

FLOOD MITIGATION MEASURES TOWARDS ACHIEVING ZERO FLOOD FOR SUNGAI KERAYONG CATCHMENT, SUNGAI KLANG RIVER BASIN

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ABSTRACT

Flash floods have caused a lot of distress to the people living in Klang River Basin; from long hours of traffic jam congestion, damages of cars, to the destruction of homes and business properties. Comprehensive flood mitigation measures have been implemented by the authority. However, the effectiveness of the flood mitigation measures is still being questioned since floods still occurs. Thus, this research aims to analyse, evaluate, predict and provide recommendations for flood mitigation measures towards achieving zero floods for Sg Kerayong river basin, a subcatchment of Klang River Basin. This research covers the development of a hydrodynamic model which is capable to simulate the integrated hydrologic and hydrodynamic analysis, production of flood forecasting maps in real-time simulation which in later stage to serve as an important data for flood relief operations as well as to propose environmental-friendly soft-structures with appropriate flood mitigation system. Flood maps for three different rainfall designs (50-year, 100-year and Probable Maximum Precipitation (PMP) events) are produced using river modelling - TREX. This study found that Kerayong River Basin has undergone quite comprehensive flood mitigation measures which include ponds and river rehabilitation. The model simulations indicate that the mitigation measures are satisfactory to cater for the 50-year and 100-year design rainfall. However, about 7% of the catchment areas are predicted to be flooded if PMP storm events occur. If rainwater harvesting is implemented in these areas, then peak discharge can be reduced by 39% and a reduction of 50% in peak discharge can be achieved if new materials such as porous rock matrix filters are used for open spaces such as parking or pavement.

Keywords: Flood; river modellin; flood mitigation; rainwater harvesting; porous pavement.

1 INTRODUCTION

Flooding is the most frequent and disastrous weather phenomenon for Malaysia ever since long time ago. The main cause of severe flooding in Malaysia is the heavy monsoon or convective rainfall. Flash floods have caused a lot of distress to the people living in Klang River Basin; from long hours of traffic jam congestion, damages of cars, to the destruction of homes and business properties. Comprehensive flood mitigation measures have been implemented by the authority including enforcing storage ponds for construction sites, improving river channel sections and building the SMART tunnel. However, the effectiveness of the flood mitigation measures is still being questioned since floods still occurs. A thorough investigation with accurate and up-to-date analysis and hydrodynamic modelling will help to gauge how effective are the flood mitigation measures at Klang River Basin and to provide recommendation towards achieving zero flood. This research focuses on implementation, types, maintenance and effectiveness of flood mitigation structures in Sg Kerayong river basin by developing a hydrodynamic model to simulate the integrated hydrologic and hydrodynamic analysis. Flood maps for three different rainfall designs (50-year, 100-year and Probable Maximum Precipitation (PMP) events) are produced using river modelling –Two-Dimensional Runoff Erosion and Export (TREX).

2 STUDY AREA

Sg Kerayong river basin is located at the Federal Territory of Kuala Lumpur and is considered to be one of the important branches of the main Klang River. Figure 1 shows the location of Sungai Kerayong river basin and its land use details. Most of the areas have been developed as residential and industrial areas. The width and length of the river are 20m and 30km, respectively. The catchment area is approximately 55km². The lowest and highest elevation is 33m and 400m, respectively.

The study site experiences the tropical rainforest climate, which is warm and sunny throughout the year. It receives more rainfall especially during northeast monsoon season between October to March. The average annual rainfall ranges from 2,500mm to 3,000mm. The maximum recorded rainfall for 1-hour duration is

94.5mm on June 1, 2010 according to the Department of Irrigation and Drainage (DID) (2014) based on the recorded data from 2007 to 2010 (DID, 2014).

Several factors had been analyzed by choosing Sg Kerayong as case study area. For instance, it was recorded some of the worst flooding events at Sg Kerayong in the past few years and the impervious surface of the area had increased by more than 95%.

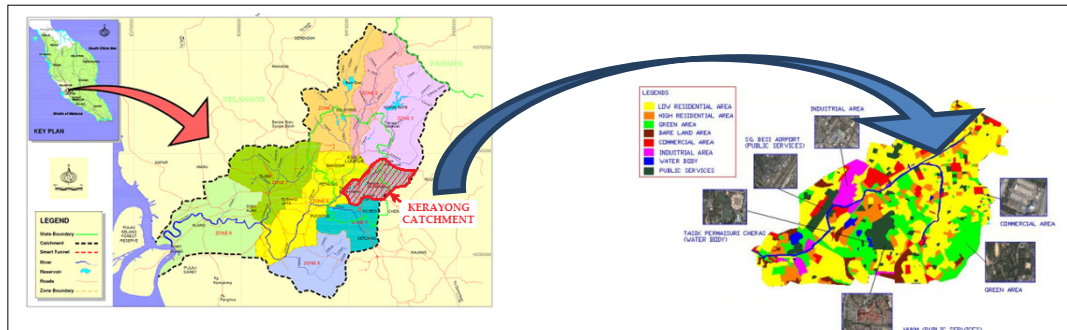


Figure 1. The location of Sg. Kerayong catchment area and landuse details.

3 METHODOLOGY OF STUDY

3.1 Data collection and analysis

The overall methodology of this research included the desktop study, data collection from the relevant agencies and the development of hydrodynamic modelling and flood forecasting mapping. Figure 2 shows the overall methodology.

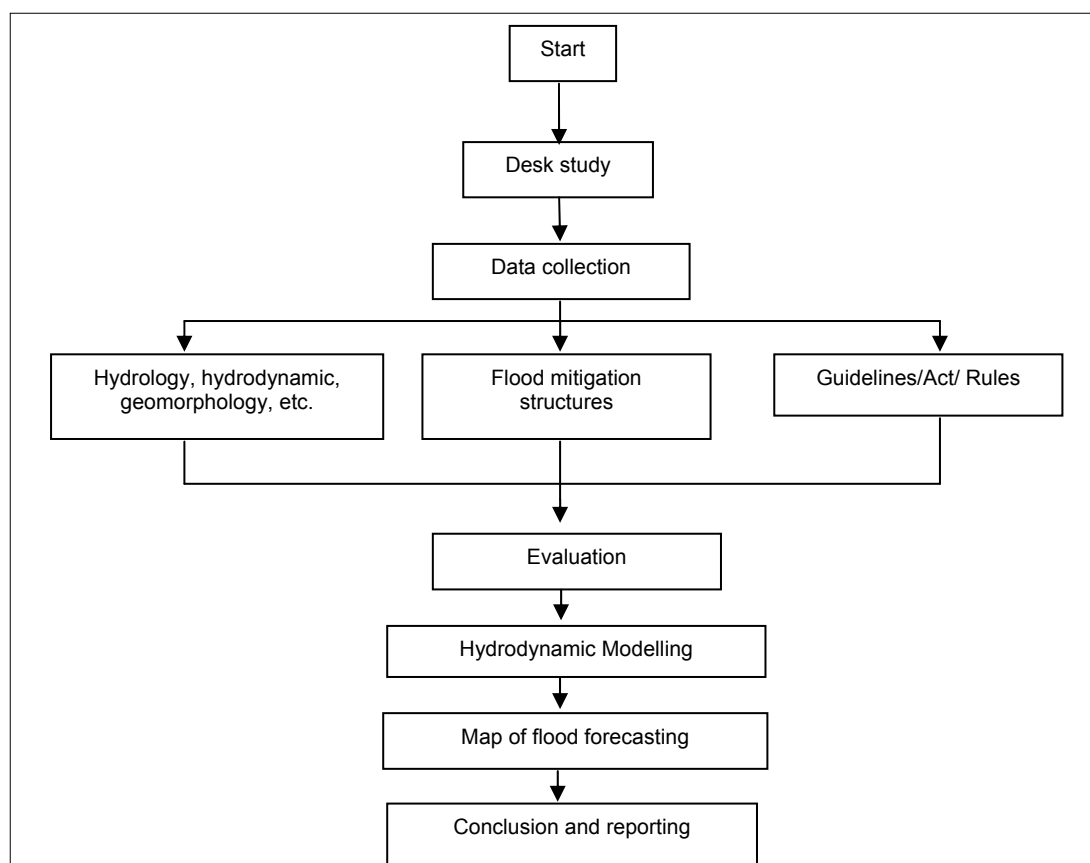


Figure 2. Overall research methodology.

3.2 Model set-up

3.2.1 TREX hydrodynamic modelling

Two-dimensional spatially distributed TREX model was used to simulate the relationship between rainfall and runoff. There were four (4) main hydrologic processes included in the TREX model: (1) rainfall and interception; (2) infiltration and transmission loss; (3) storage; and (4) overland and channel flows.

There were eleven (11) layers prepared using ArcGIS software. These layers had been prepared from four (4) basic data, *i.e.* Digital Elevation Model (DEM), soil type, land use and river flow direction. Figure 3 shows TREX hydrodynamic modelling for Kerayong River basin. The DEM was obtained from the DID with a resolution of 50m. Data for the channel flow and land use were obtained from DID and Department of Agriculture (DOA), respectively. The soil type was assumed to be limestone based on the geological map available from SMARTwebsite (DID, 2014).

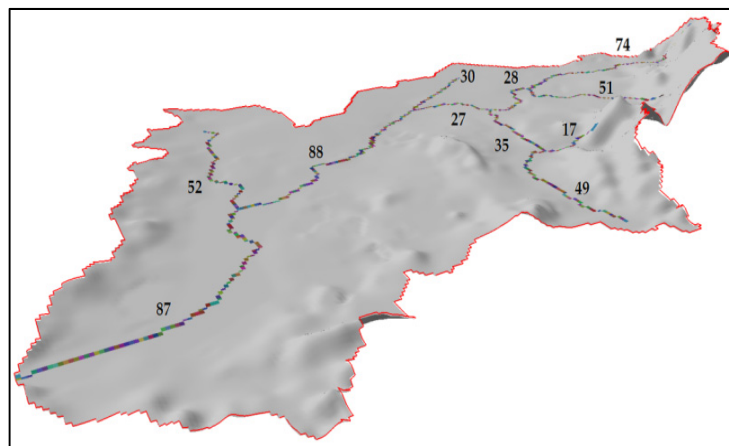


Figure 3. TREX hydrodynamic modelling.

The input data had to be tested by applying the impervious condition. The hydraulic conductivity value of soil was set to zero. The rainfall intensity of 50mm/hr was chosen. The rational method with runoff coefficient (C) equal to one (1) was used to compare the discrepancy between these two values (*i.e.* rational method and TREX model). The application of rational method is valid provided the hydrological simulations are: (1) the peak flow is reached when the entire watershed is contributing to the runoff and (2) the rainfall intensity is assumed to be uniform across the watershed and over the duration of rainfall.

The Relative Percentage Difference (RPD) and Percent BIAS (PBIAS) methods were used for the statistical analysis to check on the model performance. The RPD is the simplest statistical method among others used to calculate the differences between observed and simulated peak discharge, total volume and time to peak (Singh et al., 2005; Fernandez et al., 2005), while the PBIAS method is a statistical error analysis that measures the average tendency of the simulated results to underestimate or overestimate the observed data (Gupta et al., 1999). The summary of model performance evaluation for RPD and PBIAS methods is tabulated and shown in Table 1.

Table 1. General performance ratings to classify the performance of the model.

Performance Rating	RPD and PBIAS
Very Good	RPD, PBIAS $\leq \pm 10\%$
Good	$\pm 10\% < \text{RPD, PBIAS} \leq \pm 15\%$
Fair / Satisfactory	$\pm 15\% < \text{RPD, PBIAS} \leq \pm 25\%$

3.3 Calibration and validation

The calibration and validation procedure focused on the accuracy of simulated peak discharge, total volume and time to peak at the main outlet (*i.e.*, at the point-end-downstream of the river/channel). After the calibration process, another storm event was used for the validation purpose.

Based on the study conducted by Abdullah (2013), Velleux et al. (2006) and Velleux et al. (2008), the typical hydrologic sub model parameters subjected to be calibrated are hydraulic conductivity (K_h) and flow resistance coefficient (Manning's n). They also added that other hydrologic sub model parameters, such as interception, hydraulic suction head and dead storage are less significant in affecting the discharge magnitude.

During the validation processes, the rainfall-runoff relationship was simulated using calibrated parameters (K_h and n) without any changes. Before the validation process was made, the grid size analysis was conducted (this process was parallelly conducted during calibration). The main purpose of this process was to determine the most suitable grid size that can be used for further analyses. Four (4) different grid sizes were used; 90m, 150m, 210m and 270m. Storm event on April 2, 2008 was used for the calibration and grid size analysis purposes. Total rainfall for this event is 113mm which occurs for 3-hour of rainfall duration. This is the highest recorded rainfall and discharge. The calibration and validation procedure focused on the

accuracy of simulated peak discharge and time to peak at the main outlet (*i.e.*, at the point-end-downstream of the channel).

Tables 2 and 3 show the summary of the calibration (and validation) and grid sizes analysis, respectively. From the calibration analysis, the goodness-of-fit-test (GoFT) indicated that all grid sizes can reproduce the storm event on April 2, 2008 with an error of less than 10% based on the RPD matrix. The time to peaks were estimated with the highest lag time of 15 minutes. The lag value, for small catchment (definition of small catchment is less than 100km² as described by Singh (1995) and used by Abdullah (2013)), is still acceptable.

Table 2. Performance of the TREX model during calibration and validation processes.

CALIBRATION							
Grid Size (m)	Storm event	Q _{peak} (m ³ /s)			T _{peak} (Hour)		
		Obs.	Sim.	RPD (%)	Obs.	Sim.	Lag
90	02-Apr-08	184.4	175.9	4.6	19:00	19:06	0:06
150			201.3	-9.1		19:15	0:15
210			203.7	-10.4		18:48	0:12
270			164.8	10.6		18:51	0:09
VALIDATION							
Grid Size (m)	Storm event	Q _{peak} (m ³ /s)			T _{peak} (Hour)		
		Obs.	Sim.	RPD (%)	Obs.	Sim.	Lag
90	16-Apr-08	68.9	55.0	20.1	17:00	17:15	0:15
150			56.9	17.4		18:45	1:45
210			41.8	39.3		18:45	1:45
270			72.3	-5.0		17:09	0:09
90	27-Aug-08	97.2	61.9	36.3	19:00	20:12	1:12
150			73.2	24.7		21:00	2:00
210			95.8	1.4		18:00	1:00
270			87.9	9.5		18:06	0:54
90	14-Dec-08	36.1	42.1	-16.5	15:00	15:48	0:48
150			37.7	-4.4		16:15	1:15
210			21.6	40.2		17:06	2:06
270			55.8	-54.5		15:09	0:09
90	26-Feb-09	91.4	78.7	13.9	16:00	16:02	0:02
150			86.5	5.3		16:06	0:06
210			68.7	24.8		17:12	1:12
270			120.0	-31.3		16:00	0:00
90	24-Mar-09	54.1	74.4	-37.6	09:00	09:02	0:02
150			80.2	-48.3		10:02	1:02
210			71.6	-32.4		09:32	0:32
270			104.2	-92.7		09:00	0:00

Table 3. Grid size analysis for Kerayong River Basin for storm event on April 2, 2008.

GRID SIZE (m)	Simulation Time		Q _{peak} (m ³ /s)			Time to Peak (Hrs.)			Volume (m ³)		
	Secs.	Mins.	Sim.	Obs.	RPD(%)	Sim.	Obs.	Lag time	Sim.	Obs.	PBIAS
90	3,708	60	176	184	-4.4	20:06	19:00	0:06	669,879	731,985	8.5
150	160	2.68	201		9.4	20:15		0:15	765,120		-4.5
210	222	3.7	204		10.7	19:48		0:12	752,017		-2.7
270	45	0.75	165		-10.4	19:51		0:09	1,048,352		-43.2

Table 3 shows the simulation time for smallest grid size was about an hour and decreasing for coarser grid sizes. The simulation time for the calibration was less than five minutes for grid size more than 150m. Most of the grid sizes overestimated the volume of water except for smallest grid size, which was underestimated by 8%. However, the simulated volume using 270m grid size was unacceptable by which the difference between simulated and observed was more than satisfactory criteria, *i.e.* 25%. From this study, a conclusion can be made that the 90m grid size was suitable for flood map and 150m can be used for real time simulation. The model performance reached at least the satisfactory criteria in replicating these storm events (*i.e.* peak discharge and time to peak) when 90m grid size was used. For the 150m grid size, the model

estimated time to peak with 1 hour lag time after the observed. Overestimating the peak discharge can be found for 270m grid size. Similar conclusion was also made by Abdullah and Julien (2014). They concluded that for a small watershed (less than 100km²), the appropriate grid that can be used to represent the water depth distribution is less than 90m of grid. Figure 4 shows the distribution of water depth for storm event on April 2, 2008 at different grid sizes.

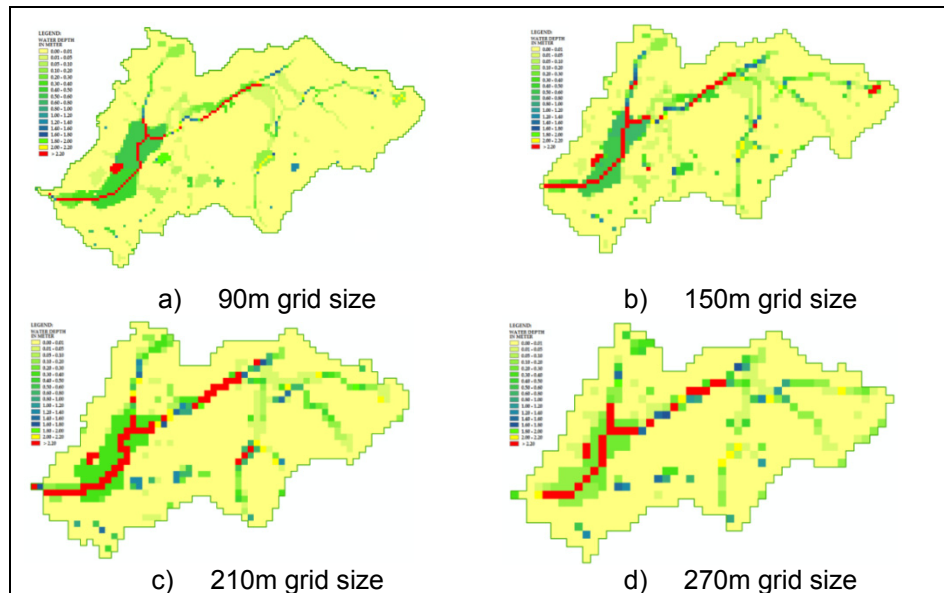


Figure 4. Distribution of water depth for storm event on April 2, 2008 at different grid sizes.

4 RESULTS AND DISCUSSIONS

4.1 Flood map

The flood maps were produced based on the 50-year, 100-year and Probable Maximum Precipitation (PMP) data. The objective was to produce flood forecasting map using real-time simulation that can evaluate and assess the flood damage caused by flooding. These rainfall events occurred for two (2) hours duration. The rainfall intensities for 50- and 100-year were obtained from DID (2012) and PMP was obtained from NAHRIM (2008). Kirpich's formula was used to calculate the rainfall duration.

Table 4. Rainfall intensity for 50-, 100-year and PMP.

	Rainfall Intensity (mm/hr)	Maximum discharge(m ³ /s)
50-year	56	185
100-year	62	238
PMP	288	3,786

According to Abdullah (2013), the discharge magnitude of PMP event is between 6 and 15 times larger than discharge for 100-year Average Recurrence Interval (ARI). From this study, the estimated PMP peak discharge was 15 times larger than peak discharge for 100-year ARI. The maximum water depth was 0.3 meter which recorded for 50- and 100-year ARI. The water depth more than 1.0 meter can be found only in the channels.

The 50-year ARI storm event was similar to the calibration storm event (refer to Table 2). An additional of total rainfall by 10mm did not change much on the water depth distribution. The existence of two ponds gives a lot of advantage in ponding excess water from overtopping the channel. The flood prone area was increased when high rainfall intensity was used. The 288mm/hr of rainfall intensity was simulated to estimate any possible flood area for the PMP storm event. Low-lying areas which had an elevation less than 35m were found prone to be flooded (Figure 5c). The grid size less than 150m is recommended for flood mapping purpose so as more accurate representation of the actual scenario can be obtained.

For the purpose of real time simulation to obtain faster result, to be used for flood forecasting for example, grid size between 150 and 210m is recommended. Most of the low-lying areas are covered by houses and business center. Using the design rainfall of 50- and 100-year return period as the input to the model, the flood maps produced were analyzed and were found that none of the area was seriously inundated. It can be concluded that the existing flood mitigation system (*i.e.* Taman Seri Desa and Sri Johor Ponds) are reliable to reduce the magnitude of flood. The maximum rainfall intensity of these cases was

62mm/hr. However, the overland water depth estimated had reached beyond 2.2m when the rainfall intensity was increased by 5 times from 62mm/hr to 288mm/hr (PMP storm event). The flooded area was estimated to be 7% (approximately 4.0km²) which occurred at low land as shown in Figure 5(c). The flood map can be used to assess flood damages knowing the values of the infrastructure and properties in the inundated areas.

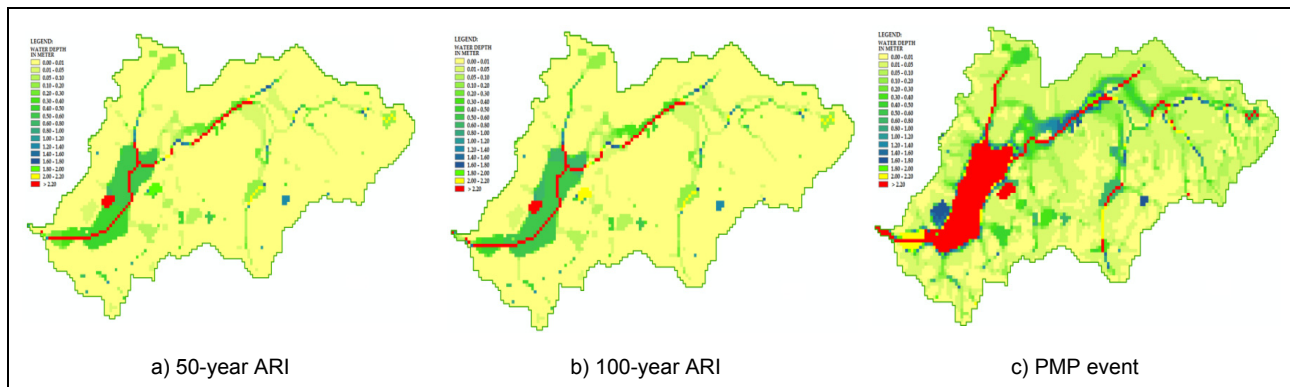


Figure 5. Water depth distribution for 50-, 100-year and PMP event.

4.2 Environmental-friendly soft structures for flood mitigation system

Flood protection measures can be structural or non-structural (soft) such as source control, zoning, flood proofing, insurance and flood forecasting system (Menzel and Kundzewicz, 2003). Watershed management which focuses on the source control is a concept used in minimizing the surface runoff, erosion and sediment transport. It includes vegetation cover management in which the concept of ‘catching water where it falls’ by enhancing storage of water on the land surface, is applied.

Another method used is green infrastructure such as installations of distributed stormwater controls such as porous pavement, bio-retention structures, green and blue roofs, infiltration systems and rain water harvesting system.

There were two different approaches considered in this study: 1) introducing more pervious and higher roughness surface materials and 2) installing rainwater harvesting system at residential and businesses areas. For the first approach, the 100-year storm event was used to study the effectiveness of this approach. A selected area which covers around 7% of Kerayong Catchment located at the flood prone area was replaced with more pervious surfaces with high roughness values. The simulated value of peak discharges was found to be reduced to 117m³/s from the original value of 283m³/s. The results show that the peak discharge can be decreased by 50% from the existing condition if there are more pervious surfaces with higher infiltration rate installed, especially at the upstream of the catchment. For the second approach, the alternative to reduce runoff was by storing the rainwater through rainwater harvesting concept. Figure 6 shows the potential residential and businesses areas for installation of rainwater harvesting system.

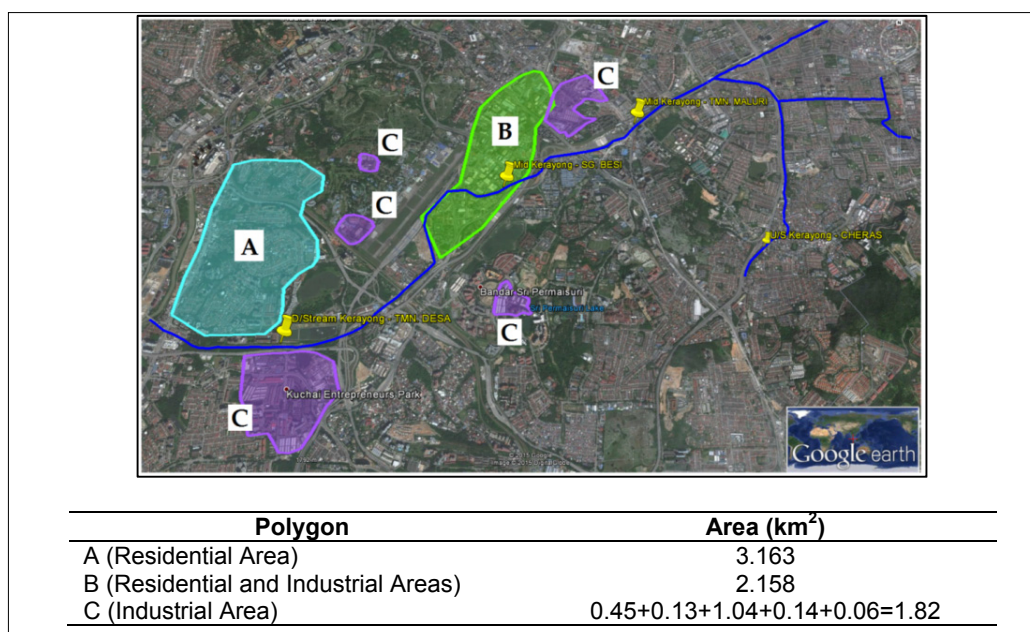


Figure 6. Potential locations for installation of rainwater harvesting.

Table 5 shows the estimation of harvested water based on four scenarios for the location of rainwater harvesting. The simulation showed that 39% of peak discharge can be reduced if a rainwater harvesting system was installed at various selected residential and businesses areas.

Table 5. Estimation of harvested water for rainwater harvesting.

No	Scenario	Harvested area (km ²)	Harvested water (m ³ /s)	Percent of reduction for peak discharge (%)
1	Installing rainwater harvesting at area A only	3.16	41	17
2	Installing rainwater harvesting at area B only	2.16	28	12
3	Installing rainwater harvesting at area C only	1.82	24	10
4	Installing rainwater harvesting at area A, B and C	7.14	92	39

5 CONCLUSIONS

It can be concluded that, as long as the flood mitigation measures at Sg Kerayong such as concrete channelization, rehabilitation with good floodplain, retention ponds are well maintained, there will be a reduction in flood risk. Many curative actions have been taken by related agencies in reducing the impact of flood in Kerayong River Basin. Hydrodynamic modelling using TRES is able to simulate the relationship between rainfall and runoff, and to further produce flood maps. Soft structures such as introducing pervious surfaces with higher roughness materials are installed in upstream of catchment, which could help in reducing peak discharges up to 50%. On the other hand, through installation of rainwater harvesting at all the residential and businesses areas, approximately 39% of peak discharge can be reduced. All these measures are suggested to be implemented especially in urban and flood prone areas like Kerayong River Basin which could help in achieving towards zero floods.

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