ASSESSING THE PERFORMANCE OF VARIOUS ON-SITE DETENTION POND DESIGN METHODS BASED ON MSMA 2 GUIDELINES

Shirline Leong Ai Lin, Jacqueline Isabella Anak Gisen

Abstract

Flash flood and monsoon flood are the common disasters caused by improper storm water management. Hence, on-site detention plays an indispensable role in the storm water management to reduce the probability of flood occurrences. The design method adopted determines the cost-effectiveness and usefulness of the designed on-site detention facility. In this study, on-site detention facility of three developments were analysed using two methods: the Simplified Method and the Modified Puls Method. It was found that Modified Puls Method is the more economical method compared to the Simplified Method. Moreover, the accuracy of the on-site detention system has affected the magnitude of rainfall intensity corresponding to various storm duration and ARI (Average Recurrence Index). The IDF (Rainfall Intensity-Duration-Frequency) curves provided in MSMA 2 (Urban Storm water Management Manual for Malaysia 2nd Edition) was not up to the current year. Thus, IDF curves were developed for the rainfall stations of each development data using the Arithmetic Mean Method and followed by mass curve analysis to check the filled rainfall data consistency.

Keywords On-site detention facility, Modified Puls Method, The Simplified Method, Arithmetic Mean Method, Mass Curve Analysis

---

S.A.L. Leong, J.I.A. Gisen

Faculty of Civil Engineering Technology, Universiti Malaysia Pahang, Leburaya Tun Razak, 26300 Gambang, Kuantan, Pahang, Malaysia

J.I.A. Gisen (Corresponding Author)
e-mail: isabella@ump.edu.my

Faculty of Civil Engineering Technology, UMP Research Series: Water, Energy, and Environment, Vol. 1, [insert doi here later]

Introduction

The flood protection measures adopted by a country decide the level of safety of the nations. Extreme flood events occurring in Malaysia are often caused by improper storm water management or poorly maintained flood prevention structures. It was reported by Raj (2017) that a substantial amount is needed to replace the poorly maintained existing retention pond in Universiti Malaya that is caused by mud deposition resulting from nearby construction. Hence, it is crucial to maintain a constructed detention pond on a regular basis to ensure the detention pond functions at its optimum performance.

The design of an on-site detention facility highly affects the cost-effectiveness and performance of the on-site detention system. Hydraulic modelling can be used to evaluate the effectiveness of the retention pond. A study conducted by Jamaluddin et al. (2011) using the HEC RAS hydraulic model showed Aman Lake constructed at the USM (Universiti Sains Malaysia) campus with the aim to reduce flood probability failed as a retention pond. The simulated flood profile for design rainfall of 2 years, 10 years and 50 years of Average Recurrence Interval were higher than the bank profile of Aman Lake. Although the main cause of the failure was not identified, failure can be caused by wrong design method, false catchment boundary identification and many other relevant reasons.

Also, another study related to the effectiveness of constructed detention pond was conducted (Liew et al., 2012). From their research, a detention pond built in 1996 prior to the publication of Urban Storm water Management Manual for Malaysia, MSMA 2nd Edition (2012) was found to have the ability to cater flow from a 100- year ARI storm and at the same time comply with the requirements stated in MSMA for detention pond of a major storm water system.

As important as the post construction effectiveness of on-site detention system, the method adopted to design the on-site detention system affects the optimum performance of the designed detention facility. Various methods can be adopted to design the on-site detention system. Nevertheless, there are two common design methods, namely the Simplified Method and hydrological pond routing procedures. A study conducted on the comparison of design method for detention pond concluded that the Simplified Method has lower accuracy as compared to hydrological routing (Hong, 2010). The study recommended using the Simplified Method for the preliminary detention facility design stage, while adopting the conventional hydrological routing method for the detail design phase.

Rainfall

The accuracy of a hydrological analysis depends greatly on the quality of rainfall data. In general, it is more favourable if at least 30 years of complete data are available for analysis. However, the rainfall data received might be incomplete and contain gaps. There are many methods available to perform rainfall gap filling. A study conducted by Caldera et al. (2016) analysed several gap filling methods, including the Arithmetic Mean Method, Probabilistic Method and Linear Regression Method. The study however cannot conclude the best method to be adopted for rainfall data gap filling. It was recommended to select the rainfall data gap filling method based on the availability of rainfall data from neighbouring rainfall stations and the target rainfall station's correlation factor with its neighbouring stations.

Rainfall duration is another important factor that can affect the design of on-site detention facility. The volume of storage needed varies with storm duration. A study by Hong (2008) investigated how detention volume was affected by rainfall duration. Both experimental and numerical simulation results concluded that detention volume increases with rainfall duration under similar allowable maximum discharge.

Methodology

In an overview, Figure 1 attached below shows the workflow of the methodologies.

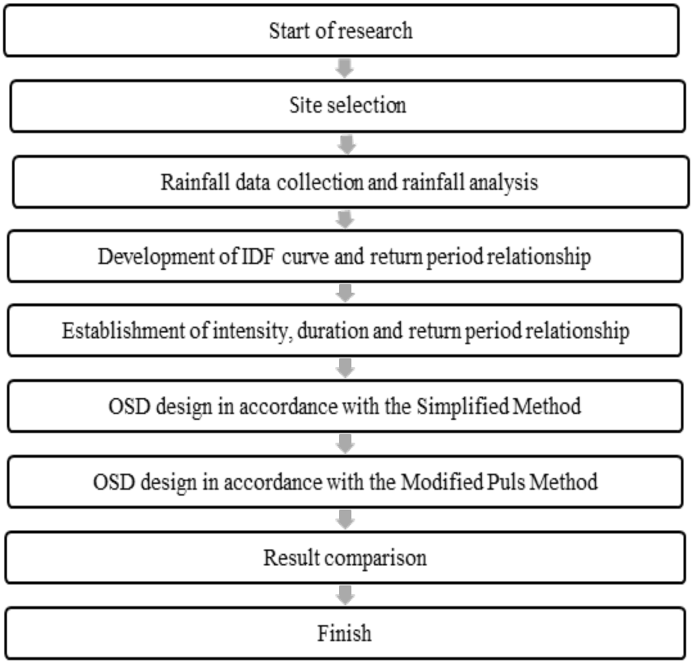


Figure 1: Methodology flow chart

Site Selection

Three development projects were selected, and the locations of these development projects are Kuantan, Jerantut and Pekan, as shown in Figures 2 to 4. All development areas were under 5 hectares. The development layout and topographical information were attained from a local civil and structural consultant. Three development projects were investigated for their terrain, as well as the pre and post development land uses. The coordinates of each development site were located on Google Earth and the nearest active rainfall station to each development site was identified.

Figure 2: Kuantan Development Boundary

Figure 3: Pekan Development Boundary

Figure 4: Jerantut Development Boundary

Rainfall Data Treatment

Rainfall data obtained from the Department of Irrigation and Drainage (DID) were incomplete. The Arithmetic Mean Method was selected to treat the missing rainfall data. In the effort of predicting the missing rainfall data for a rainfall station, the nearby rainfall stations were referred. The missing precipitation data was predicted using the Equation (1) stated below.

$$\underline{P} = \frac{1}{N}\sum_{i}^{N} P_i \qquad (1)$$

P_i = the rainfall at the i[th] rain gauge station
N = the total number of rain gauge station

Rainfall Data Consistency Analysis

The consistency of filled rainfall data was tested using the Mass Curve Method. The consistency of gap filled data can be observed from the relationship between variable X (year) and variable Y (Cumulative Annual Maximal Rainfall Depth). The Mass Curve Analysis assumes a linear relationship between variable X and variable Y. The consistency of each rainfall data set was known by comparing the cumulative annual maxima rainfall depth versus year plotting to the best line generated.

IDF Curve Development

Gumbel Type I distribution was selected to construct IDF curve for each rainfall station. The general equation (2) used to develop IDF curve is as follows.

$$X_T = \underline{X} + K_T S \qquad (2)$$

$\overline{X}$ = Arithmetic mean of observations
S = Standard deviation of the observations
K_T = Frequency factor associated with return period T

The relationship between the Intensity-Duration-Frequency (IDF) was described using the Power Law. The Power Law is expressed as Equation (3),

$$I(T,d) = \frac{\lambda(T)^K}{(d+\theta)^\eta} \qquad (3)$$

(λ, K, θ, η) = Obtained through trial and error of value θ
T = ARI
d = Storm duration

MSMA 2 IDF curves also adopt the same expression.

Simplified Method (Chapter 5 MSMA2)

This method covers development area under 5 hectares and 10 - year ARI design storm. The design of the on-site detention facility using this method requires the computation of permissible site discharge (PSD), site storage requirement (SSR), and pipe diameter of inflow and outflow outlet through the utilisation of tables provided in MSMA 2. These tables are Table 5.A1, Table 5.A2, Table 5.A3 and Table 5.A4.

Modified Puls Method (Chapter 7 MSMA2)

The Modified Puls Method is one of the conventional hydrological routing methods. The prerequisite of this method is the derivation of inflow hydrograph. In this study, the inflow hydrograph was derived using the Rational Hydrograph Method (RHM), whereas the peak discharge was computed using the Rational Method. Figure 5 displays the types of hydrograph in reference to RHM. The procedure continued with inflow hydrograph routing to produce the outflow hydrograph. Outlet orifice size was determined through trial and error methods to control the outflow discharge at the pre development level.

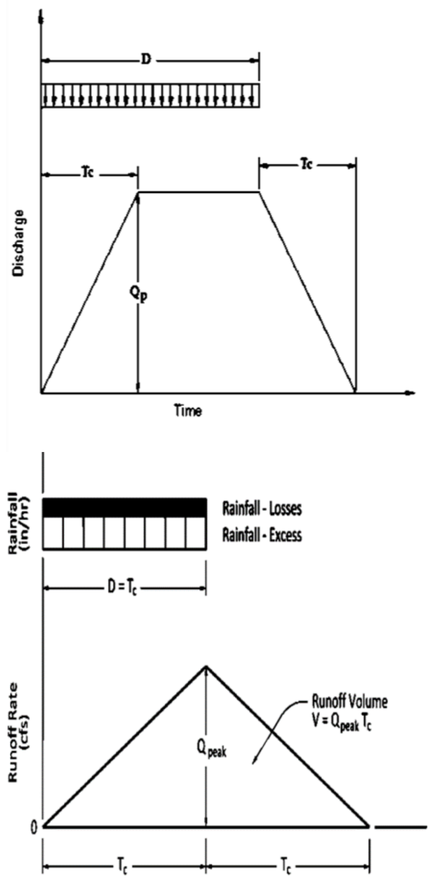


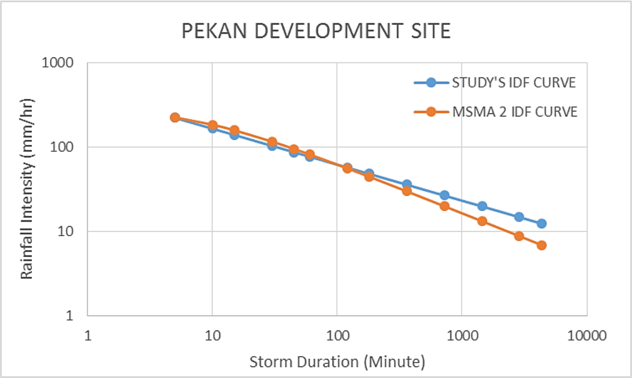
Figure 5: Types of hydrograph based on RHM

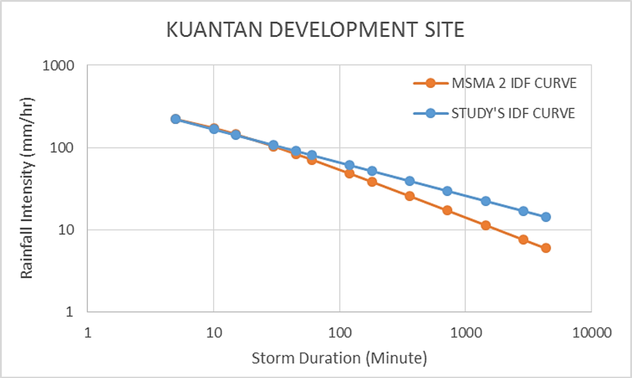
Result and Discussion

Comparison of IDF Curves

This study found that new IDF curves developed for Pejabat JPS Negeri Pahang rainfall station, Dispensari Nenasi rainfall station and Rumah Pam Paya Kangsar rainfall station cannot be compared with MSMA 2 IDF curves, due to insufficient rainfall data considered. The IDF curves provided in MSMA 2 cover up to 72 hours, whereas new IDF curves developed by this study covered up to 60 minutes only, because of the limited research duration. From Figure 6, the comparison of IDF curves shows that rainfall intensity for the first 60 minutes was comparable. Root Mean Square Error for Kuantan, Pekan and Jerantut site were 9.5mm, 9.4mm and 10.4mm respectively.

It was found that the difference between the new IDF curve developed for Kuantan development and MSMA 2 IDF curve had a great difference. This is because different rainfall station is used for comparison. The nearest rainfall station, Pejabat JPS Negeri Pahang, is not available under MSMA 2.





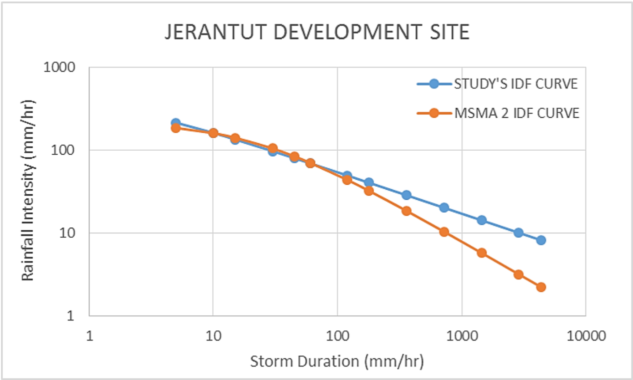


Figure 6: New IDF curve and MSMA 2 IDF curve comparison

The Simplified Method

Pekan development has the smallest development area but highest imperviousness appeared to have the highest storage required. It appeared that design outcomes from the Simplified Method had a strong dependency on the region classified for a development. From Figure 7, it was found that although Kuantan and Jerantut sites have a similar percentage of impervious area (91%) and development area, the difference of required storage between the two sites was 392 m^3. However, Kuantan and Jerantut are classified into two different regions, region 2 and region 4, as shown in Figure 7.

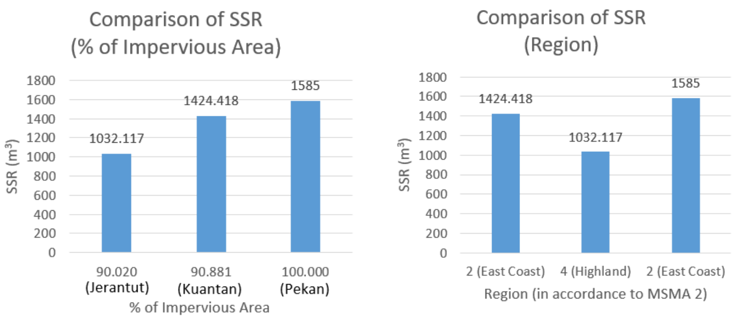


Figure 7: Relationship between SSR and % of imperviousness and the classified region

The Modified Puls Method

From Table 1, it was found that design outcomes of conventional detention pond routing greatly depend on the magnitude of rainfall intensity derived from IDF curves. The design outcomes computed using the nearest rainfall station to the development site available in MSMA 2 IDF curve appeared to be lower than design outcomes computed based on the newly developed IDF curve. Thus, this strongly indicates that the conventional pond routing method depends on the rainfall intensity.

Table 1: Design outcome comparison between MSMA 2 IDF Curves and newly updated IDF Curves

Development Location	Storage Required (m^3)	
	MSMA 2 IDF Curves	New IDF Curves
Kuantan	966.2	1487.8
Pekan	869.4	1135.7
Jerantut	786.6	915.7

Comparison of the Simplified Method and the Modified Puls Method

The comparison was made between design outcomes from the Simplified Method and design outcomes from the Modified Method based on MSMA 2 IDF curves. From the comparison made (see Table 2), it was found that Simplified Method overestimates the detention storage as much as 82% (Pekan development site).

Table 2: Difference between two design methods outcomes

Development Location	Storage Required by Simplified Method (MSMA 2 Chapter 5) (m^3)	Storage Required by Modified Puls Method (MSMA 2 Chapter 7) (m^3)	Difference of Detention Storage Required %
Kuantan	1424.4	966.2	47.4
Pekan	1585.0	869.4	82.3
Jerantut	1032.1	786.7	31.2

Conclusion

A few key findings were obtained from this study. The first finding was that insufficient rainfall data considered in the new IDF curves caused the comparison of MSMA IDF curves cannot be carried out. Next, the Simplified Method design outcomes depend greatly on the region classification and % of imperviousness, whereas the design outcomes of the Modified Puls Method include rainfall intensity into the calculation, which is missing in the Simplified Method. Lastly, it was found that Modified Puls Method is a more economical on-site detention design method than the Simplified Method.

Acknowledgement

The authors would like to express their greatest gratitude to the Department of Irrigation and Drainage Malaysia for providing the hydrological data. This research is funded by Universiti Malaysia Pahang through research grants RDU160326 and PGRS180326.

References

Caldera, H., Piyathisse, V., & Nandalal, K. (2016). A Comparison of Methods of Estimating Missing Daily Rainfall Data. Engineer: *Journal of the Institution of Engineers, Sri Lanka*, 49(4), 1-8. doi:doi.org/10.4038/engineer.v49i4.7232DID. (2012). Urban Stormwater Management Manual for Malaysia, MSMA (2nd ed.). Kuala Lumpur: Department of Irrigation and Drainage Malaysia.

Hong, Y. (2008). Numerical Simulation of Laboratory Experiments in Detention Pond Routing with Long Rainfall Duration. *Journal of Sediment Research*, 23(3), 233-248. doi:10.1016/S1001-6279(08)60021-9

Hong, Y. (2010). Experimental evaluation of design methods for in-site detention ponds. *International Journal of Sediment Research*, 25(1), 52-63. doi:10.1016/S1001-6279(10)60027-3

Jamaluddin, A., Hasan, Z., & Ghani, A. (2011). Effectiveness of Aman lake as flood retention ponds in flood mitigation effort: Study case at USM Main Campus, Malaysia. *3rd International Conference on Managing Rivers in the 21th Century*: Sustainable Solutions for Global Crisis of Flooding, Pollution and Water Scarcity, (pp. 277-383). Penang.

Liew, Y., Selamat, Z., Ghani, A., & Zakaria, N. (2012). Performance of a dry detention pond: case study of Kota Damansara, Selangor, Malaysia. *Urban Water Journal*, 9(2), 129-136. doi:10.1080/1573062X.2011.644567

Raj, R. (2017, May 17). *RM40m retention ponds to overcome KL floods*. The Malay Mail online. http://www.themalaymailonline.com/malaysia/article/rm40m-retention-ponds-to-overcome-kl-

Author(s) Biodata

Shirline Leong holds the position of civil design engineer at HL YONG Jurutera Perunding Struktur & Awam. Previously, she graduated from Universiti Malaysia Pahang in Bachelor of Civil Engineering (Hons). She has experience in handling infrastructure designs for commercial and residential projects. In her present job, she is required to analyse the assigned projects' site conditions for both pre and post development, and comes out with well-integrated infrastructures designs in accordance with the Malaysian Design Standard. She can be contacted via shirlineleong95@outlook.com
D.O.B: 26TH July 1995

Jacqueline Isabella Anak Gisen is a senior lecturer from the Faculty of Civil Engineering Technology in Universiti Malaysia Pahang. Previously, she graduated from the Delft University of Technology, Netherlands, in Doctor of Philosophy (Hydrology-saline intrusion). Apart from her academic career, she is also involved in several consulting projects in the water resources field. She has experience in river basin modelling works integrated with Geographical Information System (GIS). Her present projects focus on the surface water saline intrusion in the Malaysian estuaries and integrated GIS-SWAT modelling for the Malaysian river basin. She can be contacted via isabella@ump.edu.my
D.O.B: 3rd February 1983