where L is the length of river in the basin and S is the slope of the basin.

$$TC = \frac{.00032L^{0.77}}{S^{0.385}} \quad [3]$$

TC approximates the amount of time it takes for the runoff to travel from the farthest location to the river. When it is increased, its effect delays the peak outflow of the hydrograph. The storage coefficient which measures the volume of the runoff is temporarily stored in the subbasin. As it becomes higher, this also delays the peak outflow of the hydrograph. This lowers the magnitude of the hydrograph and expands. The recession constant slows down the rate of the flow receding before and after the storm events as it is increased. Lastly, the receding limb of the hydrograph is adjusted when the ratio to peak is also adjusted. Meanwhile, for the automated calibration, the built-in search method which is the univariate gradient of HEC-HMS was used and the objective function for the search method was peak-weighted RMS Error. Presented in Table 1 is the calibrated rainfall-run-off model parameters of Talomo river basin which gives the closest amount of discharge compared to the actual observe outflow.

Table 1. Talomo Basin Calibrated Rainfall-Runoff Model Parameters

| Basin Number | SCS Curve Number Loss | | Clark Unit Hydrograph Transform | | Recession Baseflow | |
|---|---|---|---|---|---|---|
| | Initial Abstraction (mm) | Curve Number | Time of Concentration (HR) | Storage Coefficient (HR) | Recession Constant | Ratio to Peak |
| W1000 | 4.0218 | 99 | 0.046724 | 0.0457512 | 0.0065334 | 0.5047 |
| W1010 | 7.4379 | 45.723 | 0.035392 | 0.0346548 | 0.0100985 | 0.49 |
| W1020 | 9.4434 | 66.292 | 0.048278 | 0.047274 | 0.0100984 | 0.33333 |
| W1030 | 2.3662 | 90.519 | 0.041036 | 0.040182 | 0.01 | 0.5 |
| W1040 | 5.2978 | 99 | 0.02 | 0.024 | 0.01 | 0.5 |
| W1050 | 5.2978 | 99 | 0.02 | 0.024 | 0.0100957 | 0.5 |
| W1060 | 4.9292 | 86.693 | 0.0352564 | 0.0345228 | 0.01 | 0.5 |
| W1070 | 3.7768 | 82.858 | 0.055066 | 0.0539208 | 0.01 | 0.5 |
| W1080 | 3.9317 | 81.34 | 0.044682 | 0.043752 | 0.0100956 | 0.5 |
| W1090 | 4.0936 | 80.606 | 0.048812 | 0.047796 | 0.0044445 | 0.4802 |
| W1100 | 2.3779 | 81.634 | 0.045406 | 0.0444612 | 0.0044445 | 0.5 |
| W1110 | 10.239 | 62.609 | 0.048796 | 0.0477816 | 0.0044445 | 0.5 |
| W1120 | 9.9142 | 64.292 | 0.034198 | 0.0334872 | 0.0044445 | 0.32667 |
| W1130 | 16.364 | 61.001 | 0.070236 | 0.0687748 | 0.0044445 | 0.4802 |
| W1140 | 14.289 | 65.332 | 0.044242 | 0.0433212 | 0.0044445 | 0.5 |
| W1150 | 4.3577 | 83.365 | 0.036556 | 0.035796 | 0.0044445 | 0.5 |
| W1160 | 7.0033 | 52.441 | 0.040624 | 0.0397788 | 0.0044445 | 0.32667 |
| W1170 | 9.4899 | 73.569 | 0.061724 | 0.0604404 | 0.0044445 | 0.49 |
| W1180 | 3.664 | 81.634 | 0.024358 | 0.024 | 0.0044445 | 0.4802 |
| W1190 | 2.3781 | 81.634 | 0.03325 | 0.0325584 | 0.0044445 | 0.49236 |
| W1200 | 4.5875 | 84.188 | 0.02 | 0.024 | 0.0044445 | 0.49243 |
| W1210 | 5.6156 | 80.944 | 0.048664 | 0.0476532 | 0.0044445 | 0.49241 |
| W1220 | 3.519 | 84.586 | 0.042612 | 0.0417264 | 0.0044445 | 0.75 |
| W1230 | 3.4466 | 84.81 | 0.040112 | 0.0392772 | 0.0044445 | 0.4802 |
| W1240 | 3.7836 | 81.634 | 0.03558 | 0.0348396 | 0.0044445 | 0.49 |
| W1250 | 5.2978 | 81.634 | 0.02 | 0.024 | 0.0098 | 0.575 |
| W1260 | 7.875 | 81.634 | 0.030666 | 0.0300276 | 0.0097508 | 0.5 |
| W1270 | 19.726 | 49.128 | 0.044628 | 0.0437006 | 0.0044445 | 0.49244 |
| W1280 | 16.212 | 54.024 | 0.059002 | 0.0577752 | 0.0044445 | 0.5 |
| W1290 | 4.0272 | 76.832 | 0.059738 | 0.0584964 | 0.0044445 | 0.5 |
| W1300 | 6.0297 | 76.832 | 0.04072 | 0.0398736 | 0.0044445 | 0.5 |
| W1310 | 14.366 | 57.009 | 0.040834 | 0.0399852 | 0.0044445 | 0.5 |
| W1320 | 13.482 | 58.559 | 0.032964 | 0.0322788 | 0.0044445 | 0.49225 |
| W1330 | 4.0397 | 76.832 | 0.038918 | 0.0381096 | 0.0065334 | 0.735 |
| W1340 | 15 | 78.4 | 0.064308 | 0.06297 | 0.0044445 | 0.735 |
| W1350 | 15.586 | 55 | 0.02 | 0.024 | 0.0044445 | 0.49241 |
| W1360 | 15.586 | 55 | 0.033468 | 0.0327708 | 0.0044445 | 0.49242 |
| W1370 | 15 | 78.4 | 0.04976 | 0.0487248 | 0.0044445 | 0.735 |
| W1380 | 15.586 | 55 | 0.03081 | 0.030168 | 0.0044445 | 0.49244 |
| W1390 | 15.586 | 55 | 0.037904 | 0.037116 | 0.0044445 | 0.50243 |
| W1400 | 6.7 | 72.03 | 0.032202 | 0.0315324 | 0.0098451 | 0.75 |
| W1410 | 6.6996 | 72.03 | 0.056462 | 0.0552876 | 0.0147 | 0.5 |
| W1420 | 6.5334 | 99 | 0.051818 | 0.0507396 | 0.009604 | 0.50132 |
| W720 | 2.6293 | 86.086 | 0.05684 | 0.0556572 | 0.0066981 | 0.50238 |
| W730 | 2.0881 | 65.878 | 0.045044 | 0.0441072 | 0.0100975 | 0.48901 |
| W740 | 2.3692 | 87.209 | 0.041434 | 0.040572 | 0.0100958 | 0.48446 |
| W750 | 3.5311 | 87.203 | 0.046414 | 0.0454488 | 0.0100978 | 0.48882 |
| W760 | 5.1576 | 58.317 | 0.033088 | 0.0324 | 0.0100799 | 0.4802 |
| W770 | 2.378 | 58.146 | 0.047046 | 0.046068 | 0.0100563 | 0.49 |
| W780 | 3.514 | 89.049 | 0.029312 | 0.0287016 | 0.0065334 | 0.4802 |
| W790 | 5.127 | 37.683 | 0.069848 | 0.068394 | 0.0098474 | 0.4802 |
| W800 | 2.1963 | 86.2 | 0.070008 | 0.0685512 | 0.0098474 | 0.49 |
| W810 | 6.2469 | 84.985 | 0.058538 | 0.0573204 | 0.0098476 | 0.49259 |
| W820 | 3.3961 | 55.499 | 0.030356 | 0.029724 | 0.0095363 | 0.735 |
| W830 | 2.0685 | 99 | 0.15796 | 7.5333 | 0.0044445 | 0.4802 |
| W840 | 3.5036 | 56.694 | 0.02 | 0.024 | 0.0150738 | 0.50245 |
| W850 | 4.0681 | 79.158 | 0.052126 | 0.051042 | 0.00882 | 0.49242 |
| W860 | 6.9489 | 61.67 | 0.057378 | 0.056184 | 0.00882 | 0.52988 |
| W870 | 2.3075 | 92.199 | 0.040028 | 0.0391944 | 0.0065334 | 0.49244 |
| W880 | 2.3097 | 85.476 | 0.033172 | 0.0324816 | 0.0100969 | 0.5 |
| W890 | 2.4218 | 99 | 0.047244 | 0.0462612 | 0.0044445 | 0.50199 |
| W900 | 2.3004 | 99 | 0.02 | 0.024 | 0.0066962 | 0.32667 |
| W910 | 1.8613 | 89.82 | 0.024474 | 0.024 | 0.0066667 | 0.32667 |
| W920 | 2.2614 | 89 | 0.026524 | 0.0259716 | 0.015072 | 0.49 |
| W930 | 2.3659 | 85.466 | 0.048272 | 0.0472668 | 0.0044445 | 0.33333 |
| W940 | 2.2614 | 99 | 0.02 | 0.024 | 0.00882 | 0.48736 |
| W950 | 3.3777 | 89.012 | 0.04466 | 0.0437316 | 0.0066993 | 0.32667 |
| W960 | 3.0731 | 89.892 | 0.021528 | 0.024 | 0.015062 | 0.735 |
| W970 | 2.4889 | 83.659 | 0.037458 | 0.036678 | 0.0099832 | 0.49239 |
| W980 | 3.2267 | 83.816 | 0.046482 | 0.045516 | 0.0098374 | 0.49242 |
| W990 | 3.8046 | 99 | 0.022738 | 0.024 | 0.0098469 | 0.49216 |

### 3.3 Comparison of Observed Flow against the Outflow from the Calibrated Model

After calibrating the Talomo HEC-HMS river basin model, its accuracy was measured against the observed values. Figure 3 shows the comparison between the two discharge data which are the Outflow Hydrograph of Talomo produced by the HEC-HMS model and the observed outflow which is the data gathered from the conduct of hydrological measurements in the field. The Root Mean Square Error (RMSE) method aggregates the individual differences of these two measurements. In addition, RMSE value approaching 0 indicated that the model have a better fit. In this model, it was identified at **3.47608**.

The Pearson correlation coefficient ($r^2$) assesses the strength of the linear relationship between the observations and the model. This value being close to 1 corresponds to an almost perfect match of the observed discharge and the resulting discharge from the HEC HMS model. Here, it measured **0.521298096**.

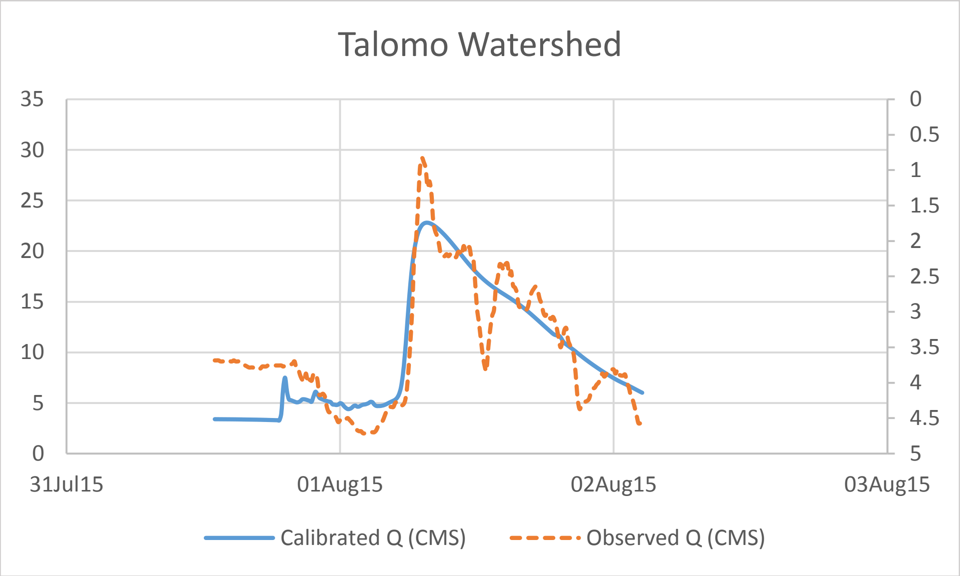


Figure 3. Outflow Hydrograph of Talomo produced by the HEC-HMS model compared with observed outflow.

Presented in Table 2 is the performance rating of the calibrated Talomo basin model. The Nash-Sutcliffe (E) or NSE method was also used to assess the predictive power of the model. Here the optimal value is 1. The model attained an efficiency coefficient of **0.728248295**. A positive Percent Bias (PBIAS) indicates a model's propensity towards under-prediction. Negative values indicate bias towards over-prediction. Again, the optimal value is 0. In the model, the PBIAS is **5.316375907**. The Observation Standard Deviation Ratio, RSR, is an error index. A perfect model attains a value of 0 when the error in the units of the valuable is quantified. The model has an RSR value of **0.521298096**.

Table 2. Performance Rating of the Calibrated Talomo Basin Model

| | | |
|---|---|---|
| NSE | 0.728248295 | Good |
| PBIAS | 5.316375907 | Very Good |
| RSR | 0.521298096 | Good |

### 3.4 Sensitivity Analysis using Rainfall Intensity-Duration Frequency (RIDF)

The simulation of hypothetical scenarios of Talomo HECHMS model outflow used the Davao Rainfall Intensity-Duration-Frequency curves (RIDF) in 3 different return periods (5-year, 25-year, and 100-year rainfall time series) and is based on the Philippine Atmospheric Geophysical and Astronomical Services Administration (PAG-ASA) data. The simulation results indicated significant increase in outflow magnitude as the rainfall intensity increases for a range of durations and return periods.

### 3.4.1 Talomo 5-Year RIDF Hydrograph

In the 5-year return period graph (Fig. 11), the peak outflow is 1442.7 cms. This occurs after 17 hours and 10 minutes and the peak precipitation is 25.1 mm.

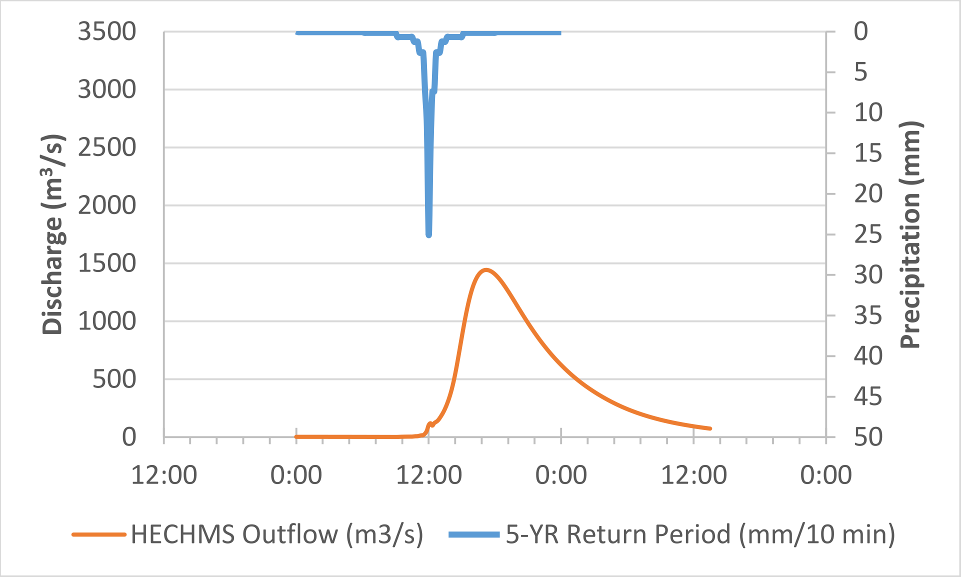


Figure 11. Outflow Hydrographs generated using Davao 5-Year RIDF Data entered in HEC-HMS.

### 3.4.1 Talomo 25-Year RIDF Hydrograph

In the 25-year return period graph (Fig. 12), the peak outflow is 2304.8 cms. This occurs after 16 hours and 50 minutes and the peak precipitation is 33.5 mm.

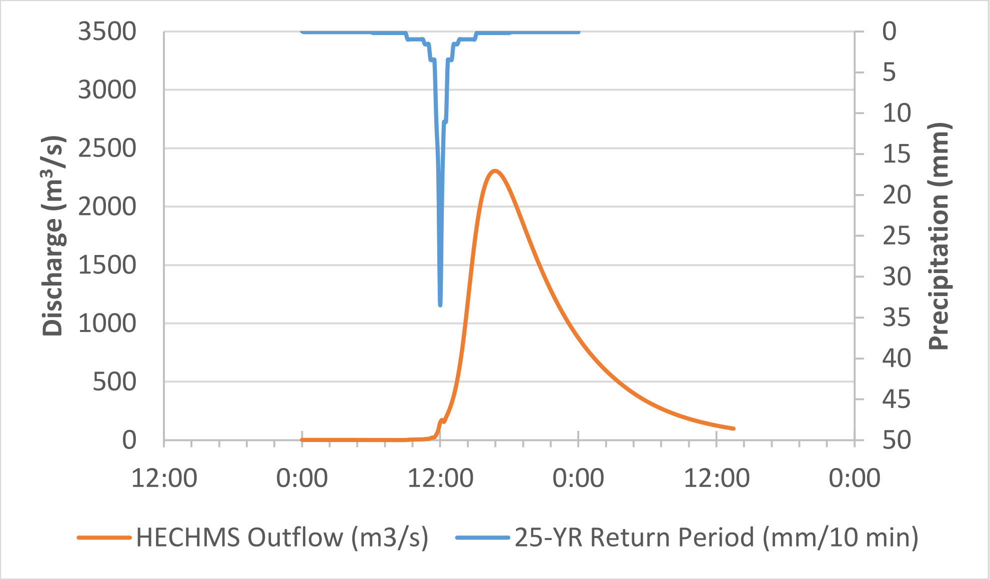


Figure 12. Outflow hydrographs generated using Davao 25-Year RIDF data entered in HEC-HMS.

### 3.4.1 Talomo 100-Year RIDF Hydrograph

In the 100-year return period graph (Fig. 13), the peak outflow is 3070.5 cms. This occurs after 16 hours and 30 minutes and the peak precipitation is 40.5 mm.

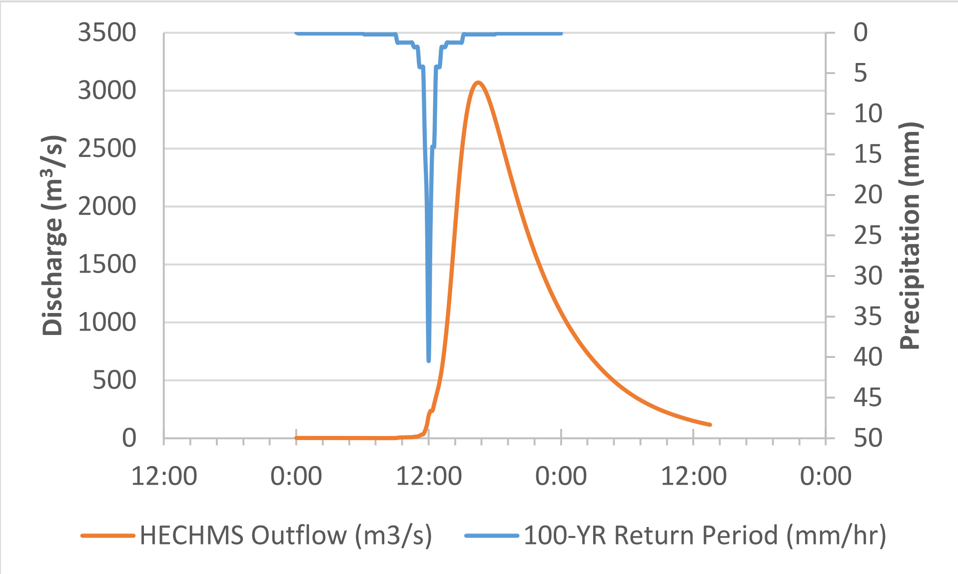


Figure 13. Outflow hydrographs generated using Davao 100-Year RIDF data entered in HEC-HMS.

A summary of the total precipitation, peak rainfall, peak outflow and time to peak of the Lipadas discharge using the Davao Rainfall Intensity-Duration-Frequency curves (RIDF) in three different return periods is shown in Table 3. It was revealed that as the rainfall intensity increases, the peak outflow also increases and the amount of time the peak outflow to occur decreases.

**Table 3. Peak values of the Talomo HECHMS Model outflow using the Davao RIDF**

| RIDF Period | Duration (hr) | Total Precipitation (mm) | Peak rainfall (mm) | Peak outflow ($m^3/s$) | Time to Peak |
|---|---|---|---|---|---|
| 5-Year | 24 | 114.9 | 25.1 | 1442.7 | 17 hours, 10 minutes |
| 25-Year | 24 | 158.5 | 33.5 | 2304.8 | 16 hours, 50 minutes |
| 100-Year | 24 | 194.4 | 40.5 | 3070.5 | 16 hours, 30 minutes |

## 4. SUMMARY AND CONCLUSION

A hydrologic analysis of the Talomo watershed was completed using the hydrologic computer model HEC-HMS. The Talomo river basin model was generated using Synthetic Aperture Radar (SAR). Precipitation was taken from DOST rain gauges and it was calibrated using data from the Mahayahay Bridge and Nanaga Bridge Automated Water Level Station (AWLS). The rainfall-runoff was calibrated using six parameters and was considered for both automated calibration using the built-in search method of HEC-HMS and manual adjustments of values. After calibrating the Talomo river basin model, its accuracy was measured against the observed values. The simulation of the Talomo river outflow used the calibrated basin parameter. Sensitivity analysis using Rainfall Intensity-Duration Frequency was conducted to determine the magnitude of the river outflow for the 5, 25 and 100 year rain return period. The following conclusions were formed as a result of the hydrologic analysis.

The generated Talomo basin model consisted of 71 sub basins, 35 reaches, and 35 junctions. During the calibration, different configurations of model parameters were made which resulted to different behaviors of the hydrograph but it was able to get the closest amount of discharge when compared to the actual observe outflow. On the comparison of the observed flow against the outflow from the Talomo river calibrated model, the Root Mean Square Error (RMSE) method aggregates the individual differences of these two measurements. Moreover, the Pearson correlation coefficient ($r^2$) was close to 1 which corresponds to an almost perfect match of the observed discharge and the resulting discharge from the HEC HMS model. The NSE method attained an efficient coefficient which is described as Good. The PBIAS which indicates the model's propensity towards under-prediction is described as Very Good. The Observation Standard Deviation Ratio, RSR which is an error index is described as Good. The simulation results indicated significant increase in outflow magnitude as the rainfall intensity increases for a range of durations and return periods.

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