MODELING TASIK HARAPAN AS A FLOOD RETENTION POND

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Abstract *Past philosophy that sought maximum conveyance of storm water at an individual site by the most rapid possible elimination of exccess surface water after a rainfall is no longer a prefered choice in the best management practice in flood control (ASCE, 1979). The desirability of retaining or storing rainfall where it falls on site to attenuate both peak runoff and total short term runoff has become a new approach to storm water management. This philosophy of storing excess surface water in constructed retention pond has been adopted by Universiti Sains Malaysia (USM) to control local flood generated in the campus. Located in a country known for its wet and humid weather with high rainfall intensity throughout the year, USM main campus has experienced occurrences of flooding. The occurrence of flooding is intensified by the development of the campus after 1970. Thus, measure was taken to attenuate the peak flows and total runoff during storms by the construction of a retention pond known as Tasik Harapan. This paper will present an analysis on the effectiveness of Tasik Harapan as a flood retention pond through model simulations by TR-55 developed by the US Department of Agriculture.*

1 Introduction

Of all the natural disasters in the world, floods are the most severe in terms of number of deaths and injury, total property and crop damage, frequency and extent of area affected (Parker 2000). Realizing that conventional drainage system which drains stormwater into drains and rivers under the shortest time period possible has increased the occurrence of flash flood at the downstream of the catchments and has actually exacerbated flooding rather than preventing it, the Drainage and Irrigation Department (DID) has embarked on a new flood management approach. Additionally, open drainage invites more polluted river and therefore has worsened the quality of life in urban community. Hence, conventional drainage is no longer an effective measure in solving flood (ASCE, 1979; Nor Azazi Zakaria et al., 2004). All new development in Malaysia now must comply with the new guideline that requires the application of Best Management Practices (BMPs) to control storm water from the aspect of quantity and quality runoff to achieve zero or minimum development impact contribution. These concepts of BMPs will be able to preserve the natural river flow carrying capacity. Research has shown that natural undisturbed forest systems, wetlands and lakes are the best forms of flood defence as they soak up a huge amount of rainwater and release it slowly, thereby allowing river systems plenty of time to drain away excess water (Chan, 2003). Even rehabilitated forests and ponds, though not as effective as their natural counterparts, are also capable of reducing flood hazards. Forests and wetlands control floods by retaining rainfall at source, a concept only recently adopted by flood control agencies in Malaysia (Chan, 2002a,b). Such systems intercept a significant amount of rainfall and regulate the flow of rain outside the system. Important processes such as interception, through fall, at-source storage, infiltration and slowing of runoff, reduces both the volume as well as the speed of water flow and prolongs the rain from reaching the river. In the case of lakes and ponds, such systems are able to hold an enormous amount of water, depending on the size of the system, the surrounding land use and the season, amongst other things. Without lakes and ponds, especially in urban areas with a low percentage of infiltration, rainwater gets into rivers at a relatively rapid rate, resulting in flash floods. Hence, it is vital for engineers and scientists to either conserve such natural systems or mimic nature by constructing artificial wetlands or ponds for flood mitigation, as will be discussed soon.

Tasik Harapan was constructed in 1990 to serve as a retention pond to accommodate anticipated increased runoff following a spade of developments. As shown in Figure 1, it has a surface area of approximately 1.5 acres and a depth of 1.0 to 1.5 m. With an average annual rainfall of about 2500 mm in Malaysia (DID, 2000), Penang on which USM is located receives approximately 75 mm to 400 mm of rainfall per month. There are occurrences of flood due to the heavy rainfall during the inter-monsoon seasons between April and May and between October and November (DID, 2000; Kirton, 2003). Urbanization and expansion of USM from an army barrack to a modern campus has resulted in increased storm water runoff. Hence Tasik Harapan was constructed to reduce surface runoff by storing part of the runoff. This paper will present an analysis on the effectiveness of Tasik Harapan as a flood retention pond through modeling the peak flows before and after development of USM campus and the size of storage needed to retain the runoff by means of the model TR-55. Technical Release 55 (TR-55: Urban Hydrology for Small Watersheds) was first developed in 1975 as a procedure to calculate the storm runoff volume, peak rate of discharge, hydrographs and storage volumes required for storm water management structures (USDA, 1975). Since its last revision in 1986, TR-55 has become a standard tool to analyze peak flow changes caused by urbanization in many locations (NRCS, 2002).

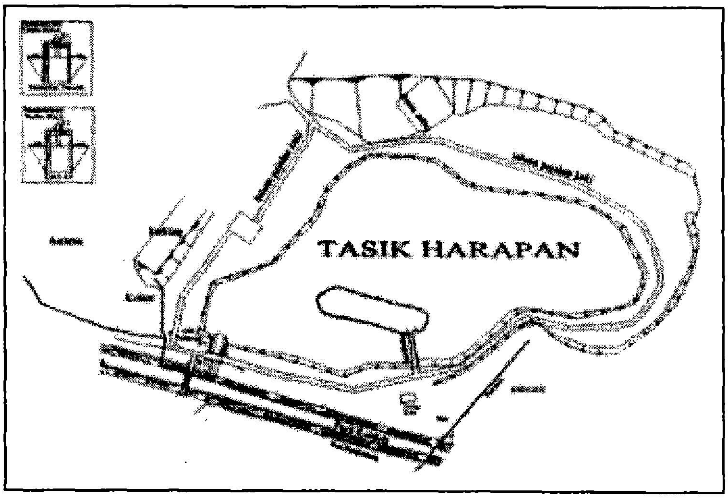

Figure 1. Tasik Harapan

2 Hydrogical Cycle

Seventy one percent of the earth's surface comprises of the ocean (Pidwirny, 2004). Therefore, it is not surprising that 86 % of the Earth's evaporation occurs over the oceans, while only 14 % occurs over land. Of the total amount of water evaporated into the atmosphere, precipitation returns only 79 % to the oceans and 21 % to the land. Surface runoff sends 7 % of the land based precipitation back to the ocean to balance the processes of evaporation and precipitation. There is a continuous cycle of water between catchments through several processes as shown in Figure 2. These processes can be simplified by dividing them into 5 parts, which are condensation, infiltration, runoff, evaporation and precipitation. Condensation happens when the state of matter change from vapor to liquid through cooling. Infiltration is the downward movement of water into layer of soils. Infiltration is controlled by soil texture, soil structure, vegetation and soil moisture status (Ritter, 2004). Runoff happens when there is a breach of soil infiltration capacity causing flow of water to lower elevations. Evaporation is the conversion of liquid water into a gaseous state which can only happens if water is available. Precipitation is a deposited state matter in liquid or solid forms that are developed in a saturated atmosphere and falls to the ground. The hydrologic cycle begins with condensation where water vapourizes to form clouds. When the clouds are saturated, the moisture is releasesd as precipitation, which can be in the solid or liquid form such as snow and rain. Infiltration, runoff and evaporation occur simultaneously. Precipitation seeps into the ground through infiltration process. If the infiltration occurs in a faster rate than the permeability of the soils, the excess will be discarded as runoffs. These runoffs will flow towards streams or rivers and eventually oceans or lakes. At the same time of the occurrence of infiltration and runoff, evaporation happens as the sun provides the energy for the change of water to gases. As shown in Figure 2, the runoffs will first accumulate in the lake before it flows to the river and eventually to the oceans. The existence of the lake helps to decrease the velocity of the runoffs thus overflow in the river will not happen drastically. When the lake is fully contained, the excess water will eventually flow to the oceans through the river slowly thus decreasing the possibility of a major overflow in the river which will cause flooding.

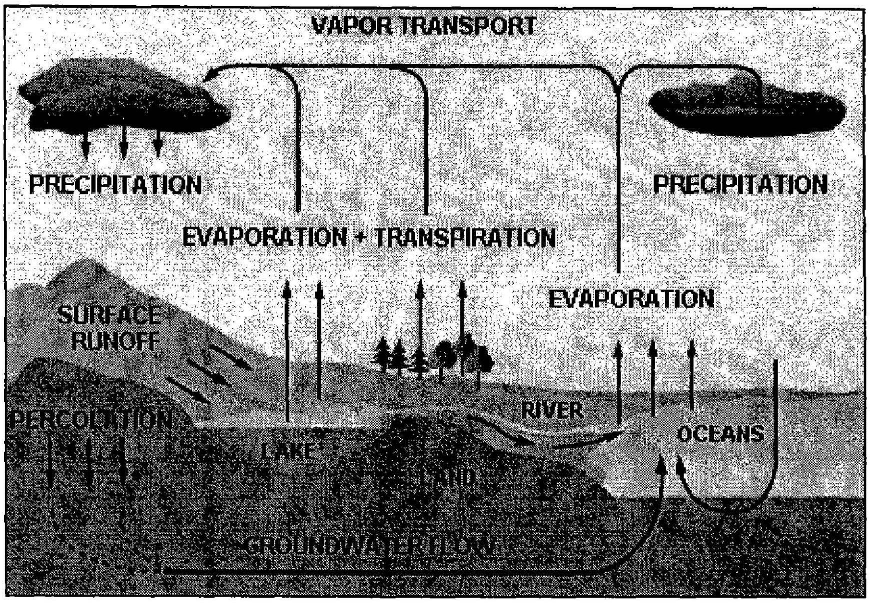

Figure 2. The hydrologic cycle

3 Topography and Hydrological Characteristics

The peak flows during storms in the past USM campus before development will be compared to the peak flows during storms in the present developed USM campus. The hydrological details of USM campus before development are not sufficient and not clearly portrayed. But it is known that previously, before development, USM campus is the site for army barracks. Therefore, three different cases indicating different topography of USM campus before development will be simulated. The hydrological characteristics of the present USM campus after development will be studied by dividing the USM campus into 8 subareas as shown in Figure 3. Adding the subareas will bring about a total of 222 acres. These divisions are made based upon consideration of several factors such as the land descriptions and the hydrological characteristics. Only the areas that are hydrologically connected to Tasik Harapan are considered. The hydrological routing between the subareas are simplified. A routing method such as as TR-20 (USDA, 2001b) or SITES (USDA, 2001a) should be used if the channel hydraulics requires a complex rating relationship. By analyzing the maps of the present USM campus obtained from the Development Department of USM, some parameters values indicating the topography and hydrology for each subareas can be estimated. These parameters values will form the database for the simulation of flood mitigation. The parameters values estimated are as listed in Table 1. Due to limited availability of rainfall database, simulation will consider both 6 inches and 4 inches of type III rainfall. Based upon past available data, there will be 4 inches of rain for approximately 2-year return period while 6 inches of rain are approximately for 4-year return period.

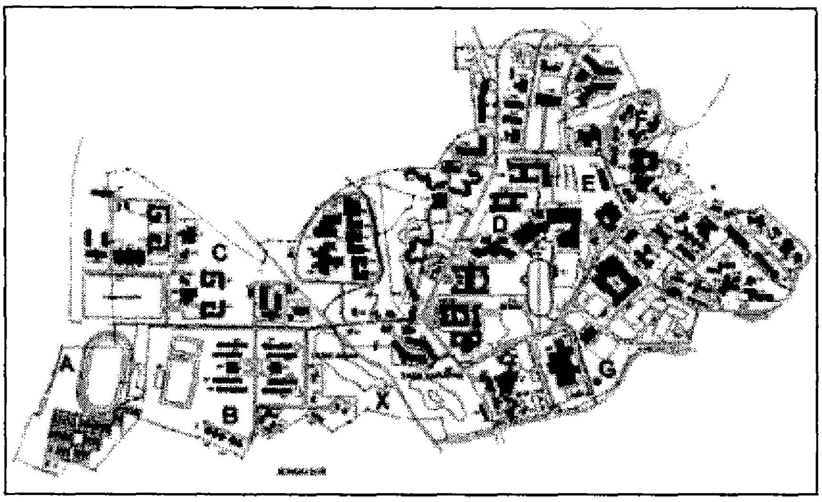

Figure 3. Subareas of developed USM campus

Table 1. Topography and hydrological characteristics of developed USM campus

Sub area	Area (acre)	Land Description	Down stream sub area	CN	Slope (ft/ft)	Length (ft)			Rainfall depth (inch)			
						Sheet flow	Conc flow	Chan-nel flow	6		4	
									Tc (hr)	Tt (hr)	Tc (hr)	Tt (hr)
A	11	Open space; fair condition; grass cover 50 % - 70 %; group B, Impervious areas	B	91	0.052	300	300	300	0.05	0.02	0.05	0.02
B	33	Open space; poor condition; grass cover < 50 %; group B, Urban districts; commercial and business; group C, Residential districts – 1 ac; group B, Impervious areas	X	93	0.025	300	890	840	0.15	0.12	0.16	0.12
C	45	Open space; poor condition; grass cover < 50 %; group B, Urban districts; commercial and business; group C, Impervious areas	X	92	0.063	300	500	980	0.07	0.04	0.07	0.04
D	56	Open space; poor condition; grass cover < 50 %; group B, Urban districts; commercial and business; group C, Impervious areas	X	92	0.048	300	780	1600	0.39	0.09	0.46	0.09
E	22	Open space; poor condition; grass cover < 50 %; group B, Urban districts; commercial and business; group C, Impervious areas	D	91	0.089	300	480	600	0.05	0.03	0.06	0.03
F	11	Urban districts; commercial and business; group C Impervious areas	E	95	0.089	300	180	480	0.04	0.02	0.04	0.02
G	22	Open space; poor condition; grass cover < 50 %; group B, Urban districts; commercial and business; group C, Impervious areas	X	94	0.175	300	280	560	0.03	0.02	0.04	0.02
X	22	Open space; fair condition; grass cover 50 % - 70 %; group B, Impervious areas, Streets and roads; paved; curbs and storm sewers	Outlet	81	0.125	300	400	760	0.05	0.03	0.05	0.03

4 Tc and Tt

4.1 Predevelopment

Time of concentration, Tc for each subareas and travel time through each subareas, Tt as listed in Table 1are obtained from TR-55 through the insertion of other parameters values in Table 1. The time that the water takes to travel from one location to another in a watershed is known as travel time whereas the summation of all the travel times for consecutive components of the subarea is known as Tc. The components referred to the sheet flow length, shallow concentrated flow length and open channel length. Tc and Tt will be used for further analysis to obtain the peak flows. The downstream subarea indicates the hydrological connections between the subareas. There is no downstream subarea for subarea X as the final outlet, Tasik Harapan, is located in the subarea X. The land surface for each subareas are assumed based upon site observation. As can be deduced from Table 1, the Tc varies from one subareas to another dependant upon many land characteristics of the subareas such as slope and land surface.

4.2 Postdevelopment

The areas of USM campus before development are divided into the same subareas as in the case of after development. Three different USM campus topography and hydrologic conditions before development are indicated by different CN values. The CN of 71 indicates a meadow type land with mediocre infiltration rate and the CN of 75 indicates a row crops land with mediocre infiltration rate (USDA, 1986). An open space with grass cover less than 50 % with mediocre infiltration rate is indicated by CN of 79. The land surface for each scenario is assumed based upon the CN values. The Tc and Tt for all three scenarios for 6 inches and 4 inches of rain are as shown in Table 2.

Table 2. Tc and Tt for each subareas with different CN

Sub area	Rainfall = 6 inches						Rainfall = 4 inches					
	CN=71		CN=75		CN=79		CN=71		CN=75		CN=79	
	Tc (hr)	Tt (hr)	Tc (hr)	Tt (hr)	Tc (hr)	Tt (hr)	Tc (hr)	Tt (hr)	Tc (hr)	Tt (hr)	Tc (hr)	Tt (hr)
A	0.32	0.03	0.25	0.03	0.12	0.03	0.38	0.03	0.30	0.03	0.13	0.03
B	0.53	0.14	0.44	0.14	0.25	0.14	0.61	0.14	0.50	0.14	0.28	0.14
C	0.33	0.07	0.27	0.07	0.14	0.07	0.39	0.07	0.32	0.07	0.16	0.07
D	0.42	0.13	0.35	0.13	0.21	0.13	0.49	0.13	0.40	0.13	0.23	0.13
E	0.28	0.05	0.22	0.05	0.11	0.05	0.33	0.05	0.26	0.05	0.13	0.05
F	0.26	0.02	0.20	0.02	0.09	0.02	0.31	0.02	0.24	0.02	0.11	0.02
G	0.20	0.02	0.16	0.02	0.07	0.02	0.24	0.02	0.19	0.02	0.08	0.02
X	0.24	0.04	0.19	0.04	0.10	0.04	0.29	0.04	0.23	0.04	0.11	0.04

5 Results and discussion

5.1 Rainfall depth of 6 inches

Figure 4 shows the hydrograph for each subareas for developed USM campus. The peak discharge for subareas that have longer distance from the final outlet occurs later as the travel time needed to reach subarea X is longer. But the occurrence of peak does depend on the length of the channels. The peak discharge for subarea D occur the latest between all subareas even though subarea D is located nearer to the final outlet when compared to other subareas. The reason is subarea D has a longest length of shallow concentrated flow and open channel flow. Subarea C captures more rain as it is a considerably large area, second to D. Furthermore, subarea C is considerably steeper than the subarea D. Therefore, subarea C has the highest peak flow.

In the present USM campus condition, approximately 5 inches from 6 inches of rainfall will be discarded as runoffs after some of the water infiltrate into the soil or retained by surface depressions. For 6 inches of rainfall for a 4-year return period, the total discharge for the past and present USM campus is as shown in Figure 5. The peak runoff for the present USM campus after development is 840 cfs while the peak runoff for the USM campus before development are 387 cfs, 483 cfs and 652 cfs with the CN values of 71, 75 and 79 respectively.

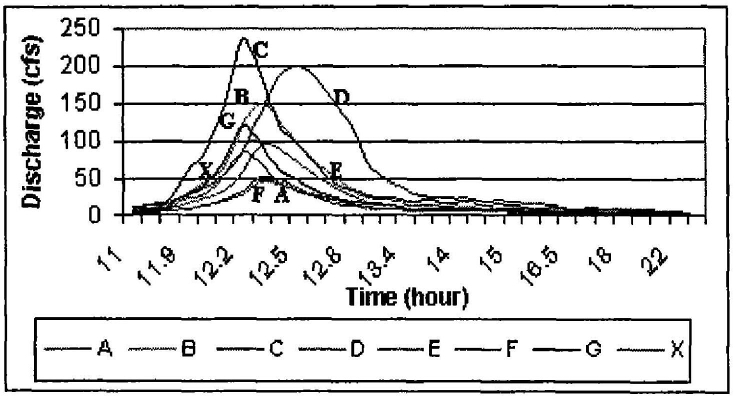

Figure 4. Hydrograph for subareas in present USM campus with 6 inches rainfall

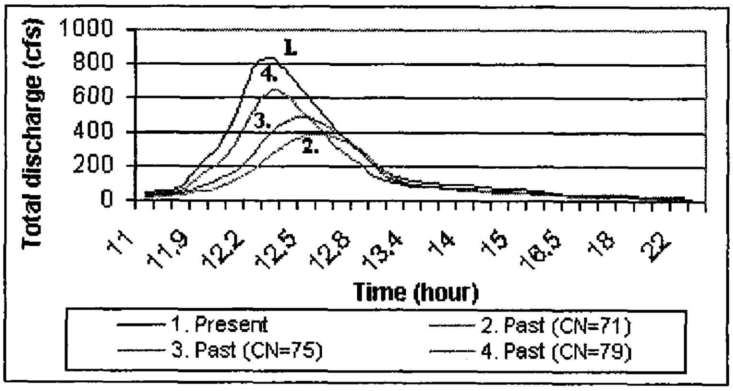

Figure 5. Hydrograph for past and present USM campus with 6 inches rainfall

Table 3 shows the detention basin storage needed to regain the past USM campus hydrological characteristics for 6 inches rainfall. To regain the discharges of the past USM campus represented by CN of 71, a detention basin storage volume of 27 acre feet is needed. This means that approximately 1.46 inches from 5 inches of runoff needed to be stored to regain the past USM campus runoffs. To regain the runoffs by CN of 75 and 79, the detention basin storage volume needed is 23 acre feet and 17 acre feet respectively. Therefore, 1.24 inches and 0.92 inches from 5 inches of runoffs need to be stored for CN of 75 and CN of 79 respectively.

Table 3. Detention basin storage volume needed for 6 inches rainfall

CN=71	CN=75	CN=79
27 acre feet (1.46 inches)	23 acre feet (1.24 inches)	17 acre feet (0.92 inches)

5.2 Rainfall depth of 4 inches

From Figure 6, it can be seen that the pattern of the peak flow of each subareas do not differ significantly when compared to the pattern of peak flow for 6 inches of rainfall. However, the peak flow for each subareas change significantly by a difference of approximately 100 cfs. This is not surprising as the rainfall depth is reduced causing lesser volume of runoffs. Approximately 3 inches from 4 inches of rainfall will be discarded as runoffs in the present USM campus. The total discharge for USM campus before and after development for 4 inches of rainfall for a 2-year return period is shown in Figure 7. The peak runoff for the present USM campus after development is 489 cfs while the peak runoff for the USM campus before development are 182 cfs, 234 cfs and 315 cfs with the CN values of 71, 75 and 79 respectively. The detention basin storage needed to regain the past USM campus hydrological characteristics for 4 inches rainfall is shown in Table 4. A volume of 19 acre feet need to be stored in order to regain the discharges of the past USM campus represented by CN of 71. Thus, approximately 1.03 inches from 3 inches of runoff need to be stored to regain the past USM campus runoffs. To regain the runoffs by CN of 75 and 79, the detention basin storage volume needed is 16.1 acre feet and 12.8 acre feet respectively which means that 0.87 inches and 0.69 inches from 3 inches of runoffs needed to be stored for CN of 75 and CN of 79 respectively.

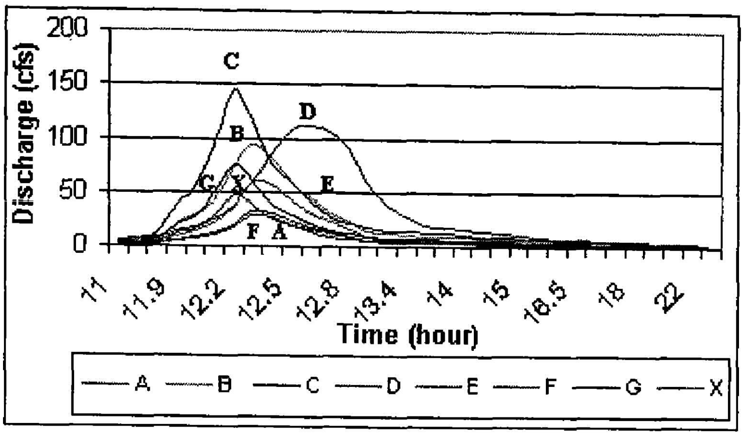

Figure 6. Hydrograph for subareas in present USM campus with 4 inches rainfall

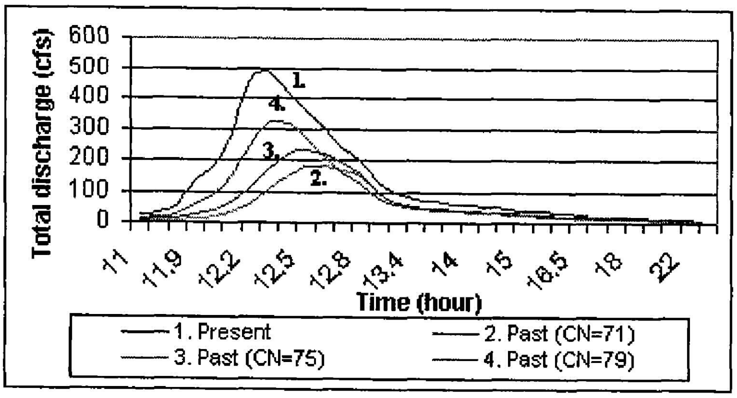

Figure 7. Hydrograph for past and present USM campus with 4 inches rainfall

Table 4. Retention basin storage volume needed for 4 inches rainfall

CN=71	CN=75	CN=79
19 acre feet (1.03 inches)	16.1 acre feet (0.87 inches)	12.8 acre feet (0.69 inches)

6 Conclusion

The extra storage volume of Tasik Harapan is approximately 6 acre-feet. Under 6 inches of rainfall for a 2-year return period, the storage volume needed to resume the past USM runoffs is approximately 3 folds the storage volume for Tasik harapan. Thus, flood under this condition is inevitable. On the other hand, a significant flood which occurred once every 4 years is not intolerable. Effectiveness of Tasik Harapan in this case though not at its best, Tasik Harapan is able to store one third of the runoffs which means that the severity of the flood is reduced by one third. For 4 inches of rainfall for 2 year return period, Tasik Harapan is able to reduce the runoffs by half. Therefore, there may be an occurrence of flood in 2 years period but the severity of the flood is reduced by half due to retention in Tasik Harapan. Hence, it can be concluded that Tasik Harapan is considerably effective in its function as a flood retention pond for 4 inches rain for 2-year return period. There are indications that TR-55 tends to over predict the results as the peak flows are the main consideration. Thus, there will be further study on the effectiveness of Tasik Harapan as a flood retention pond by using another model, SWMM4 which enable a better simulation of the study site in terms of characteristics of the hydrology.

7 Acknowledgement

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