STREAM FLOW SIMULATION FOR AYEYARWADDY BASIN

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Abstract - This paper presents stream flow simulation for Ayeyarwaddy basin and rainfall-runoff model which has been widely used to formulate a reliable relationship between the precipitation (input of the model) and runoff (output of the model). In the rainfall-runoff model, terrains processing of watershed delineation and basin characteristics (basin slope, longest flow length, etc.) of Ayeyarwaddy basin are processed in HEC-GeoHMS which is extension to ArcGIS. Curve number grid map for study area is developed by using soil map, land use map (2014), CN lookup table and filled DEM in utility tool of HEC-Geo HMS. Transformed and loss methods are defined by SCS-CN method. Base flow is estimated by Recession model and channel routing which is calculated by Muskingum method. The daily rainfall for fifteen years record, base-flow data, land use data and soil data are used to simulate runoff and calibration process in HEC-HMS model. Peak discharge and volume of the values in model are 124193.6 m^3/sec and 3761.34 mm in respectively which are simulated results in Pyay (outlet). The calibration process in Pyay (outlet), the difference in volume percent is 28% and that of peak flow is 15.81%. After simulating the hydrological model, streamflow rate for Ayeyarwaddy basin is obtained.

Keywords - Channel Routing, HEC-GeoHMS, HEC-HMS, Recession Model, SCS-CN, Stream Flow.

I. INTRODUCTION

Nowadays, the digital simulation of runoff is widely used to assist in the solution of hydrologic problems. Simulation is a commonly used and practical technique for modeling and analyzing the real operating systems in order to make more effective decisions. The use of a hydrological model to simulate the stream flow plays a fundamental role in this study. Hydrological models are significant instruments for water resource managements, development and future planning. Therefore, many models have been applied to hydrological modeling and water resources management. Among them, HEC-HMS model is used in this study. HEC-HMS is the US Army Crop of Engineers' Hydrologic Modeling System computer program developed by the Hydrologic Engineering Centre. In this study, ArcGIS software is used for creating contour layer and digital elevation model, HEC-Geo HMS is used for delineating watershed and calculating hydrologic parameters, HEC-HMS is used for software for simulation and calibration process of the surface runoff. The main objective of this paper is to simulate the stream flow in Ayeyarwaddy Basin.

II. DESCRIPTION OF THE STUDY AREA

The Ayeyarwaddy river is the largest river in Myanmar and it arises from the confluence of the May-Kha and Mali-Kha rivers. It is running through the centre of the country and the most important commercial waterway in Myanmar (about 1350 miles or 2170 km) long. In this study, research area in Ayeyarwaddy basin is started from May-Kha and Mali-Kha and terminated in Pyay (outlet). Study Area is about 363280 sq km and lie between north latitude 20° 22' and 28° 31' and east longitude 94° 56' and 98° 45'. It is covered by Kachin State, Mandalay Division, Sagaing Division and Shan State and Bago Division. The location of study area is shown in Figure 1.

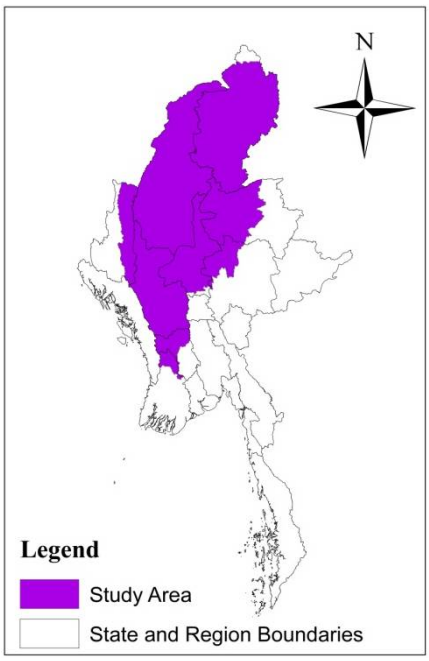


Figure. 1 Study area for Ayeyarwaddy basin

III. METHODOLOGY

Numerous hydrologic models to simulate the stream flow namely, Soil and Water Assessment Tool Model (ArcSWAT), Coupled Routing and Excess Storage (CREST), Hydro-informatics Modeling System (HIMS) rainfall–runoff model. Even though these models are helpful in simulation but they have their limitations. Some models cannot perform continuous-time simulations without a consistent scale, some are unable to characterize the watershed with enough spatial detail and some cannot provide an optimized number of sub-watersheds. Among them, HEC-HMS model is helpful in simulation to complete

the process and input required data sets are easy to compute. Nevertheless, many of these models contain parameters with a physical basis and may be estimated from measurable properties of the watershed. These models can be performed very effectively when calibration data is available. In the ungaged case, it is generally accepted that physically-based models are a better choice. Simulation results can be used in conjunction with other software for studies of water availability, urban drainage, flow forecasting, future urbanization impact, reservoir spillway design, flood damage reduction, floodplain regulation, and systems operation.

A. Description of HEC-HMS Model

The Hydrologic Modeling System (HEC-HMS) was designed to simulate the rainfall-runoff processes in a wide variety of watershed types. Water movements in the cycle relevant to common problems in water resources engineering were included: precipitation, infiltration, surface runoff, baseflow, and open channel flow. It is designed to be applicable in a wide range of geographic areas for solving the widest possible range of problems. This includes large river basin water supply and flood hydrology, and small urban or natural watershed runoff. Hydrographs produced by the program are used directly or in conjunction with other software for studies of water availability, urban drainage, flow forecasting, future urbanization impact, reservoir spillway design, flood damage reduction, floodplain regulation, and systems operation.

B. Model Input Data

HEC-HMS model requires hydrological data, background maps (sub-basin and river network), land use map, Soil map, curve number grid map, base flow, routing parameters and 15 years meteorological data (2001-2014) in daily scale. The brief methodology for preparation of the data is described as follows:

1) Hydrologic Parameters Estimation: This estimation includes curve number, catchment lag time, potential maximum retention and initial abstraction.

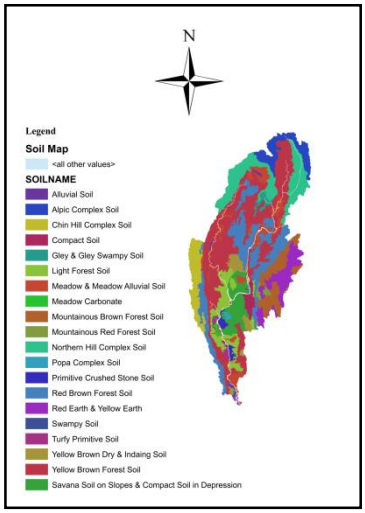


Figure.2 Hydrologic soil map for Ayeyarwaddy basin

2) Soil Map: These four types of hydrologic soil groups and twenty number of soil types are composed in study area. The hydrologic soil map for study area is shown in Figure 2.

3) Land Use Map: To obtain landuse data of Ayeyarwaddy basin, a satellite image of 2014 (LANDSAT -7) was classified by using Google Earth Engine. Five types of land use classes; water body, closed forest, degraded forest, agricultural land and bare land are shown in Figure 3.

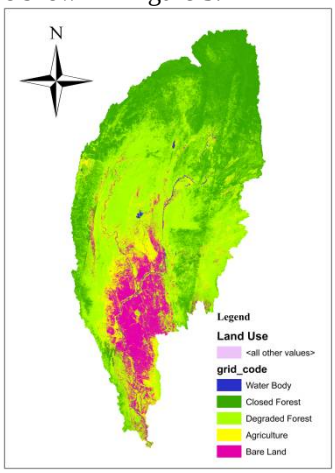


Figure. 3 Landuse map for Ayeyarwaddy basin

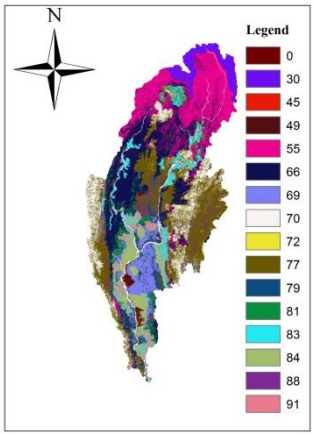


Figure. 4 Curve number grid map for Ayeyarwaddy basin

5) Meteorological Data: The meteorological model calculates the precipitation input required by sub-basin element. In this study, 15 years historical rainfall and discharge records are inputted in meteorological data components.

6) Base Flow by Recession Model: The recession base flow model is applied both at the start of simulation of a storm event, and later in the event as the delayed subsurface flow reaches the watershed channels. The recession constant can be estimated if gagged flow data are available. The recession constant (k=0.954) is used for upper basin which is calculated by using Myitkyina's flow data and another one (k=0.98) is used for lower basin which is also calculated by using Pyay's flow data.

7) Routing Parameters: Muskingum routing method is one of the most popular hydrologic stream routing procedures. In first trial, routing parameters K and X

are assumed to 1 hour and 0.2 for entire basin. By using trial and error in every reach (R_1 to R_{23}) started from R_1, routing parameters constants for Ayeyarwaddy basin are obtained.

C. Model Components

The primary model components are basin models, meteorological models, time series data and control specifications.

1) Basin Model: In basin model, an element uses a mathematical model to describe the physical process. It is composed by the number of sub-basin elements. In this study, the total numbers of sub-basins are forty seven. Hydrologic elements are connected in a dendritic network to simulate runoff processes. In this study, available elements are 47 sub-basins, 23 reaches, 23 junctions and outlet.

2) Meteorological Models: The meteorological model calculates the precipitation input required by sub-basin elements. These required rainfall and discharge data for all sub-basin elements are obtained from Department of Meteorology and Hydrology.

3) Time Series Data: Hydrologic model requires time series of precipitation data for estimating basin average rainfall. Time series data are stored in project as gage. In this study, there are 22 numbers of rainfall stations and 8 number of discharge stations are available.

4) Control specifications: Hydrologic elements are connected in a dendritic network to simulate runoff processes and the time span of a simulation is controlled by control specifications.

D. Input Parameter Values

The values for basin curve numbers, catchment lag time, potential maximum retention and initial abstraction are shown in following Table I.

No	Name	Basin CN	Lag Time (min)	S (mm)	Ia (mm)
1	W480	44.829	292.616	312.599	62.520
2	W490	51.459	225.891	239.600	47.920
3	W500	48.002	165.892	275.149	55.030
4	W510	63.756	96.952	144.394	28.879
5	W520	60.703	101.595	164.430	32.886
6	W530	56.129	139.468	198.533	39.707
7	W540	63.843	145.806	143.849	28.770
8	W550	66.105	86.113	130.238	26.048
9	W560	46.202	151.049	295.759	59.152
10	W570	62.263	134.702	153.945	30.789
11	W580	64.186	106.607	141.725	28.345
12	W590	68.800	153.832	115.188	23.038
13	W600	69.977	79.481	108.974	21.795
14	W610	69.198	108.624	113.063	22.613
15	W620	71.179	79.791	102.846	20.569
16	W630	36.607	181.040	439.864	87.973
17	W640	72.728	115.640	95.245	19.049
18	W650	64.820	196.762	137.853	27.571
19	W660	77.922	71.469	71.968	14.394
20	W670	68.764	71.556	115.378	23.076
21	W680	73.353	55.923	92.272	18.454
22	W690	75.777	83.950	81.193	16.239
23	W700	76.291	27.413	78.938	15.788
24	W710	74.147	146.079	88.561	17.712
25	W720	75.889	124.867	80.701	16.140
26	W730	73.572	55.440	91.239	18.248
27	W740	78.006	51.043	71.618	14.324
28	W750	76.839	74.126	76.560	15.312
29	W760	73.101	117.176	93.467	18.693
30	W770	76.399	40.726	78.465	15.693
31	W780	81.874	50.894	28.988	5.798
32	W790	83.156	45.479	18.500	3.700
33	W800	68.739	27.188	115.514	23.103
34	W810	82.140	93.842	55.227	11.045
35	W820	72.827	37.511	94.770	18.954
36	W830	83.368	72.973	50.674	10.135
37	W840	76.857	80.231	76.486	15.297
38	W850	75.351	77.384	83.090	16.618
39	W860	76.108	67.427	79.734	15.947
40	W870	73.270	75.769	92.664	18.533
41	W880	71.717	114.278	100.172	20.034
42	W890	76.784	60.240	76.799	15.360
43	W900	76.969	84.950	76.004	15.201
44	W910	75.673	60.001	81.656	16.331
45	W920	72.133	70.416	98.127	19.625
46	W930	71.593	63.690	100.782	20.156
47	W940	76.365	106.137	78.611	15.722

TABLE I
Hydrologic Parameters Values of Ayeyarwaddy Basin

IV. SIMULATION RESULTS

Simulation runs are one of three components that can compute results and optimization trials for all hydrologic elements. Simulation results are visualized as graphs, summary tables and time series tables for all hydrologic elements.

A. Muskingum Routing

Channel routing technique has been developed to facilitate this final step in the rainfall-runoff modeling process. The results for value of K and X in reaches connected to junctions are shown in Table II.

Reach Name	Travel Time, K (Hrs)	Weighted Flow, X
R_1	2.5	0.06
R_2	2.25	0.03
R_3	1	0.1
R_4	10	0.15
R_5	7.5	0.025
R_6	6.75	0.01
R_7	7.2	0.04
R_8	10.3	0.07

R_9	8.5	0.025
R_{10}	4.25	0.05
R_{11}	12.5	0.23
R_{20}	3	0.18
R_{21}	7.25	0.23

TABLE II
Routing Parameters For Ayeyarwaddy Basin

B. HEC-HMS Results

The simulation results for all hydrologic elements that are sub-basins, junctions, reaches and outlet are shown in Table III.

Hydrologic Element	Drainage Area (km^2)	Peak Discharge (m^3/s)	Volume (MM)
Subbasin-1	23301.6	11442.4	4318.48
Subbasin-2	17962.6	8504.2	4174.93
J_1	41264.2	19798.9	4255.99
R_1	41264.2	19895.4	4255.78
Subbasin-4	9529.3	9408.6	9909.16
Subbasin-3	6794.1	8789.3	13731.5
J_2	57587.6	37125.8	6309.2
R_2	57587.6	37054	6309.14
Subbasin-7	14931.5	7875.9	4761.05
Subbasin-6	14491	7733.7	4620.49
J3	87010.1	52197.5	5762.24
R3	87010.1	51777.2	5762.42
Subbasin-5	5007	7149.9	15484.11
Subbasin-47	792.43	1433	21634.91
J4	92809.53	60082.1	6422.42
R4	92809.53	59669.2	6422.4
Subbasin-8	5976.4	1128.5	763.77
Subbasin-9	3816.9	764.7	881.02
J5	102602.83	60136.5	5886.65
R5	102602.83	60553.3	5886.63
Subbasin-39	6312.1	1194.3	1840.67
Subbasin-40	4837.6	936.7	1915.9
J20	11149.7	2131	1873.31
R20	11149.7	2054.6	1873.31
Subbasin-42	7007	1355.5	1854.65
Subbasin-41	3647.2	705.5	1886.74
J21	21803.9	4059.6	1869.56
R21	21803.9	3981.8	1869.55
Subbasin-45	8282.5	1653.4	1000.28
Subbasin-44	7731.9	1691.2	1475.14
J22	16014.4	3344.6	1229.55
R22	16014.4	3331.3	1229.64
Subbasin-43	7927.4	1604.8	1383.84
Subbasin-46	567.6	117.8	888.44
J23	46313.3	7518.3	1553.12
R23	46313.3	7434.5	1553.16
Subbasin-10	1443.32	303	931.56
Subbasin-12	272.49	57.6	963.09
J6	150631.94	64859.1	4497.88
R6	150631.94	64999.2	4497.9
Subbasin-38	19713.2	3044.9	937.48
Subbasin-11	1745.34	567.3	1647.51
J7	172090.48	66662.8	4061.14
R7	172090.48	66676.7	4061.36
Subbasin-23	7830.1	7784.9	5455.27
Subbasin-24	6221.7	4974.6	5146.13
J13	14051.8	12302.5	5318.39
R13	14051.8	11817.3	5320.55
Subbasin-26	6782.9	6663.6	5436.05
Subbasin-25	5723.4	6379	5963.1
J14	26558.1	24235.4	5488.52
R14	26558.1	23438.5	5489.17
Subbasin-28	7270.6	5757	4796.14
Subbasin-27	5773.9	6341	5907.14
J15	39602.6	34652.7	5422.88
R15	39602.6	34142.7	5424.74
Subbasin-30	11344.7	10655.7	5303.35
Subbasin-29	3876.7	4449.5	6257.03
J16	54824	46664.1	5458.47
R16	54824	47156.7	5459.07
Subbasin-31	8072.5	2396.6	2328
Subbasin-32	6238.5	6990.1	6197.11
J17	69135	53350.6	5160.07
R17	69135	54289.1	5160.74
Subbasin-35	11858.8	6988.9	3927.15
Subbasin-36	8627.8	9498.8	4800.35
J18	20486.6	13333.7	4294.89
R18	20486.6	13252.3	4295.52
Subbasin-33	4222.2	5158.9	5177.55
Subbasin-34	3881.6	4997.2	6957.44
J19	97725.4	74541.3	5051.45
R19	97725.4	74289.2	5058.91
Subbasin-37	16667.6	4230.4	1772.91
Subbasin-13	2897.2	1640.4	5833.54
J8	289380.68	122403.4	4284.17
R8	289380.68	121904.7	4285.73
Subbasin-15	6926.4	2500	1732.33
Subbasin-14	5739.2	2000	2175.12
J9	302046.28	122117.9	4187.07
R9	302046.28	122772.6	4189.17
Subbasin-17	7993.2	1026.3	550.36
Subbasin-16	5591.3	702.1	875.35
J10	315630.78	123389	4038.31
R10	315630.78	123389.3	4039.31
Subbasin-18	6137.2	779	882.65
Subbasin-19	3955.9	503	888.91
J11	325723.88	124134.7	3941.57
R11	325723.88	123484.2	3943.17
Subbasin-20	6944.5	758.3	924.36
Subbasin-21	4379.4	850.7	1382.65
J12	337047.78	124572.4	3847.71
R12	337047.78	122845.6	3850.16
Subbasin-22	12623.1	2218.7	1389.64
Pyay (Outlet)	349670.88	124193.6	3761.34

TABLE III
Simulation Results of Ayeyarwaddy Basin

V. OPTIMIZATION RESULTS

In this research, Katha, Sagaing, Monywa and Pyay (Outlet) stations were calibrated with simulated and observed values.

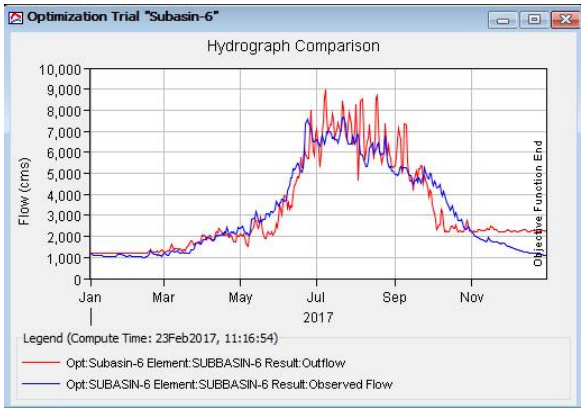


Figure. 5 Hydrograph comparison for simulated and observed flow for Katha Station

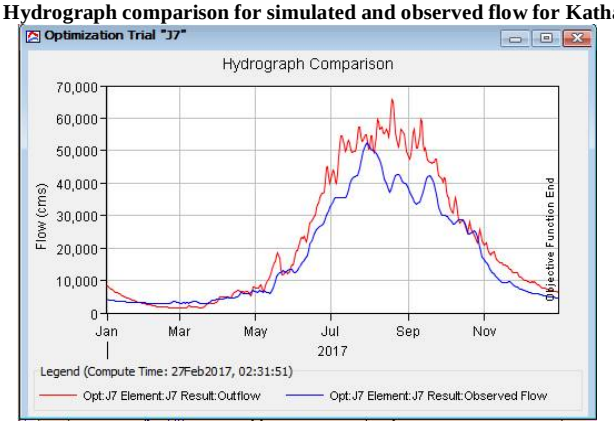


Figure. 6 Hydrograph comparison for simulated and observed flow for Sagaing Station

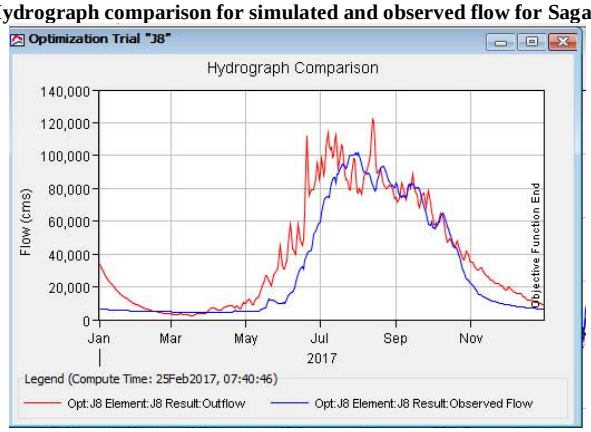


Figure. 7 Hydrograph comparison for simulated and observed flow for Monywa Station

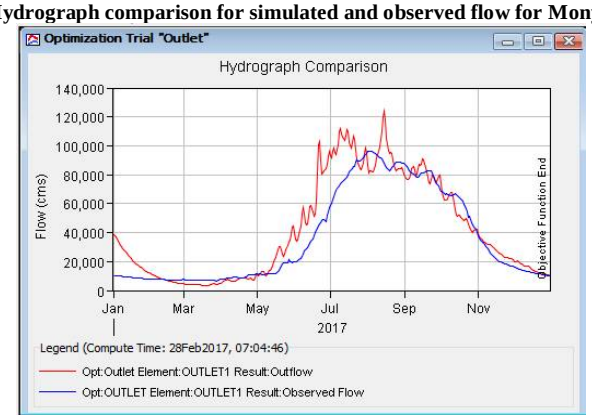


Figure. 8 Hydrograph comparison for simulated and observed flow for Pyay Station

A. Hydrograph Comparison

The optimization results by hydrograph comparison are shown in Figures 5,6, 7 and 8. In this hydrograph, red limb shows the simulated results and the blue limb shows the observed value.

B. Calibration Results

Calibration uses observed hydro meteorological data in a systematic search for parameters that yield the best fit of the computed result to the observed runoff. The optimization Tables are summarized with the value of peak flow and volume in individual element and compare the results of simulated and observed values. In this calibration process, allowable percent limit for discharge is between 25% to negative infinity and for volume is between 35% to negative infinity. So, the computed values are all within in allowable limit. The calibration results of Ayeyarwaddy basin that is percent differences for volume and discharge between simulated and observed values are shown in Table IV and V.

Discharge Stations	Simulated Volume (mm)	Observed Volume (mm)	Difference	Percent Difference
Katha	7125.25	6885.38	239.87	3.48
Sagaing	4061.18	3126.04	845.14	26.28
Monywa	4284.23	3454.89	829.34	24.00
Pyay	3764.34	3250.37	513.97	15.81

TABLE IV
Calibration Results of Ayeyarwaddy Basin

Discharge Stations	Simulated Peak Flow (m^3/sec)	Observed Peak Flow (m^3/sec)	Difference	Percent Difference
Katha	8933.5	7665.9	1267.6	16.50
Sagaing	65809.3	52330.7	13478.6	25.80
Monywa	122273.5	101739.8	20533.7	20.20
Pyay	123536.9	96477.2	27059.7	28.00

TABLE V
Calibration Results of Ayeyarwaddy Basin

DISCUSSION AND CONCLUSION

In this study, stream flow rate for Ayeyarwaddy basin is simulated by HEC-HMS model, with GIS interface HEC-GeoHMS was successfully applied. Simulated values of peak discharge and volume depth at Pyay (outlet) are 123536.9 m^3/sec and 3764.34 mm. Time of peak was occurred in August. After calibration and validation processes, percent differences of volume and that of peak discharge are 15.81% and 28.00% which are within in allowable limit. So, these simulated results in model for Ayeyarwaddy basin are ready to apply. Channel routing has been calculated by Muskingum process and total time duration along the river is 91 hours (about 3 days and 19 hours) to reach outlet along the Ayeyarwaddy river.

ACKNOWLEDGEMENT

First of all, the author wishes to express special thanks to his parents for their kind support and encouragement. The author owes a debt of gratitude to Dr. Nilar Aye, Professor and Head of Department of Civil Engineering, Mandalay Technological University, for her true-line guidance and precious supervision. The author also wishes to acknowledge to Daw Aye Aye Thant, Lecturer, Department of Civil Engineering, Mandalay Technological University. The authors would like to express his heartfelt gratitude to Dr. Kyaw Zayar Htun, Lecturer, Remote Sensing Department, Mandalay Technological University and all teachers for their supports, valuable suggestions and discussions.

REFERENCES

[1] Matthew J. Fleming, James H. Doan: *HEC-GeoHMS Geospatial Hydrologic Modeling Extension User's Manual Version 10.1*, US Army Corps of Engineers, Institute for Water Resources Hydrologic Engineering Center, February, (2013).

[2] Jeongwoo Han: *Streamflow Analysis Using ArcGIS and HEC GeoHMS*, Texas A&M University, Zachry Department of Civil Engineering, December, (2010).

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