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# Flood Mitigation Measures in Urban Areas of Malaysia Using the Integrated Catchment Modelling Approach

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**Abstract.** Integrated catchment modelling has been used to provide non-structural measures for the mitigation and management of urban flood prone areas. This paper aims to demonstrate a model-based approach through flood mapping that generates multiple simulation results of flood mitigation alternatives for the Sungai Gombak basin. Hydrological and hydraulic analysis, as well as hydrodynamic modelling were carried out using Infoworks Integrated Catchment Modelling (ICM) to evaluate the changes of flood extent caused by different structural components. Rainfall analyses were carried out through the computation of rainfall-runoff and design storms at various return periods and durations. Historical rainfall and stage data were used in the calibration process before the design storm events were fed into the hydrological model. Simulation of the design floods were run under different return periods, storm durations, and land use conditions. The results show that the existing rivers downstream of Sungai Gombak can only provide a flood protection level of 5 to 20-year Average Recurrence Intervals (ARIs). The main cause of frequent flooding can be attributed to the rapid change in catchment land use as development has far exceeded the Kuala Lumpur Structure Plan 2020, and the lack of compliance to the practices recommended in Manual Saliran Mesra Alam (MSMA). The findings suggest that bridge constriction removal is the key solution and that its combination with other flood mitigation works would significantly reduce the flood levels. In conclusion, the study provides useful results and a technical proposal for the authority, and successfully recommends further improvements in flood mapping practices for future studies.

## 1. Introduction

Flooding is one of the most common and harmful natural hazards affecting societies around the world. The average annual losses between 1980 and 2012 accumulated to 23 billion USD [1]. The effects of climate change on the hydrological systems are anticipated due to the global warming phenomena, such as severe floods and droughts [2]. A common approach to mitigate the flood problems can be divided into two main categories, structural and non-structural measures. According to the Department of Irrigation and Drainage (DID) of Malaysia [3], the structural measures in flood mitigation work refer to a choice of solutions by installing structures and implementing physical improvement works directly at the cause of flooding. These include river widening, deepening, and straightening, which target a decrease in the extent of flooding, but may simply transfer the flood problem downstream. Structural measures include building, channel improvement, flood bypass, pumping, flood storage dams, and flood detention basins. On the other hand, for non-structural measures, some tools can be used to quantify the effects of human interference with the river system, such as computer models, flood forecasting and warning, flood zoning and risk mapping, and resettlement of the affected population [4]. According to SEPA [5], floods that occur from time to time cannot be prevented entirely. This is because, sometimes, an area of dry ground is inundated temporarily due to the overflowing of water at the natural or artificial bank of a stream [6][7]. According to Rafiq et al. [8], floods can occur at a high stage in the river water course, in a stream, or tributary, or a water reservoir. Thus, the analysis of flood control plan performance in reducing flood damage before actual implementation is an essential aspect of flood mitigation planning. The implementation of these measures involves huge capital expenses and human capacity, especially in terms of a structural approach. It is necessary to carry out an analysis to understand the impact of such measures in the reduction of flood damage and various scenario analyses are needed to choose the best alternative. The simulated results portrayed that the model could be used effectively in flood control management activities in river basins. However, urban flooding in the city centre becomes a major problem in highly populated areas like the Sungai Gombak basin. In 2009 to 2014, the area of Sungai Gombak experienced a series of storms and major flood events [9]. Many properties that had never been flooded before were inundated to a height above floor level. Table 1.1 shows that despite the increase in the recorded rainfall of 20% in the Gombak basin in the year 2014 compared to 2009, the water level at Jalan Tun Razak was managed to control flooding with an increase of only 0.5%. Presumably, this was due to the completion of Package B, Batu-Jinjang Pond Schemes in 2011. However, the situation in the area surrounding Jalan Tun Razak still experienced floods of 1.15m in depth. Therefore, this study is crucial to investigate and fully understand the root causes of the problem in the Sungai Gombak basin prior to formulating the flood mitigation alternatives. This study aims to develop a model-based approach through flood mapping that generates multiple simulation results to find optimal flood mitigation alternatives that are applicable to the Sungai Gombak basin. The current flood mitigation measures will be evaluated and implemented in Sungai Gombak. Through this study, the flood hazard map is also developed by using the Integrated Catchment Modelling (ICM) approach. Hence, the improvement of the flood control alternative measures are recommended for the reduction of flood damage.

## 2. Methodology

The development of a river and flood model can be divided into three main components, which are hydrology, hydraulic, and floodplain. These three components are interrelated and integrated to produce a reliable and interactive hydrodynamic model. Rainfall analysis includes the processing of historical data, and the derivation of design rainfall events of various return periods and durations of the historical rainfall, and flow data were used to calibrate the hydrological model. After the calibration, analysed simulations of the calculated model were found to be reliable and consistent with the recorded flows on site. Once the model was calibrated, design storm events were fed into the hydrological model to simulate design floods under various design conditions like different return periods, storm durations, and land use conditions. The flows simulated from the hydrological model were later assigned into the hydrodynamic model to investigate the flow characteristics along the river system for both historical conditions as well as for various design alternatives. The hydraulic analysis was conducted in order to evaluate the capacity and conveyance of the existing rivers in the Sungai Gombak catchment. The catchment discharge from the historical flood and design storm events served as primary input to the hydraulic model. Subsequently, the flood flows were simulated to determine the flood water levels, discharges, and flow velocities in the river channels and hydraulic structures. Various flood mitigation measures can then be formulated and evaluated for their effectiveness concerning the runoff from the present as well as future land use conditions.

### *2.1. Study area*

The Sungai Gombak basin is located on the west coast of Peninsular Malaysia between 3° 8.725'N to 3° 22.390'N latitude and 101° 40.953'E to 101° 47.996'E longitude. The area is encompassed by the State of Selangor at the upper section while the lower section falls within the Federal Territory of Kuala Lumpur. Sungai Gombak is the tributary of Sungai Klang whereby the confluence is located at the Masjid Jamek building about 2.5 km downstream from the confluence of the Sungai Batu and Sungai Gombak. A flood gauging station is located upstream of the confluence Batu-Gombak near to Jalan Tun Razak. Sungai Gombak flows through two districts – Gombak and Kuala Lumpur – which are under the jurisdiction of Majlis Perbandaran Selayang (MPS) and Dewan Bandaraya Kuala Lumpur (DBKL), respectively. Generally, the urban development dominates the catchment, although there are a few squatter settings. The main tributary of the Sungai Gombak basin is Sungai Kemunsing. As shown in Figure 1, Sungai Gombak has a total drainage area of 116 km$^2$ with a length of approximately 35 km and average bed slope of 1.6%. The catchment of Sungai Gombak, which is located between the Sungai Batu catchment and upper Sungai Klang catchment, covers some areas from the Hospital JHEOA at the north to the DBKL headquarters at Jalan Parlimen.

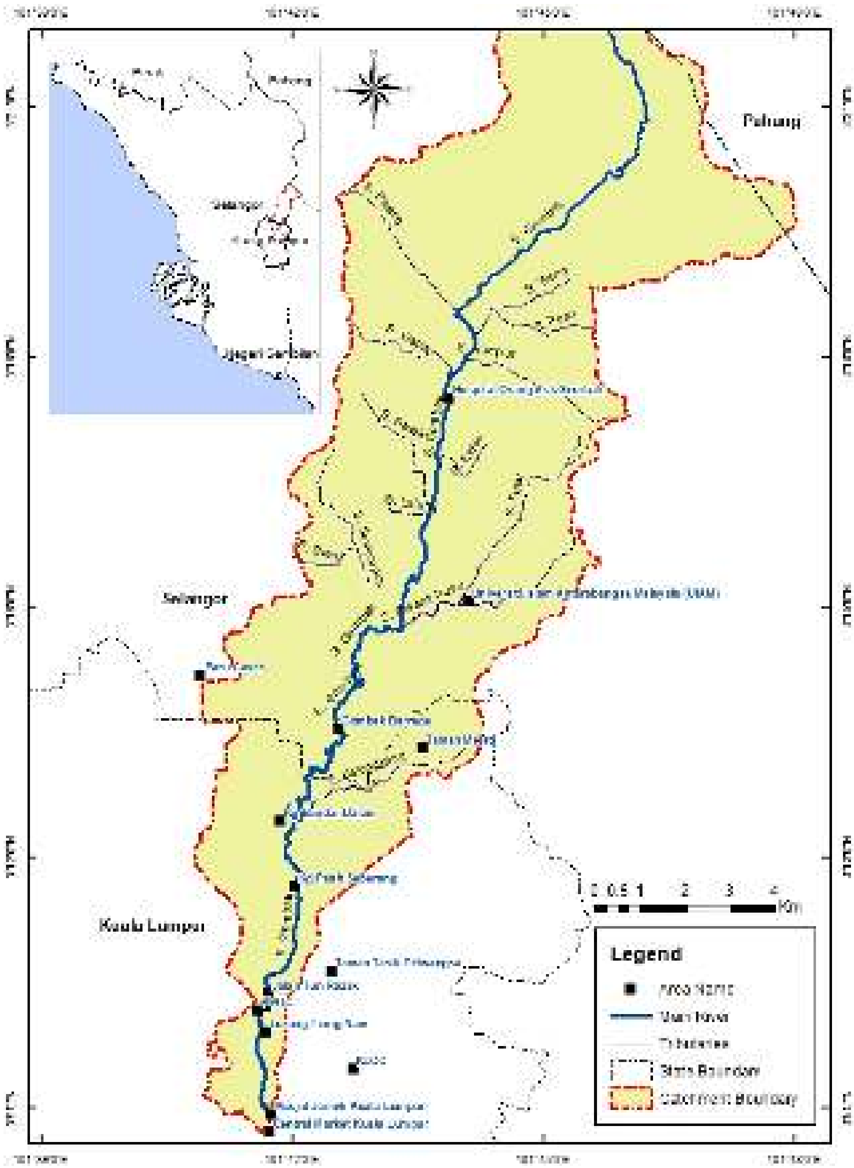


**Figure 1.** Sungai Gombak catchment area.

*2.2. Hydraulic and hydrological components*

The principal hydrological analysis for river and floodplain modelling involves the development of rainfall-runoff modelling with various requirements. A delineation of the sub-catchment is needed to present all the major tributaries of the main river. The size of the catchment should be small to reduce errors in hydrological calculations. The characteristic of each sub-catchment, such as slope, land use, and time of concentration are determined using GIS.

For the hydraulic component, the development of the river and floodplain are divided into two components – the in-bank model and the out-bank model. The in-bank model consists of all related features that influence water flowing within the riverbank without spilling over to the floodplain. The most critical information for the in-bank and out-bank models are river cross-section, riverbank, floodplain data or digital terrain model, and infrastructure, such as road, bund, and storage area.

### *2.3. Hydrodynamic modelling and analysis*

As mentioned in the hydrological and hydraulic components, the descriptions give a detailed working process of preparing and formulating the input for the hydrodynamic modelling works. The outputs from these two analyses were gathered as an input into the model to perform various hydrodynamic simulations. The essential parameters include the hydrological characteristics of the sub-basin and river basin morphological information, which were assembled and used to develop a hydrodynamic model for the Sungai Gombak basin. Various simulations were conducted including the event-based calibration, sensitivity analyses of the storm durations and simulation of various average recurrence intervals. The model was simulated in 2D computation mode. Simulations were carried out using Infoworks ICM, which is an unsteady 1D and 2D computer model, with a capability to compute the flow and water level along the river through structures, such as culverts and bridges. The software was developed by Innovyze, United Kingdom. It deployed a full St. Venant equation that is capable of modelling open channels including structures, such as bridges, culverts, weirs, and gated structures [10]. The software was used to provide water levels along the channel that would indicate flooded areas once the water level exceeds the ground level. The floodplain was considered as the storage area or conveyance system using 2-Dimensional computations. It was designed to handle a big river network while taking into consideration the provided infrastructure. The software was used to generate a flood map using either 1D or 2D floodplain techniques.

The drainage and flood plain analyses were divided into catchment model, 1D river modelling, and 2D flood plain modelling. The catchment discharges from the historical events and design flood events were the main input of the hydrodynamic model. Historical flow was simulated by applying historical storms into the rainfall-runoff model while the design flood flow was obtained using the design storms as input. Design storms of various durations and return periods were used to simulate the design flow. The derived flow was then defined in the model setup as a point of inflow into the sub-catchments with the exact tributary outfalls, while the distributed flow boundary type was defined for the sub-catchments without actual river outfall.

## 3. Results and Discussion

The main catchment for the hydrologic model is available from the Integrated Flood Forecasting and Warning System for the Klang Valley (iFFRM) model. Further enhancement of the sub-catchment was carried out based on the latest ground survey data. The required input for the model is river network, river cross sections, time series data (as boundary conditions), initial water levels, and Manning’s roughness coefficients (as hydrodynamics parameters). The river network was digitized into the model either from the topographical maps or the survey plans. The configurations of all the hydraulic structures and waterway crossings, such as weirs, bridges, and culverts, which have a significant influence on the hydraulics of the river flows, were also defined at the specified chainages of the river. The whole of the Sungai Gombak system, where survey data was available, was modelled as one system. A topographical description of the modelled river system was achieved through the specification of cross-sections for the channel and floodplains, which were approximately perpendicular to the flow direction. The existing river cross-sections were modelled based on the chainages provided in the survey plans.

### *3.1 Model calibration results*

The model was calibrated with a hydrodynamic model of a flood event on 25th December 2014. The result of the calibration simulation at Jalan Tun Razak station is shown in Figure 2. The overall comparison, as shown in Figure 3, indicates that the peak and shape of the hydrograph for the simulation is in good agreement. However, it can be seen that there is a time difference between the observed and the simulated model, which may lead to inaccuracy in the modelling. It is important to mention the limitations of the modelling to ensure that modellers and researchers are aware of various problems that may arise in the future. Many disturbances that occurred in the channel may cause an error in the flood level estimation. The presence of rubbish and boulders leads to a reduction of the channel capacity and is not properly addressed in the model. Calibration was carried out based on a single event at Jalan Tun Razak. The only suitable data used were the observed water level since no rating curve was available. The water level at this location is highly influenced by the capacity of the in-flow discharge from Sungai Batu downstream of the Jalan Tun Razak station with an unknown flow rate due to the lack of recorded water level station at this confluence. From the calibration plots, it can be seen that the model is able to simulate the river flow at the key locations of the study area. Analysis of the flood extent along Jalan Sultan Azlan Shah (Jalan Ipoh) and Jalan Tun Razak is shown in Figure 4. The flood extent is almost similar to the recorded value with the depth of flooding more or less than 1 metre.

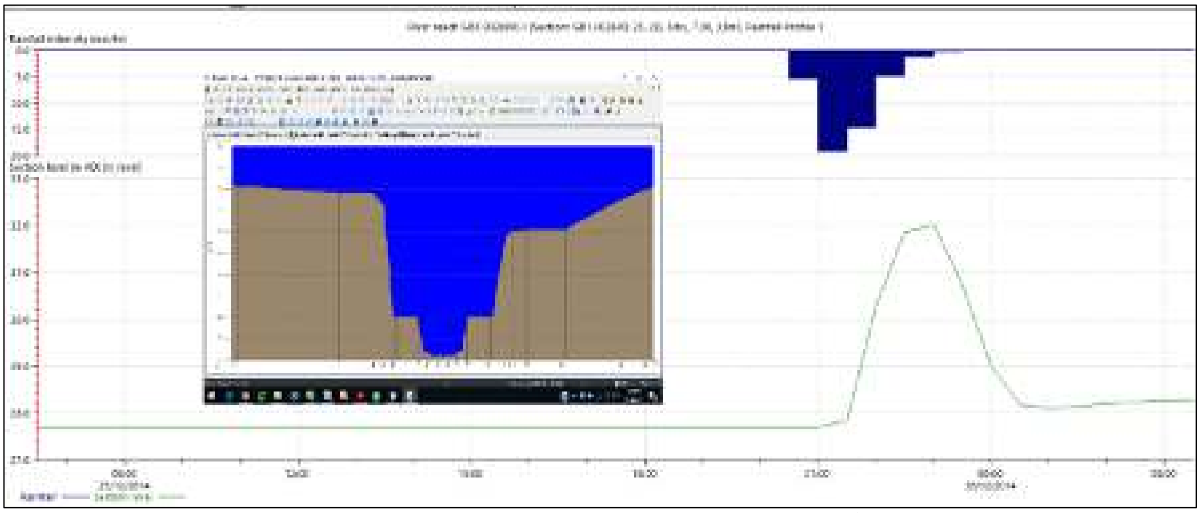

**Figure 2.** Simulated results at Jalan Tun Razak station on 25th December 2014.

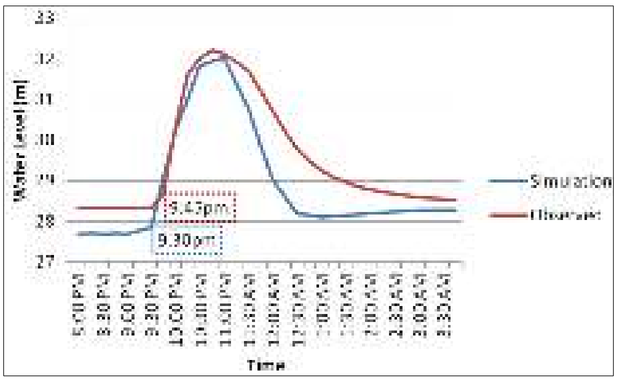


**Figure 3.** Comparison of hydrograph between the observed and simulation results on 25th December 2014.


**Figure 4.** Flood extent from simulation results on 25th December 2014 along Sungai Gombak.

### *3.2. Causes of flood and runoff control*

With the implementation of the SMART project and the Batu-Jinjang Pond Schemes (KLFM), flood occurrences still persist within the study area, in particular at PWTC, Lorong Tiong Nam, and Jalan Tun Razak. Hence, it is crucial to investigate and fully understand the root causes of the problem before formulating flood mitigation proposals. From the observed historical flow recorded at the Sungai Klang and Sungai Ampang confluence (SMART gauging station), there have been numerous occasions where the recorded peak flow exceeded the 100-year ARI design that has a discharge of $280m^3/s$ [11]. The flows, which are higher than the design flow event, are suspected to be one of the main factors that contribute to the flood events at Kuala Lumpur city centre.

In validating the suspected increased inflow to the Sungai Klang Basin, GIS analysis on the change of land use was carried out by comparing the available historical satellite image records. Two sources of satellite images were used for the comparison analysis; the first image was captured in 2001 by Landsat ETM+ and the second image by Landsat 8 in 2014 representing the current land use condition. The superimposing of the two images shows the land use changes in the Sungai Klang Basin from 2001 to 2014. New settlement areas, agriculture land, forestry and water areas were identified and demarcated into the GIS to extract and tabulate the surface areas. The land use analysis was carried out and a summary of the percentage of impervious areas in the Sungai Klang Basin is given in Table 1. The results show that a significant increase in the impervious areas occurred for settlement and reduced forestry in the Sungai Klang basin land use. Therefore, it can be inferred that the rapid development in Sungai Klang Basin is one of the main causes of the increase in flood flows into the Klang river system that resulted in flood occurrences at the Sub-catchment Gombak areas even after the completion of the Batu-Jinjang and SMART flood mitigation schemes.

Besides the rapid development of the Sungai Klang basin beyond the Kuala Lumpur Structure Plan 2020 [12], another factor that would have a significant impact on the increase in flood flow is the effectiveness in implementing runoff control at source under the Manual Saliran Mesra Alam (MSMA). When the KLFM Master Plan was formulated, it adopted the assumption that MSMA should be implemented at 50% effectiveness for all new developments starting from year 2000 (ADB, 2003). However, if the current effectiveness in the implementation of MSMA is less than 50%, there will be an increase in catchment runoff, thus stressing the river system beyond its design capacity. Both GIS analysis and hydraulic modelling were carried out to analyse this possibility.

Based on the study and analysis by SMART [11], the result shows that the current effectiveness of the MSMA runoff control at source is about 25% in the Sungai Klang basin. With only 25% effectiveness of the MSMA runoff control implemented on the ground, which is lower than the design 50% MSMA effectiveness assumed during the formulation of the KLFM Master Plan, the actual flood flows discharged into the Sungai Klang system actually exceeds its design flow capacity. Therefore, it is deduced that the current effectiveness of the MSMA runoff control, which is below 50%, is one of the main reasons that frequent flooding still occurs at the Kuala Lumpur city centre despite the full operation of the recently completed flood mitigation schemes. The Sungai Klang and its main tributary Sungai Gombak traverse the city centre of Kuala Lumpur that has intense development. Over the past few decades, development has occupied most of the natural river reserves leaving only enough space for construction with concrete-lined river channels and maintenance access.

As the pressure for the city's transportation increased, more bridges were built. Many of which are now causing constrictions to flow due to the narrower river sections beneath them. The advent of the LRT for the city with numerous bridge piers on and along the river berms with stations built on top or next to the rivers has caused a detriment in the river conveyance and the surrounding areas. In an attempt to recoup the lost natural river habitats, rock cascades were also constructed. As such features were carried out without considering the flood conveyance required in the river channels, such blockages with the massive siltation immediately upstream would invariably cause flooding in the upstream areas. There are also numerous remnants left behind by previous construction activities, natural outcrops, old structures, etc. which present bed obstructions to the flood flows.

### *3.3. Map and mitigation measures*

With the hydrodynamic model set up and calibrated, various model runs were undertaken to simulate the flooding conditions at the Sungai Gombak. If all the assumptions and implementation of flood mitigation works fully comply with the proposed KLFM Master Plan, the city centre of Kuala Lumpur should be guaranteed with 100-year ARI protection by the two completed major flood mitigation schemes (Batu-Jinjang scheme and SMART project). However, as discussed before, the catchment land use and flow conditions have deviated significantly from the original Master Plan. Hence, the overall KLFM scheme is inefficient and has caused flooding of the city to perpetuate. In order to evaluate the present capacity of the Sungai Gombak system, 20-year ARI and 100-year ARI design rainfalls were applied to the hydrology and hydraulic models to generate the flood profiles along the rivers.

The 100-year ARI maximum simulated flood level for existing condition along Sungai Gombak is shown in Figure 5 while the 20-year ARI maximum simulated flood levels along Sungai Gombak are shown in Figure 6. From the simulated 20-year and 100-year ARI maximum flood levels, it is observed that most stretches of Sungai Gombak are below the 20-year ARI flow capacity, with some stretches having ample protection compared to the unprotected stretches. The maximum flood level immediately downstream of the Batu-Jinjang scheme is comparatively lower even under the 20-year ARI flood condition with ample protection. However, at the critical locations, such as PWTC, Lorong Tiong Nam, Jalan Sultan Azlan Shah (Jalan Ipoh), and another part of Kuala Lumpur city centre, the protection level can only cover 5-year to 10-year ARI floods.

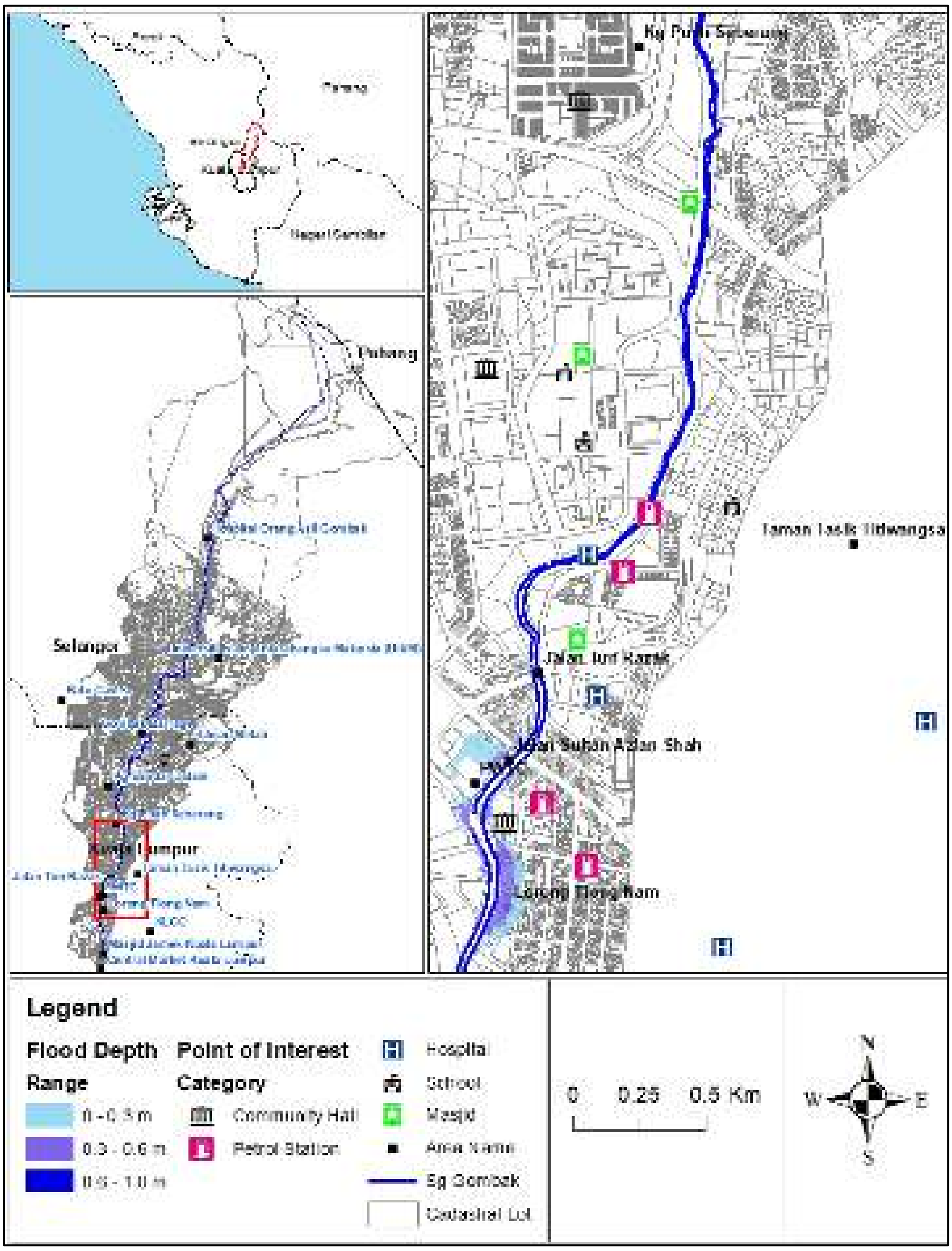

**Figure 5.** Flood map for existing condition (20 ARI)

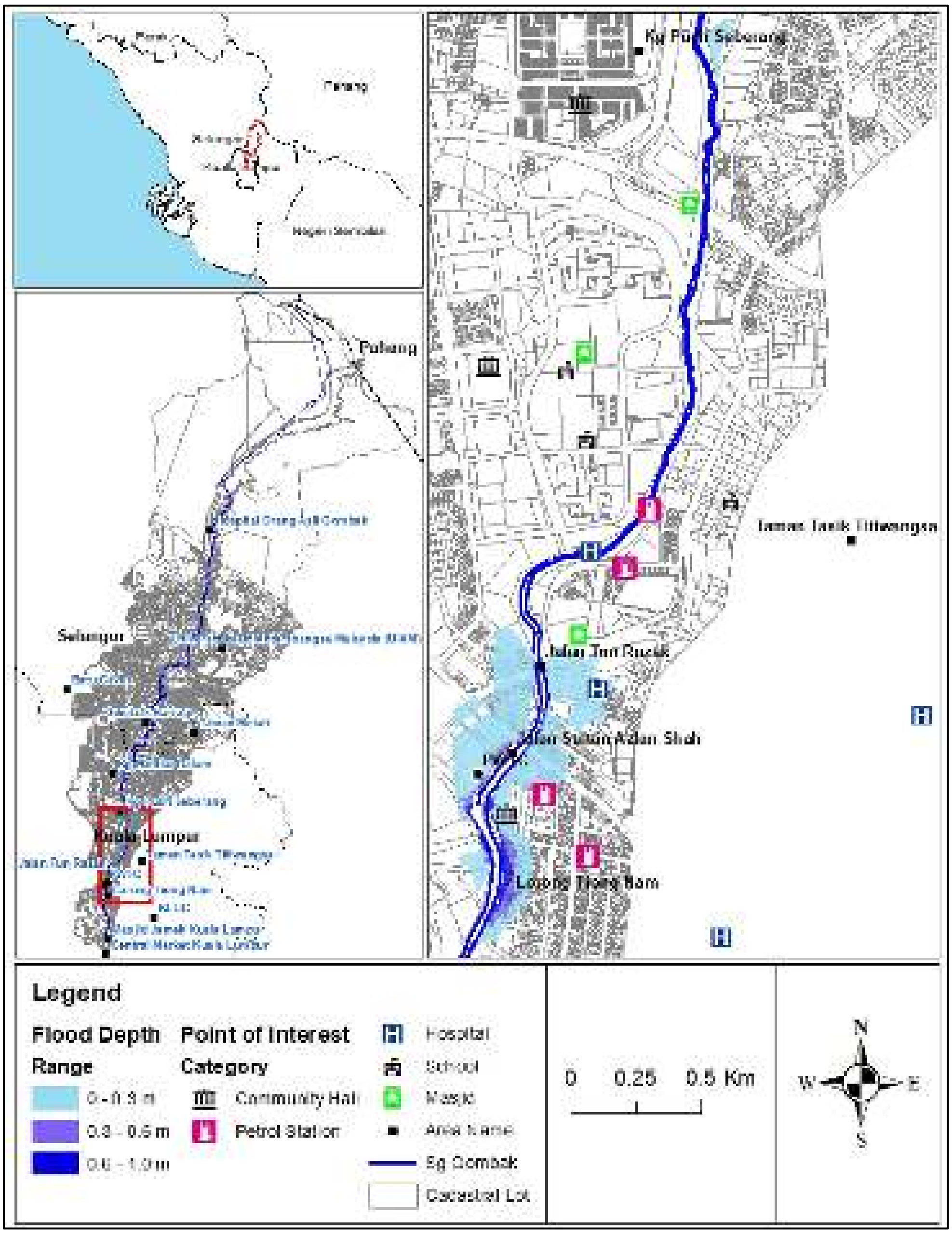


**Figure 6.** Flood map for existing condition (100 ARI)

The causes of flooding can be identified from the hydrodynamic simulations of the existing condition and the design storm event scenario. With the known causes of flooding, various flood mitigation strategies were incorporated in the model and simulations were carried out to test the effectiveness of the options for reducing floods in flood-prone areas, especially at Jalan Tun Razak, PWTC, and Lorong Tiong Nam. The multiple simulation methods were used to find optimal flood mitigation alternatives based on 20-year ARI and 100-years ARI floods.

One of the main causes of flooding in recent years is the increased runoff due to rapid development in the Sungai Klang basin beyond what was planned in the Kuala Lumpur Structure Plan 2020. It is understood that the existing operation rules of the Sungai Gombak Diversion scheme are designed based on catchment runoff derived using the 2020 Structure Plan and not on the increased runoff from the actual development. Therefore, one of the most immediate flood mitigation options that can be carried out to mitigate flooding in Kuala Lumpur is to revise the existing operation rules and optimize them to cater for higher flood discharge. This includes setting up a higher overriding threshold to divert more flood water to the Batu Detention Pond system and optimize the gate opening and closing sequence to capture higher flood peaks. For the modelling analysis, existing overriding rules are amended to allow all upstream floodwater to be diverted into the Batu Detention Pond instead of releasing it to the city centre when it breaches the threshold. The model simulation results show that the water level downstream of the Gombak Barrage inlet reduced significantly. For the 100-year ARI design storm, the flood level at Jalan Tun Razak reduced by 1.5 m from 34.5 m LSD to 33 m LSD. The water level at PWTC reduced by 0.9 m from 33.6 m LSD to 32.7 m LSD, as shown in Figure 7. The water level immediately upstream of the Gombak Barrage diversion weir increased to 48 m LSD for the 100-year ARI.

The rock cascades in Sungai Batu and Sungai Gombak at PWTC caused obstructions to river flows and are the main contributors to flooding at PWTC. The adverse impact is most obvious for the rock cascade in Sungai Gombak, which has caused heavy siltation and a substantial reduction in the channel section upstream with its effect extending well beyond the upstream bridge. The reduced flow capacity below the bridge has very often caused flood water to overspill the roadway into the PWTC exhibition area. In the Alternative 2 model run, on top of the optimization of the SMART operation rule, the PWTC rock cascades are removed to see their impact on the flood profile. Figure 11 shows that removing the rock cascades without removing the bridge constrictions causes the water level at PWTC to increase around 0.3 to 0.6m because more floodwater is transferred downstream but backed up by the downstream bridge constrictions. Therefore, removing the PWTC rocks cascades without removing the downstream bridge constrictions does not improve, but, in fact, exacerbates the flood condition at PWTC.

Since removing the PWTC rock cascade without removing the downstream bridge constrictions is counter-productive to relieve the flooding conditions, Alternative 3 was tested in which the Gombak Diversion operation rules were optimized for total flow diversion with bridge constrictions removed. Figure 12 shows the simulated 100-year ARI flood profiles along Sungai Gombak for Alternative 3. It can be seen that optimizing the Gombak Diversion operation rules and removal of bridge constrictions reduces the 100-year flood level by about 1.5m at Jalan Tun Razak and 1.2m at PWTC.

Alternative 4 is an additional scenario to Alternative 2; smoothing of the riverbed is performed from the Gombak Barrage to Jalan Tun Razak. Smoothing the bed involves desilting and deepening of the riverbeds including removal of bed obstructions in order to increase the conveyance capacity of the river channels. Figure 13 shows the simulated 100-year ARI flood profiles along Sungai Gombak when Alternative 4 is implemented as compared with Alternative 2. The average flood reduction in Sungai Gombak downstream Gombak Barrage inlet is 0.2m. It is observed that, at PWTC, the water level increased by 0.4m from Alternative 2 to Alternative 4. This is because smoothing of the riverbed causes more water to be conveyed downstream during floods and the water level will rise if the downstream bridge constrictions still exist.

Alternative 5 consists of the flood mitigation components of optimizing the Gombak Diversion operation, removal of the PWTC rock cascades, smoothing of the riverbed, and the removal of bridge constrictions. Constrictions at the bridges are to be removed to enhance the conveyance capacity of the river channels. Constrictions at bridges caused by narrow cross sections and large piers will be rectified through removing the berms and widening the channel sections underneath the bridges. The simulated 100-year ARI flood profile along Sungai Gombak for this alternative is given in Figure 11. Removing bridge constrictions produces a very good reduction in floods levels in Sungai Gombak by about 2m at Jalan Tun Razak and 2.2m at the PWTC area compared to Alternative 4. A similar reduction in the 100-year ARI flood level at Lorong Tiong Nam occurs with 2 m. It can be seen from the Alternative 5 flood profiles that very few locations of riverbanks will be overtopped, and the flood level at Jalan Tun Razak will be detained within the riverbanks with no freeboard. Flooding will be mitigated if flood walls are constructed along the riverbanks to create the affected stretches.

**Figure 7.** Flood profile based on Alternative 1.

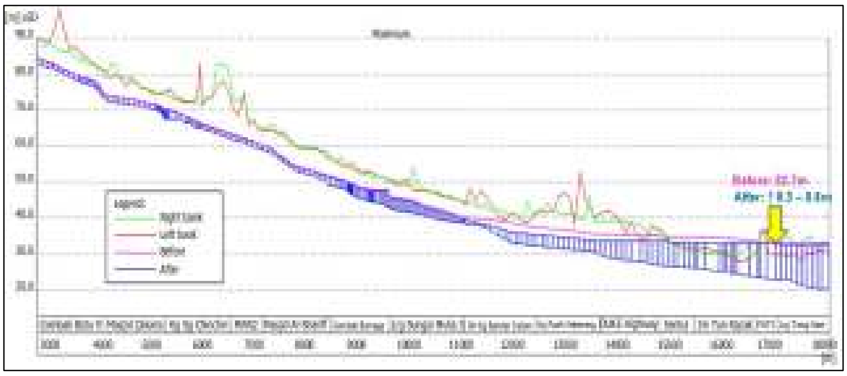

**Figure 8.** Flood profile based on Alternative 2.

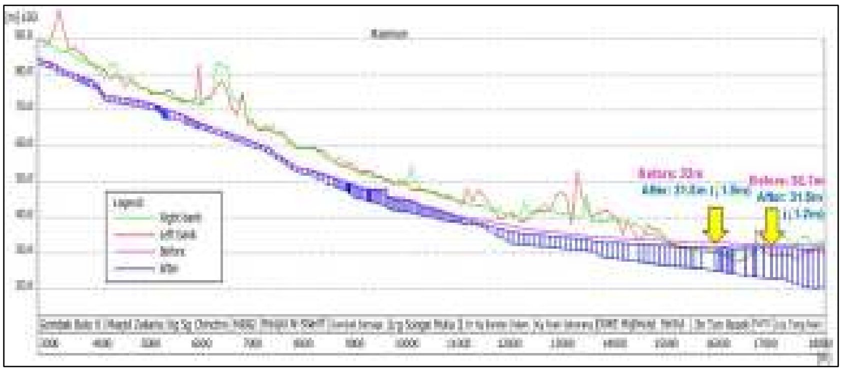

**Figure 9.** Flood profile based on Alternative 3.

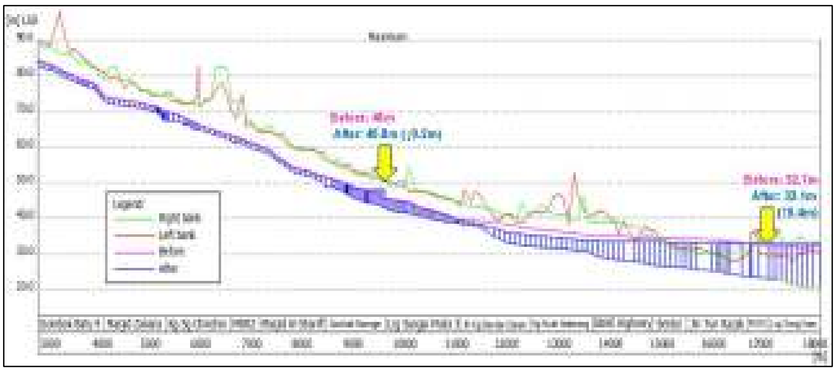

**Figure 10.** Flood profile based on Alternative 4.

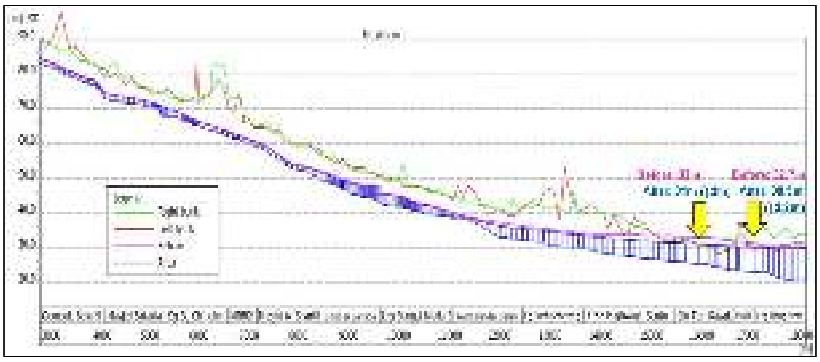

**Figure 11.** Flood profile based on Alternative 5.

With the implementation of all flood mitigation components in Alternative 5, the river stretch within the study area can contain the 100-year ARI design flood. No significant case of overtopping of banks will happen at the very few low-lying areas. The flood hazard maps for various ARI were prepared to show the performance of the flood mitigation option. As the main river model was developed for the purpose of design, some modifications were made to convert the model to produce flood inundation indicators. The flood plain was represented by 2D for which the information was obtained from DTM, which is available from the iFFRM project. The simulated 100-ARI flood map for Sungai Gombak under the Alternative 5 flood mitigation scheme shows that the Sungai Gombak basin can fit the 100-year ARI flood. Flooding at localized low lying areas can be mitigated by constructing floodwalls. The average difference between the 100-year ARI and 20-year ARI flood level profile along Sungai Gombak, from Jalan Tun Razak to the Lorong Tiong Nam area is about 1m. The output of the flood map was analysed and the findings are tabulated in Table 1.

**Table 1.** Flood inundation area under existing conditions and Alternative 5 flood mitigation

| Condition | Range of flood depth | Flood inundation area (hectare) | |
|---|---|---|---|
| | | 20 ARI | 100 ARI |
| Existing conditions | 0 to 0.3 m | 5.17 | 29.20 |
| | 0.3 – 0.6 m | 3.16 | 7.08 |
| | 0.6 – 1.0 m | 0.01 | 1.22 |
| | Total | 8.34 | 37.50 |
| Alternative 5 flood mitigation | 0 to 0.3 m | 0.29 | 1.31 |
| | 0.3 – 0.6 m | 0.10 | 0.77 |
| | 0.6 – 1.0 m | NIL | 0.30 |
| | Total | 0.39 | 2.38 |

## 4. Conclusion

An integrated catchment model was developed to evaluate the flood protection level under existing conditions and with the mitigation schemes of the Sungai Gombak catchment. The study found that substantial reaches of the existing rivers downstream of Sungai Gombak can only provide a flood protection level for 5 to 20-year ARIs. The main cause of frequent flooding can be attributed to the rapid changes in catchment land use as development has far exceeded the development planned under the Kuala Lumpur Structure Plan 2020 land use and the lack of compliance with the MSMA practices. Other factors, such as bridge constrictions and obstructions in the river channels, and rock cascades are also identified as causes of flood flow at certain areas.

It was found that a significant improvement in reducing the flood level can be observed by removing bridge constrictions, smoothing the river channel beds, and removing the rock cascades. To further improve the situation and attain the 100-year ARI protection, the Gombak Diversion operation rules can be optimized to convey more flood water into the Batu Detention Pond during major flood events, thus reducing flood flow to the city centre. The recommended flood mitigation works well in Alternative 5.

The presence of new infrastructure like the DUKE Highway (Lebuhraya Duta – Ulu Klang) in the Gombak catchment area has led to many new development projects along the stretch of Sungai Gombak. The increased urbanization and spread of impervious area, and diversification of land use will cause runoff impact on the receiving water flow, water quality, and ecology. Urbanization causes the rivers to suffer from an increased rate of runoff volume and pollutant discharge. The discharge poses major problems, such as frequent flash flood occurrence in residential areas. Due to the insufficient capacity to carry the increased runoff, the drainage systems in all the residential and business areas need to be investigated. In both options – the 20-year ARI and 100-year ARI protection – there are pockets of localized low-lying areas where flood proofing may be required. In addition, the effect of climate change will cause an unpredictable rise in flood levels.

The study recommends that the flood evacuation zones map should be adopted in upcoming studies. The flood evacuation zone map is a zonal map that is produced based on a combination of flood extent boundaries for various ARIs. The zones are proposed to have a few categories of degrees of flood risk (highest to lower risk) based on the flood recurrence interval. The map can be used by the response agencies and residents to plan for evacuation during floods. To produce better flood hazard maps, all of the related control structures in the study area should be considered in the model to improve the accuracy. The reliability of the model is required to simulate the flood water that will spill on the flood plain when it reaches the infrastructure level. The improvement of the hydraulic survey, such as floodwalls, ponds, and pumps in the model development, will lead to an enormous improvement in the model accuracy under the normal conditions during the flood events.

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