JOURNAL OF
ENVIRONMENTAL HYDROLOGY

The Electronic Journal of the International Association for Environmental Hydrology
On the World Wide Web at http://www.hydroweb.com

VOLUME 20 2012

UNCERTAINTY OF RAINFALL CHARACTERISTICS WITH MINIMUM INTER-EVENT TIME DEFINITION FOR A RAINGAUGE STATION IN JOHOR, MALAYSIA

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Monte Carlo simulation (MCS) is a process of replicating the real world based on specified distributional properties. It is a statistical sampling method often utilised to perform risk and uncertainty analysis. In this study 10,000 MCS trials were used to determine the uncertainties for rainfall duration, depth, intensity and storm separation time for a rainfall station in Johor, Southern Malaysia. Simulation results from the study indicate that the mean and standard deviation values of rainfall depth, rainfall duration and rainfall separation time increased as the minimum inter-event time (MIT) increases from 2 hrs to 24 hrs. Similarly, the most likely ranges and most likely percentages also increased as the MIT increased. However, these values were found to remain almost within a constant value for rainfall intensity until an MIT value of 12 hr is reached after which a decline was observed.

INTRODUCTION

Peninsular Malaysia receives heavy rainfall in the east of the peninsula during the northeast monsoon season and in the west of the peninsula during southwest monsoon seasons. Heavy rainfall season occurs from November to March (northeast monsoon) and June to September (southwest monsoon). Furthermore, the peninsula also receives heavy rainfall during a transitional period in April/May and September/October, as the peninsula is located in the Inter-Tropical Convergence Zone (ITCZ). During this period, the ITCZ becomes an area with convective activity of thunderstorms driven by solar heating, and this condition draws air or trade winds to the zone. Rainfall variation range is high; regular and fairly uniform (Malaysia Meteorological Department, 2009). Due to this condition, a good understanding of rainfall characteristics becomes important for the proper design of agricultural systems, runoff and water quality control systems. Intense rainfall of long duration is not uncommon in the peninsula and often becomes disastrous to farmers and settlements near river courses. Typical example is the Kota Tinggi flood which occurred in December 2006 as a result of long duration rainfall of high intensity (Atikah, 2009; Benjamin et al., 2006).

This paper aims to investigate the uncertainty of rainfall duration, depth, intensity and storm separation time, as minimum inter-event time definition changes, using Monte Carlo simulation (MCS). MCS is a process of replicating the real world based on specified distributional properties. The MCS generates samples that preserve the specified distributional properties and provide numerical evaluations of the probabilities. It is a statistical sampling method often utilised in risk and uncertainty analysis. Uncertainty analysis for engineering systems is being treated in different perspectives by researchers as a result of the imperfect knowledge of the system under consideration (Tung and Yen, 2005). Furthermore, the presence of large uncertainties in modelling and simulation could be related to lack of information or data from the study (Freni et al., 2009). In predicting runoff from rainfall, Moreira et al. (2006) defined the uncertainties as the failure of accurate catchments' response prediction. Goodrich (1990) showed that the level of uncertainties in runoff estimation on semiarid catchments is reduced when the number of rainfall spatial characteristics or variability is increased. Habib et al. (2008) analysed the uncertainties associated with radar rainfall error and their propagation to hydrological stream flow simulation. MCS is being used widely to assess uncertainty (McCuen et al., 1990; Kuo et al., 2007). Nielsen and Harremoes (1996) used MCS as a stochastic technique to assess the overall uncertainty and predict the future behaviour of the rainfall. In addition the uncertainty analysis was used to assess the detrimental effects of urban storm drainage and the relative contributions of the individual components to the overall uncertainty. Supiah et al. (2009) used MCS to assess the uncertainty of sediment load prediction at a detention pond using the universal loss equation.

METHODOLOGY

Hourly rainfall data covering a period of 40 years (1971-2010), from a station (Station no. 1437116) in Larkin, Johor, were collected. The data were divided into individual rainfall events using MIT values of 2hr, 4hr, 6hr, 9hr, 12hr, 18hr and 24hr. The mean and standard deviation of rainfall duration, depth, intensity and storm separation time were obtained from the hourly rainfall data. The effect of MIT variation on the mean and standard deviation of the rainfall duration, depth, intensity and inter-event time were determined (Supiah et al., 2010).

Rainfall depth (V) was obtained from the equation

$$V = \Sigma v_i \quad (1)$$

where v_i is the rain depth at certain *ith* hour of particular rainfall event under consideration.

Rainfall duration *(T)* from each individual event was obtained using the equation

$$T = t_i - t_2 \quad if \quad b \geq MIT \quad (2)$$

where t_1 and t_2 are the starting and end of the event, and b is the rainfall separation time. When $b < MIT$, rainfall are combined as one event.

The rainfall intensity *(I)* was obtained from the equation

$$I = V/T \quad (3)$$

The inter-time between two consecutive events *(b)* was obtained according to the equation

$$b = t_j - t_i \quad if \quad b \geq MIT \quad (4)$$

where t_i is the end of last event, t_j is the beginning of following event using *MIT* values of 2, 4, 6, 9, 12, 18 and 24 hrs were used.

In this paper, the actual mean and standard deviation values obtained from Supiah et al. (2010) were subjected to 10,000 trials of MCS with normal distribution to assess the uncertainty and to generate the new mean and standard deviation values using normal distribution function of RiskAmp software.

The MCS was conducted for 2, 6, 12 and 24 hrs MIT. After the MCS, new values for mean, standard deviation, median, standard error, skewness and kurtosis were generated. Other results obtained from the MCS were the most likely range and most likely percentage. The most likely range is a range of fourth higher values between the histograms or probability density curve while most likely percent is the percent of most likely range of fourth higher values between the histograms or probability density curve.

RESULT AND DISCUSSIONS

Rainfall Depth

Table 1 shows the actual mean and standard deviation of the rainfall depth. From the MCS with 10,000 trials, the new mean and standard deviation were generated. The actual mean and standard deviation values increased steadily from 12.38 to 27.91 mm and 19.93 to 40.16 mm respectively with increasing MIT from 2 to 24 hrs while the simulated mean and standard deviation also increased from 12.36 to 27.30 mm and from 20.03 to 39.35 mm respectively for MIT range of 2 to 24 hrs (Figure 1). The maximum occurrence for rainfall depth increased from 9.75 (15.62) at 2 hr MIT to 27.18 mm (15.12%) at 24 hrs MIT, while the most likely occurrence range increased from a range of 4.76-12.22 mm (12.14-13.89%) for 2 hrs MIT to the occurrence range of 22.08-36.95 mm (12.23-13.05%) for 24 hrs MIT.

Rainfall Duration

Table 2 shows the actual mean and standard deviation of the rainfall duration. From the MCS with 10,000 trials, the new mean and standard deviation were generated. The actual mean and standard deviation values increased steadily from 5.10 to 26.97 hrs and 8.49 to 38.25 hrs respectively with increasing MIT from 2 to 24 hrs while the simulated mean and standard deviation also increased from 5.09 to 26.39 hrs and from 8.53 to 37.48 hrs respectively for MIT range of 2 to 24 hrs (Figure

Table 1. Actual and simulation outputs for rainfall depth (mm) with 10,000 MCS trials.

MIT	2hrs	6hrs	12hrs	24hrs
Actual Mean (mm)	12.38	14.33	16.44	27.91
Actual Standard Deviation(mm)	19.93	22.14	25.42	40.16
MCS Mean value (mm)	12.36	14.23	16.33	27.30
MCS Standard Deviation (mm)	20.03	22.24	25.37	39.35
Most Likely Range (mm)	4.76-12.22	5.75-14.31	6.70-16.27	22.08-36.95
Most Likely Percent (%)	12.14-13.89	12.72-13.59	12.49-13.66	12.23-13.05

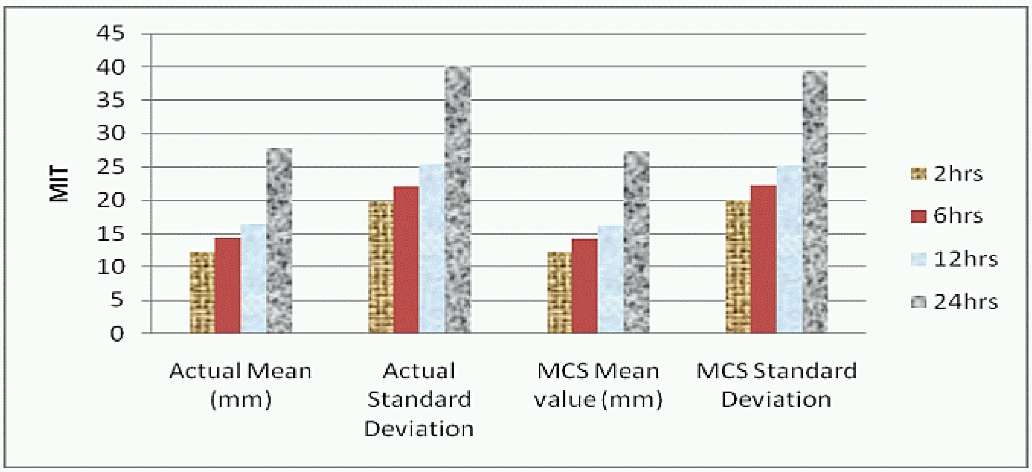

Figure 1. Mean and standard deviation values for rainfall depth.

2). The maximum occurrence for rainfall duration increased from 3.98 (19.09%) at 2 hour MIT to 26.28 (16.31%) at 24 hour MIT, while the most likely occurrence range increased from a range of 2.96-6.08 (13.51-15.22%) for 2 hrs MIT to the occurrence range of 21.42-35.58 (11.43-14.43%) for 24 hrs MIT .

Rainfall Intensity

Table 3 shows the actual mean and standard deviation of the rainfall intensity. From the MCS with 10,000 trials, the new mean and standard deviation were generated. The actual mean and standard deviation remains nearly at constant value with increasing MIT from 2 to 12 hrs after which the values decline steadily at 24 hrs. The simulated mean and standard deviation also exhibit a similar passion. Parameters for rainfall intensity did not show any significant change with MIT, especially at MIT values less than 12 hrs (Figure 3). The maximum occurrence for rainfall intensity decreases from 3.59 mm/hr (18.43%) at 2 hour MIT to 3.38 mm/hr (22.00%) at 24 hr MIT, while the most likely occurrence range remains almost constant from the occurrence range of 2.49-4.11 mm/hr (14.67-15.07%) for 2 hrs MIT to the occurrence range of 2.49-3.87 mm/hr (15.46-15.73%) for 24 hrs MIT.

Storm Separation Time

Table 4 shows the actual mean and standard deviation of the storm separation time. From the

Table 2. Actual and simulation outputs for rainfall duration (hr) with 10,000 MCS trials.

MIT	2hrs	6hrs	12hrs	24hrs
Actual Mean (hr)	5.10	6.39	8.61	26.97
Actual Standard Deviation (hr)	8.49	9.78	13.26	38.25
MCS Mean value (hr)	5.09	6.34	8.56	26.39
MCS Standard Deviation (hr)	8.53	9.83	13.23	37.48
Most Likely Range (hr)	2.96-6.08	2.60–6.38	3.53–8.52	21.42-35.58
Most Likely Percent (%)	13.51–15.22	12.50–13.82	13.94–14.38	11.43-14.43

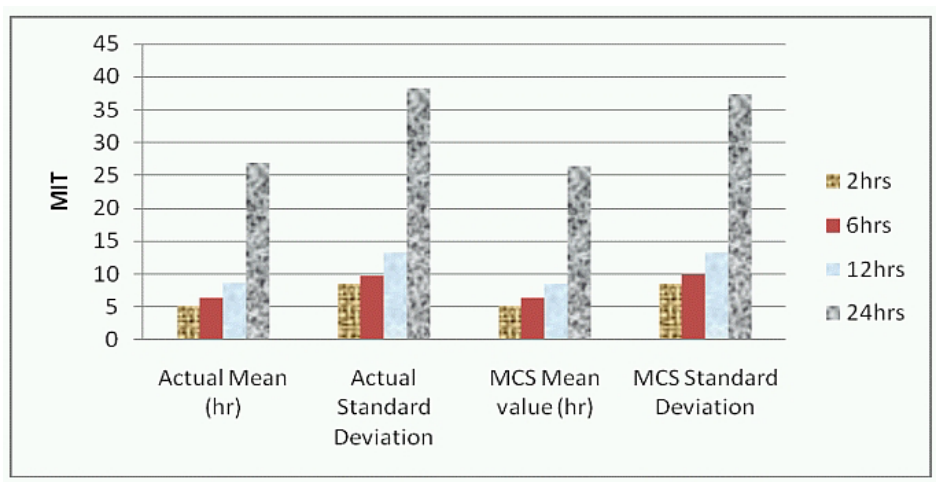

Figure 2. Mean and standard deviation values for rainfall duration.

MCS with 10,000 trials, the new mean and standard deviation were generated. The actual mean and standard deviation values increased steadily from 40.18 to 75.05 hrs and 58.32 to 73.63 hrs respectively with increasing MIT from 2 to 24 hrs while the simulated mean and standard deviation also increased from 40.11 to 73.94 hrs and from 58.61 to 72.15 hrs respectively for MIT range of 2 to 24 hrs (Figure 4). The maximum occurrence for storm separation time doubled from 32.48 (15.80%) at 2 hour MIT to 73.72 (15.40%) at 24hr MIT, while the most likely occurrence range increased from a range of 17.89-39.70 (11.68-13.90%) for 2 hrs MIT to the occurrence range of 64.37-91.62 (12.58-12.96%) for 24 hrs MIT.

Knowledge of rainfall characteristics and its spatial variation over an area plays a major role as input to various models used in agriculture, storm water management and many others. Therefore, the selection of proper rainfall parameters becomes very imperative. Goodrich et al. (1995) assessed the spatial variability of small scale convective rainfall over a 4.4 ha catchment and it was indicated that rainfall represent a 4-14% variation of the mean rainfall depth over a 100 m distance. It was therefore proven that the assumption of spatial rainfall uniformity at small watershed scale appears to be invalid. Other studies assessed the effects of rainfall variability on rainfall-runoff and water quality model parameters and it was shown that a large uncertainty in the model parameters affects the performance of the model parameters (Chaubey, 1999). The uncertainties may also be due to sparse rain gauge stations which could cause spatial variation (Hwang et al., 2011). In this

Table 3. Actual and simulation outputs for rainfall intensity (mm/hr) with 10,000 MCS trials.

MIT	2hrs	6hrs	12hrs	24hrs
Actual Mean (mm/hr)	2.98	3.00	2.91	2.14
Actual Standard Deviation (mm/hr)	4.23	4.24	4.14	3.48
MCS Mean value (mm/hr)	3.05	2.95	2.86	2.08
MCS Standard Deviation (mm/hr)	4.24	4.27	4.06	3.50
Most Likely Range (mm/hr)	2.49-4.11	2.93–4.60	2.87–4.37	2.49-3.87
Most Likely Percent (%)	14.67-15.07	14.16-14.74	14.47-14.62	15.46-15.73

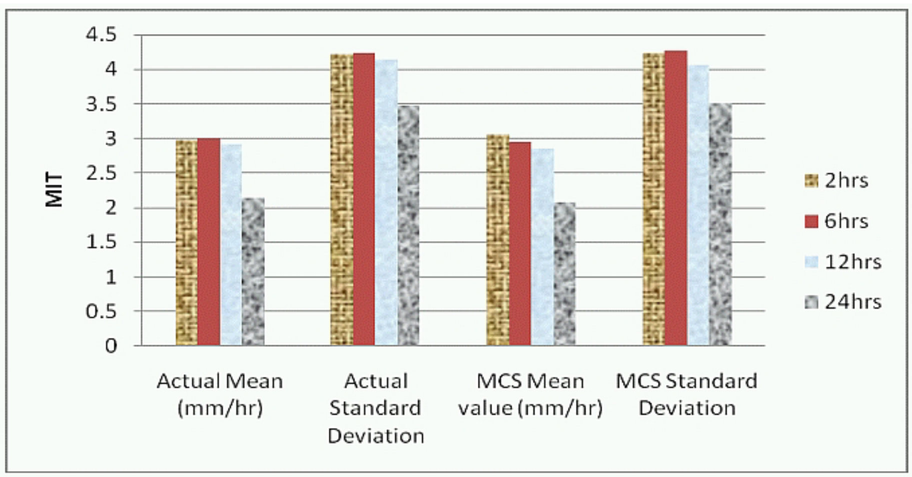

Figure 3. Mean and standard deviation values for rainfall intensity.

study, the uncertainty of rainfall characteristics for a tropical region has been identified using hourly rainfall data. MIT definition has been known to affect rainfall parameters in many ways (Dunkerly, 2008) and this study further continues to explore the uncertainty arising from the variation of MIT on the rainfall characteristics of depth, duration, intensity and inter-event time for a tropical area.

CONCLUSIONS

In this study MCS with normal distribution was used to determine the uncertainty of rainfall characteristics for a rainfall station in Johor, Southern Malaysia. The MCS showed that the maximum occurrence for rainfall depth increased from 9.75 mm (15.62%) at 2 hrs MIT to 27.18 mm (15.12%) at 24 hrs MIT while the maximum occurrence of rainfall duration also increased from 3.98 (19.09%) at 2 hour MIT to 26.28 (16.31%) at 24 hrs MIT. However, the maximum occurrence of rainfall intensity changed slightly from 3.59 mm/hr (18.43%) at 2 hrs MIT to 3.38 mm/hr (22.00%) at 24 hrs MIT. The maximum occurrence of storm separation time at 2 hr MIT was 32.48 hrs (15.80) and this value increased at 24 hr MIT to 73.72 hrs (15.4%).

The most likely occurrence range for rainfall depth increased from a range of 4.76-12.22 mm (12.14-13.89%) for 2 hrs MIT to the range of 22.08-36.95 mm (12.23-13.05%) for 24 hrs MIT while the most likely occurrence range for rainfall duration increased from 2.96-6.08 hrs (13.51-15.22%) for 2 hrs MIT to the range of 21.42-35.58 (11.43-14.43%) for 24 hrs MIT. However, the

Table 4. Actual and Simulation outputs for storm separation time (hr) with 10,000 MCS trials.

MIT	2hrs	6hrs	12hrs	24hrs
Actual Mean (hr)	40.18	45.99	51.51	75.05
Actual Standard Deviation (hr)	58.32	60.72	63.19	73.63
MCS Mean value (hr)	40.11	45.71	51.24	73.94
MCS Standard Deviation (hr)	58.61	61.00	63.07	72.15
Most Likely Range (hr)	17.89- 9.70	22.45-45.94	27.31-51.08	64.37– 91.62
Most Likely Percent (%)	11.68-13.90	12.42-13.84	12.58-13.75	12.58-12.96

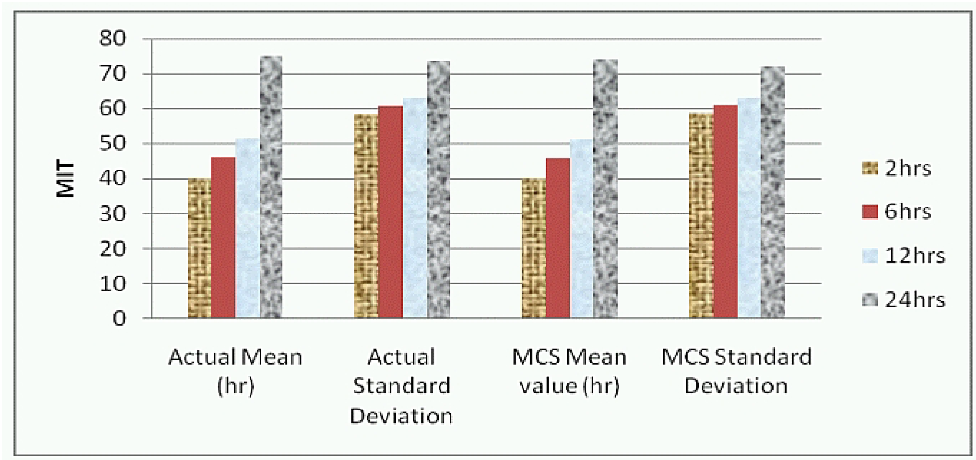

Figure 4. Mean and standard deviation values for storm separation time.

most likely occurrence range for rainfall intensity remains almost at constant values of 2.49-4.11 mm/hr (14.67-15.07%) for 2 hrs MIT to the range of 2.49-3.87 mm/hr (15.46-15.73%) for 24 hrs MIT. Finally, the most likely occurrence range for storm separation time increased from a range of 17.89-39.70 (11.68-13.90%) for 2 hrs MIT to the range of 64.37-91.62 (12.58-12.96%) for 24 hrs MIT as the MIT increased from 2 to 24hr.

As rainfall occurrence is highly uncertain, the results presented herein can be used to ascertain the level of uncertainty associated with rainfall characteristics in Johor, Southern Malaysia and the result could be extended to regions with similar rainfall characteristics.

ACKNOWLEDGMENT

Authors wish to thank Assoc. Prof. Dr. Sobri Harun and Dr. Noor Baharim Hashim of Faculty of Civil Engineering, Universiti Teknologi Malaysia for reviewing this paper. This research would not have been possible without support from Universiti Teknologi Malaysia and Ministry of Science Technology and Innovation MOSTI (Vote no. 79394). Authors wish to acknowledge the Department of Irrigation and Drainage, DID, Malaysia for the supply of rainfall data.

REFERENCES

Atikah, S. 2009. Extreme Flood Event: A Case Study on Floods of 2006 and 2007 in Johor, Malaysia. MSc Thesis, Department of Civil and Environmental Engineering, Colorado State University Fort Collins, Colorado.

Benjamin, N., H.R. Abdullah, M. Tan, M. Vijayan, F. Zolkepli, M.H. Hanafiah, F. Begum, A. Edwards, L.Y. Peng, M.N. Anis and I. Shari. 2006. Articles related to Johor flooding incidences 20th December 2006 to 31st December 2006. The Star, Online newspaper.

Chaubey, I., C.T. Haan, S. Grunwald, and J.M. Salisbury. 1999. Uncertainty in the model parameters due to spatial variability of rainfall. Journal of Hydrology, Vol. 220, pp. 48-61.

Dan'azumi, S., S. Supiah, and A. Aris. 2010. Modeling the distribution of rainfall intensity using hourly data. American Journal of Environmental Sciences, Vol. 6(3), pp. 238-243.

Dan'azumi, S., S. Supiah, and A.A. Rahman. 2010. Probability distribution of rainfall depth at hourly time-scale. Proceedings of International Conference on Environmental Science and Engineering, Singapore, 26-28 August, 2010. World Academy of Science Engineering and Technology.

Dunkerley, D. 2008. Identifying individual rain events from pluviograph records: a review with analysis of data from an Australian dryland site. Hydrol. Process., Vol 22, pp. 5024-5036.

Freni, G., G. Mannina, and G. Viviani. 2009. Uncertainty assessment of an integrated urban drainage model. Journal of Hydrology, Vol. 373, pp. 392–404.

Goodrich, D. C. 1990. Geometric simplification of a distributed rainfall-runoff model over a range of basin scales. PhD. Dissertation. University of Arizona, Tucson.

Goodrich, D.C., J-C. Faures, D.A. Woolhiser, L.J. Lanea, and S. Sorooshian. 1995. Measurement and analysis of small-scale convective storm rainfall variability. Journal of Hydrology, Vol. 173, pp. 283-308.

Habib, E., A.V. Aduvala, and E.A. Meselhe. 2008. Analysis of radar-rainfall error characteristics and implications for streamflow simulation uncertainty. Hydrological Sciences Journal, Vol. 53(3), pp. 568-587.

Hwang, Y, M.P. Cark, and B. Rajagopalan. 2011. Use of daily precipitation uncertainties in streamflow simulation and forecast. Stochastic Env. Res. and Risk Assessment., Vol. 25(7), pp. 1-16.

Kuo, J. T., Y.C. Yen, Y.C. Hsu, and H.F. Lin. 2007. Risk analysis for dam overtopping—Feitsui Reservoir as a case study. Journal of Hydraulic Engineering, ASCE, Vol. 133(8), pp. 955-963.

Malaysia Meteorological Department 2009. http://www.met.gov.my. Accessed on 29/12/2010.

Moreiraa, L.F.F., A.M. Righetto, and V.M. Medeiros. 2006. Uncertainty analysis associated with rainfall spatial distribution in an experimental semiarid watershed. Proceeding of 3rd Biennial Meeting of International Environmental Modelling and Software Society. University of Vermont, USA.

Nielsen, K. A., and P. Harremoës. 1996. The importance of inherent uncertainties in state-of-the-art urban water storm drainage modelling for ungauged small catchments. Journal of Hydrology, Vol 179, pp. 305-319.

McCuen, R. H., B.M. Ayyub, and T.V. Hromadka. 1990. Risk of debris-basin failure. Journal of Water Resources Planning and Management, Vol. 116, pp. 473-483.

Supiah, S., S. Dan'azumi, and A. Aris. 2010. Effect of storm separation time on rainfall characteristics – A case study of Johor, Malaysia. European Journal of Scientific Research, Vol. 45(2), pp. 162-167.

Supiah, S., I.N. Mohamad, and A.A. Rahman. 2009. Uncertainty of sediment load prediction at a detention pond based on Monte-carlo simulation. Journal of Environmental Hydrology, Vol. 17(4), pp. 1-12.

Tung Y-K, and B-C. Yen. 2005. Hydrosystems engineering uncertainty analysis. NewYork; McGraw Hill.

Varis, O. 1997. Bayesian decision analysis for environmental and water resource management. Journal of Environmental Modelling & Software, Vol. 12(2-3), pp. 177-185.

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