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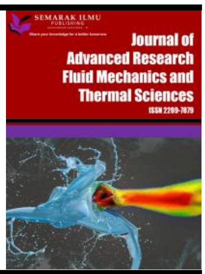


# Housing Estate with Flood Resilience: Merging Housing Features and Drainage Design

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**ABSTRACT**

This paper describes the human intervention to increase flood resilience in a housing estate. Stormwater storage facility is a structure designed to temporarily hold water, in which such a structure was tried for underneath the car porch and front road of a terrace house. A design rainfall of 5-minute, 10-year average recurrent interval intensity was selected for urban runoff analyses. A row of 12 terrace houses with a land area 2,472 $m^2$ was selected as the study area. An intervention was formulated, in which it consisted of the car porches embedded with a series of underground water storage facilities having 46.9 $m^3$ of effective storage volume and receiving water from 820 $m^2$ of catchment area; combined with the front road embedded with a series of underground water storage facilities having 55.2 $m^3$ of effective storage volume and receiving water from 278 $m^2$ of catchment area. The characteristics of the intervention in the study area were represented through Storm Water Management Model version 5.0 to simulate the urban runoff in pre-development and post-development conditions, as well as the intended intervention. The results showed that the intervention had reduced 54% of peak flow compared with post-development condition. The intervention also achieved flow nearest to the pre-development condition. No overflowing was predicted in the drainage system.

## 1. Introduction

This study is manipulating the space underneath a residential car porch and the space underneath a road in front of a residential house. In Malaysia, it is a house-buying criteria to offer spacious car porches for residential houses. This is because a majority of residential house owners keep one or more cars. Therefore, most of the car porch for a residential house is spacious enough to fit two cars at the same time. The car porch of the residential houses can be an effective location for an underground stormwater storage facility if the stormwater from the roof is directed to the car porch. In addition, the road in front of a residential house has large surface area. Typically, the road in front

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of residential houses is a two-way road. An underground stormwater storage facility underneath the front road can directly capture the urban runoff.

A housing estate is a product of urbanization, in which large number of houses are built at the same time covering a large surface area [1,2]. This type of land use changes the nature of the formerly forested land area which could take in the rainwater by plant roots and soil infiltration. Instead, the forested lands are converted to hard surfaces, particularly the built-up area for houses and roads. Rainwater hitting on these hard surfaces is no longer going into the ground but accumulated above the ground forming a substantial amount of urban runoff or running water [3].

The existing design of housing estate is equipped with a drainage system to channel away the generated urban runoff. As depicted in Figure 1, a single property lot has perimeter drain, usually in nominal size, to drain runoff from the roof, patio and garden out of the lot [4].

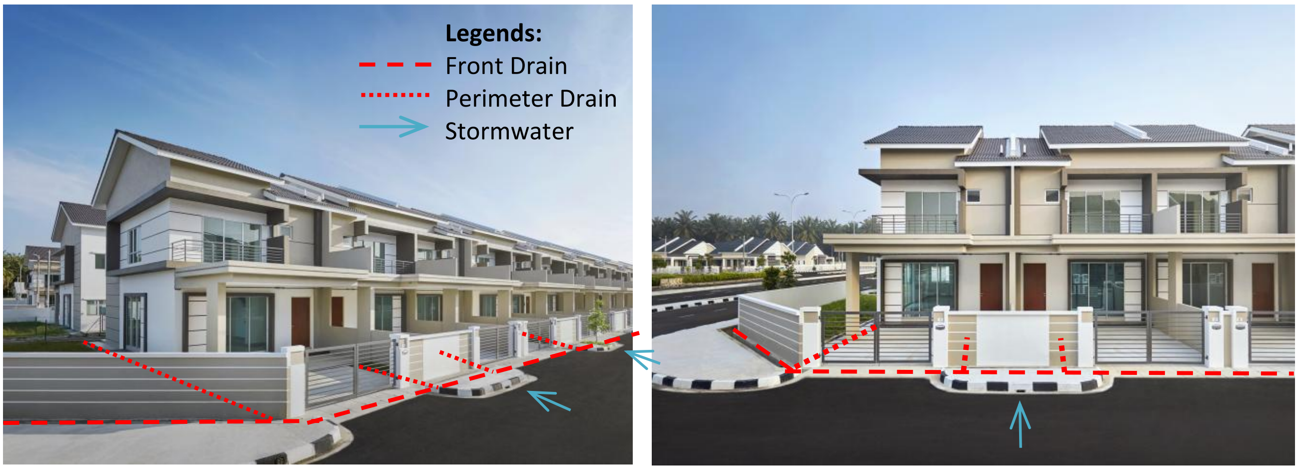



**Fig. 1.** Housing estate selected as study area

A row of terrace houses has a stretch of drain in front and at the back of the houses. As highlighted in the same figure, a front drain acts as the receiver of runoff from the front portion of each property lot and the road surface in front of the houses via stormwater inlets. The runoff is eventually drained away to a final discharge point. Similar flow patterns occur for the back drain that receives waters from the property lots and back lane.

As the numbers of housing estate are growing, the amount of urban runoff being generated is increasing as well. More and more runoff volumes are being discharged to the urban drainage system. During rainy seasons, high volume of running waters travel through the network of drain and eventually, congestion of water could occur, particularly at the downstream stretches. Flash flood would follow when the drain is overwhelmed with the running waters. These urban floods have caused a lot of negative effects to the areas affected. The urban flooding endangers life, private properties, and public infrastructures; erodes banks, and channels of waterways; and contaminates streams and rivers in urban areas [5].

There is a need to increase the flood resilience in housing estate which would be a long-term solution [6]. Engineers are trying to introduce interventions to the built-up area of buildings and roads so that the volume of urban runoff could be controlled [7,8]. Urban runoff volume is targeted to restore to the pre-development condition, in which manmade structures are introduced to mimic the function of plant roots and ground layer to hold water.

A stormwater storage facility could be designed to temporarily store water during heavy rainfall periods to reduce the urban runoff [9,10]. After that, the runoff is slowly released at a controlled rate to prevent urban flooding. Slow releases of water into the nearby drains can decrease the overall burden of the drain and decrease the risk of the drain overflowing [11]. Figure 2 shows a drawing of the mentioned facilities utilizing the spaces offered by car porch and front road in a housing estate. Investigation into the water storage facilities and their performances are reported in the following sections.

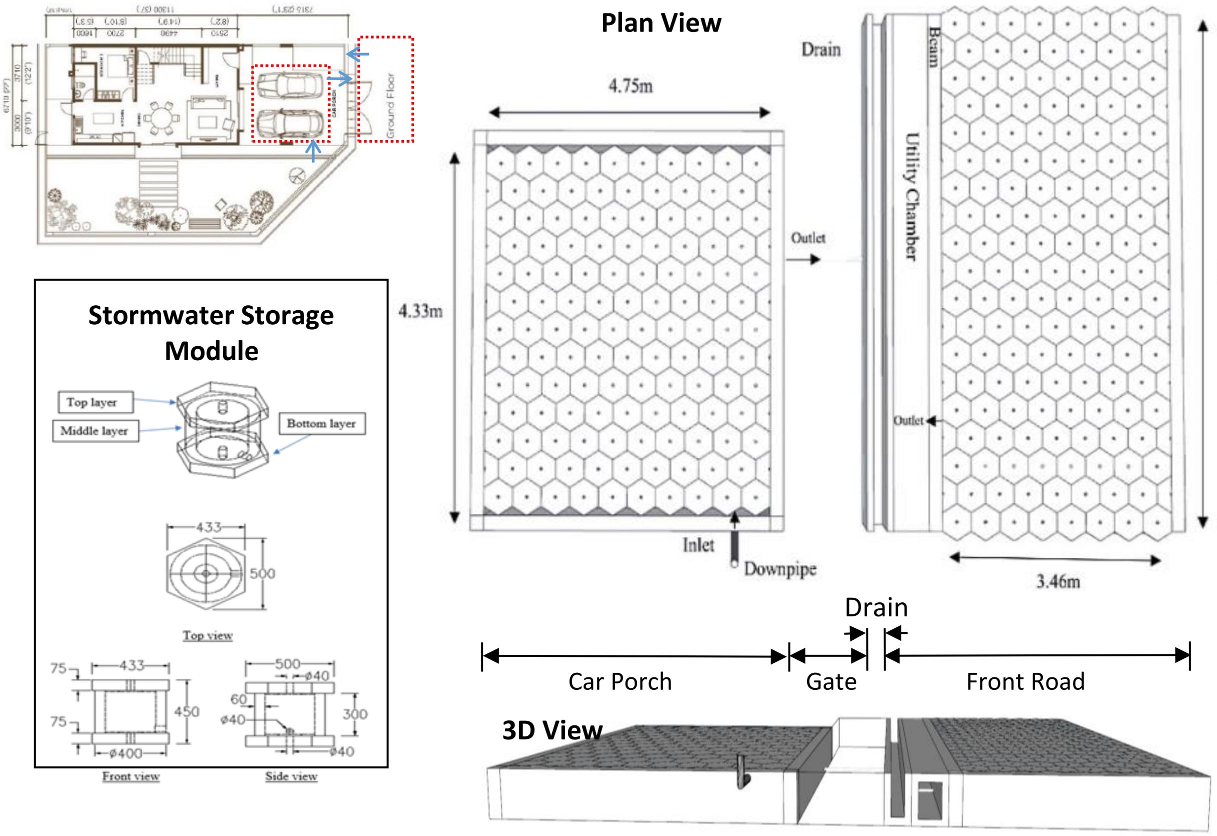



**Fig. 2.** Stormwater storage facilities underneath car porch and front road

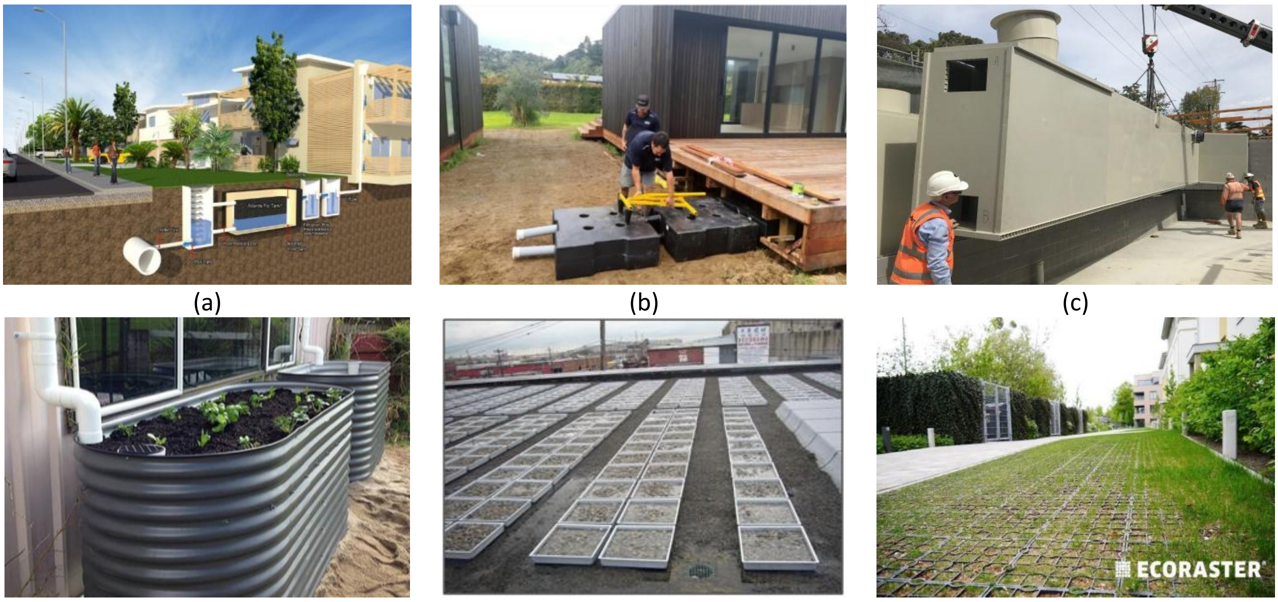
Stormwater storage facilities have been reported to reduce 95.5% of peak flow by one source [12]. The facilities are also reported to decrease network flooding for smallest extreme rainfall events up to 75% and for largest extreme rainfall events, up to 30% by another source [13]. Today, drainage engineers tend to design localized stormwater storage facilities, for example small structures than centralized large size storage structures such as detention basins, and wet ponds which were popular in the past. The shifting to small structure is due to the fact that, it is not possible to progressively augment drainage system while resources of empty land is limited particularly in urban areas.

To highlight a few examples, small stormwater storage structures are presented in Figure 3. A detention tank in Figure 3(a), is popular for their smaller size. The tank could be in a variety of materials, shapes, and sizes. It could be installed closed to the stormwater source, in the case, as depicted in the sub-figure, the tank is outside a house. Runoff generated from the house could be captured in the tank and therefore, less runoff is discharged to the urban drainage system [14].

The trends nowadays are to merge stormwater detention structures with urban features. Modules are created, for an example in Figure 3(b), hollow boxes that could store water are placed under the house deck. Other modules in different materials, shapes and sizes could be placed within building's slab, driveway, patio and other housing features [15,16].

There are also examples of tanks that no longer placed below ground, but above ground. The tank depicted in Figure 3(c), is fabricated in such a way that it is also a wall beside being a water storage structure. Moreover, the tanks depicted in Figure 3(d), are demonstrated to take in water from the roof, as well as planter boxes that blended as landscaping features [17]. Other than that, water storage can be installed on flat roof, like the one presented in Figure 3(e) [18]. Another example is permeable pavement as in Figure 3(f), in which water could be directed to the driveway or parking lot [19].

These examples are able to capture a small amount of water. As one structure, its effect may be small. With a substantial amount of such small structures across the urban areas, it has a cumulative effect of attenuating water flowing downstream [20].




(a) (b) (c)
(d) (e) (f)

**Fig. 3.** Small stormwater storage structures, (a) underground tank, (b) modules under deck, (c) wall mounted tank, (d) rain barrels, (e) rooftop modules and (f) permeable pavement [21-26]

## 2. Materials and Methods
### *2.1 Stormwater Storage Module*

Stormwater storage module was introduced as the major component of water storage facilities in this case. The module is a non-commercialized R&D product developed by Mannan *et al.,* [27]. A single modular unit is depicted in Figure 2. Each unit is made up of three concrete pieces which consist of two identical hexagonal plates at top and bottom layers, and one hollow cylinder in the middle layer. Each of the unit could withstand a loading up to 100 kN. Therefore, the top hexagonal plate could function as pavement to support traffics and other loads. The hollow cylinder functions as water storage chamber, while the bottom hexagonal plate functions as the base. The surface area of the hexagonal plate is 0.16 $m^2$ and the height of plate is 0.75 m. Each plate has a service inlet of 0.04 m diameter in the middle of the plate. The hollow cylinder has a height of 0.3 m, an inner diameter 0.18 m and an outlet of 0.04 m diameter at the bottom side wall of the cylinder. The stormwater storage module is designed to hold water at a capacity of 0.19 $m^3/m^2$ of pavement area.

For the facility under the car porch, runoff from the roof was channeled into the facility via downpipe. Taking the sizes of two cars, the delineated surface area was 4.33 m in width, 4.75 m in length, 0.45 m in depth, and as such, it was estimated to have an effective storage volume of 3.9 $m^3$ per house.

For the facility under the front road, runoff entered the facility via the service inlets on the top hexagonal plates. Following the size of the property lot, the delineated surface area was 3.46 m in width, 7 m in length and 0.45 m in depth which the segment was having an effective storage volume of 4.6 $m^3$ per segment. In both facilities, the captured runoff was released at a controlled rate to the front drain via 0.05 m diameter orifice outlets.

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### *2.2 Design Rainfall*

A row of twelve terrace houses with a total catchment area of 2,472 $m^2$ (0.3 ha) were selected as the study area (Figure 4). As the total catchment area fall in the range of 0.2 - 2.0 ha which was classified as small catchment, a time of concentration of 5 minutes was considered [28]. Besides, the drainage system within the selected housing estate was classified as a minor system, thus an average recurrent interval (ARI) of 10 years was considered [29]. The 5-minute, 10-year ARI design rainfall was determined as 278 mm/hr in rainfall intensity and 23 mm in rainfall depth, obtained from a locally-derived Intensity-Duration-Frequency (IDF) curve by the Sarawak Department of Irrigation and Drainage.

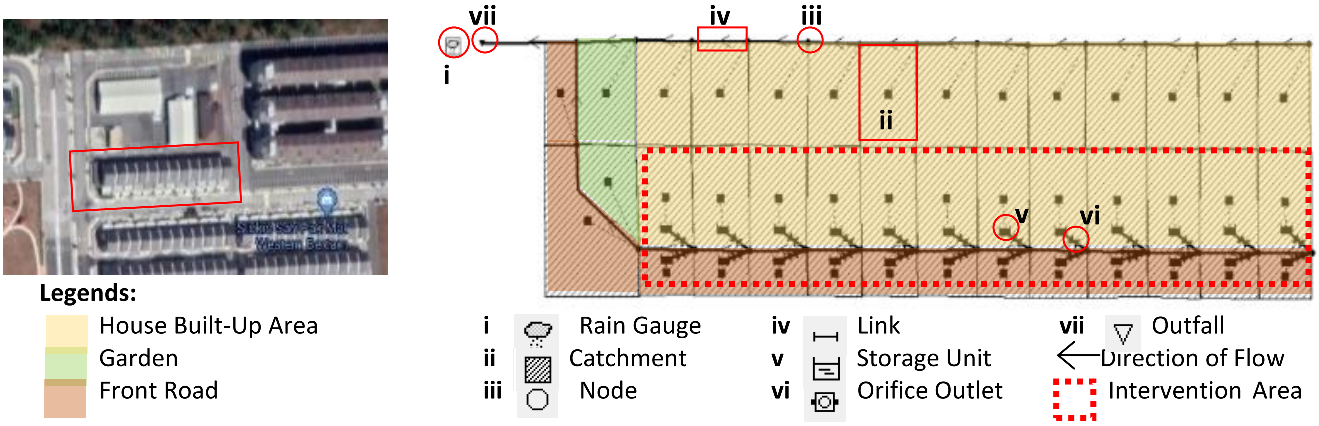



**Fig. 4.** SWMM5 model

### *2.3 Storm Water Management Model*

Storm Water Management Model version 5.0 (SWMM5) developed by the United States Environmental Protection Agency [30] was used as the model to investigate the intended water storage facilities. SWMM5 simulates real storm events on the basis of rainfall and other meteorological inputs and system (catchment, conveyance, storage and flow restrictor) characterization to predict outcomes in the form of quantity and quality values [31,32].

Referring to Figure 4, the scenario of post-development condition generally involved a process of rainfall (i), sub-catchments (ii), node (iii), link (iv) and outfall (vii). The runoff component of SWMM5 operates when rainfall (i) is intercepted by the sub-catchment areas (ii); and, as a result, runoff is generated. Eq. (1) calculates the catchment flow ($Qc$) in SWMM5 according to the catchment characteristics. Parameters such as width ($W$), slope of catchment ($Sc$), depression storage ($dp$) and depth of water over the catchment ($d$) were measured from the study area. Manning's $n$ value in the equation was a variable. An $n$ value of 0.4 was used for the pre-development condition, and an $n$ value of 0.8 was used for the post-development condition [28].

$$Q_C = W\frac{1.49}{n}\left(d - d_p\right)^{5/3} S_C^{1/2} \tag{1}$$

From the sub-catchments, urban runoff enters the drain which is represented as node (iii) and link (iv). The node shows the location and elevation of the drain. The link shows the geometry of the drain. Eq. (2) calculates the drain flow ($Q_D$). The parameters that can be measured at the study area included the distance between the two nodes ($x$), flow geometry ($\alpha$), cross-sectional area of the drain ($A$) and surface roughness of drain ($m$). The flow routing time step in the equation was a variable. A time step of 30 seconds was found suitable for drain in urban areas [33].

$$Q_D = \frac{\delta \mathrm{A}}{\delta \mathrm{t}} + \alpha m A^{(m-1)}\frac{\delta \mathrm{A}}{\delta \mathrm{x}} \tag{2}$$

On the other hand, the scenario of post-development with intervention, in this case, involved rainfall (i), sub-catchments (ii), from the roof catchment to storage under car porch and from road catchment to storage under the road which are represented as storage units (v) and controlled release by orifice outlet (vi), node (iii), link (iv) and outfall (vii). Storage units were used to represent the underground facilities [34]. The storage volume ($S$) of a storage unit was governed by Eq. (3), in which it was a net flow (inflow ($Qs$) minus outflow ($Qo$)) in the structure over a specific time ($\Delta t$).

$$S = \sum\nolimits_i (Q_S - Q_{0)}\Delta t \tag{3}$$

The outflow was governed by Eq. (4), in which the parameters involved discharge coefficient ($Co$), area of orifice outlet ($Ao$) and head of water ($Ho$). The outflow was through a 0.05 m diameter orifice and a discharge coefficient of 0.22 was found suitable based on a past study [35].

$$Q_o = C_o\, A_o \sqrt{2gH_o} \tag{4}$$

Each of the property lot has a built-up area of 6.7 m (22’) x 20.4 m (67’). The model separated one lot into two-sub-catchments, taking into consideration that the front sub-catchment drains water to the front drain while the back sub-catchment drains to the back. Only the front sub-catchments with an area of 820 $m^2$ (6.7 m x 10.2 m x 12 houses) were intervened with a series of twelve (12) water storage facilities under the car porches with accumulated effective storage of 46.9 $m^3$ (3.9 $m^3$/house x 12 houses). There were twelve (12) orifice outlets draining the urban runoff from the property lot to the front drain.

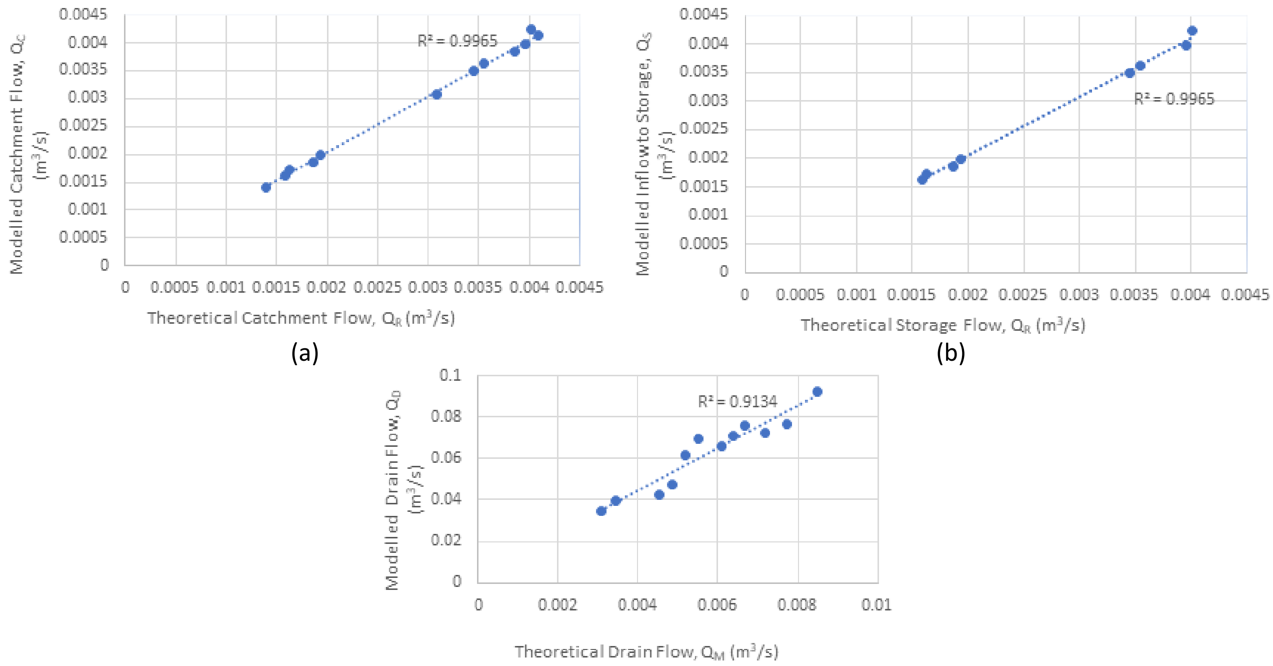
Only half of the front road (3.46 m) was included following the road crown. Half of the road shall drain water to the front drain, while another half, to the drain opposite row of houses. The selected half of the road was further divided following the size of the houses. There were twelve (12) road sub-catchments with an area of 278 $m^2$ (3.46 m x 6.7 m x 12 houses). These were intervened with a series of twelve (12) water storage facilities under the road with accumulated effective storage of 55.2 $m^3$ (4.6 $m^3$/segment x 12 houses). There were twelve (12) orifice outlets draining the urban runoff from the front road to the drain.

### *2.4 Model Verification*

Before applying to a scenario, a model must be verified. The coefficient of determination ($R^2$) could quantify how well a model forecasts an outcome [36]. The runoffs from front road and roof catchment were verified by comparing the runoff values computed by SWMM5 (Eq. (1)) and manual calculations using the Rational Method (Eq. (5)), in which catchment flow ($Q_R$) is a function of runoff coefficient ($C$), rainfall intensity ($I$) and catchment area ($A_C$) over 360. The modelled catchment flows against theoretical catchment flows were plotted in Figure 5(a). A best-fit line was drawn, and the $R^2$ value obtained was 0.9965.

$$Q_R = \frac{C\ I\ A_C}{360} \tag{5}$$

The storage units received water close to the catchments that generated the runoff. As such, the inflow to the storage was verified between the runoff values computed by SWMM5 (Eq. (1)) and manual calculations using Rational Method (Eq. (5)), as well. The modelled storage inflows ($Q_S$) against theoretical storage inflows were plotted in Figure 5(b). The $R^2$ value obtained was 0.9965.




(a) (b) (c)

**Fig. 5.** Model verification for (a) catchment flow, (b) storage inflow and (c) drain flow

For the in-channel drain flow, verification was done between the runoff values computed by SWMM5 (Eq. (2)) and manual calculation using the Manning formula (Eq. (6)). The formula computes flow based on roughness coefficient ($n$), wetted area of the drain ($A$), hydraulic radius ($R$) and slope of drain ($S_D$) [37]. The modelled drain flows ($Q_D$) against theoretical drain flows ($Q_M$) were plotted in Figure 5(c). The $R^2$ value obtained was 0.9134.

$$Q_M = \frac{1}{n}\ A\ R^{2/3}\ S_D^{1/2} \tag{6}$$

Based on Figure 5, the $R^2$ values obtained were more than 0.9 which were classified as good matches. Therefore, the SWMM5 model was acceptable [38].

## 3. Results and Discussion

### *3.1 Flow*

The overall picture of the drainage characteristics in the housing estate was shown through the flow patterns at the outfall which represented the conditions of the whole catchment. Figure 6 shows the flow hydrographs resulted from the whole catchment with and without intervention.

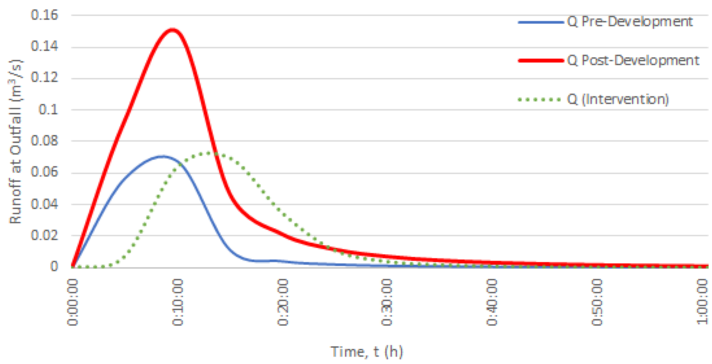


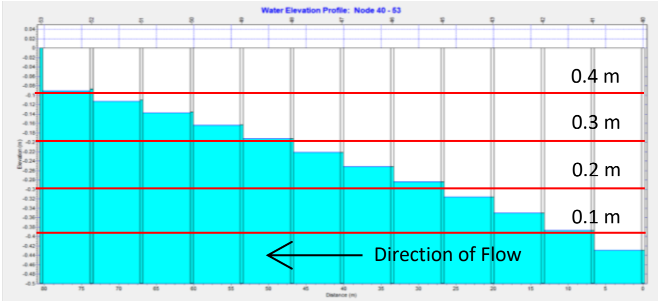

**Fig. 6.** Simulated flow hydrographs at outfall

The model estimated that the flow hydrograph for post-development without intervention had the highest peak value which was 0.15 $m^3/s$ after 10 minutes of design rainfall. On the other hand, the model estimated that the flow hydrograph for pre-development had only a peak of 0.067 $m^3/s$ after 10 minutes. The difference of the two was staggering 55% which the drastic change in the post-development condition had double its urban runoff rate.

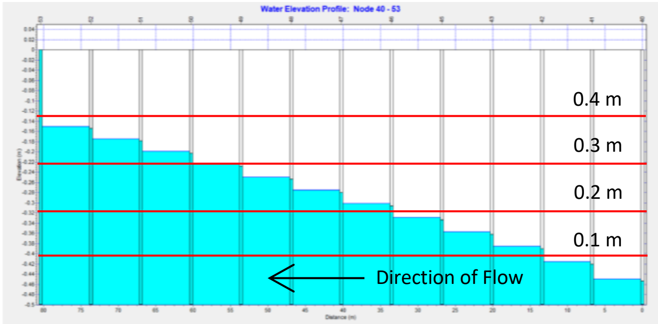
After intervention was introduced, the third flow hydrograph was found lowering to the pre-development condition. The peak value of the flow hydrograph due to the invention was estimated at 0.069 $m^3/s$. The intervention involved only 44% of land area (820 $m^2$ of property lot and 278 $m^2$ of front road). With about slightly less than half of the total catchment, the intervention was found to alter the flow pattern, firstly by further delaying the time of peak to 15 minutes and secondly by widening the hydrograph base to 30 minutes. The lengthen time to peak indicated slower response while the widen base was a result of slow release from the water storage facilities. These two new hydrograph characteristics would promote flood resilience in ways of restoring the natural runoff rate mimicking the pre-development condition and allowing more time for the drainage system to flush out the volume of urban runoff.

### *3.2 Water Level*

The 80 m long (6.7 m x 12 houses) front drain was selected to analyse its flow path. The water levels of the front drain revealed the drainage characteristics in the drain with and without intervention. Figure 7 shows the maximum water level profiles along the selected stretch of drain.




(a)




(b)

**Fig. 7.** Simulated water level profiles along the front drain for post-development condition, (a) without intervention and (b) with intervention

Four markers are inserted in the figure to indicate the depth of drain. The total depth of the front drain was 0.5 m. Generally, the model estimated lower water levels at the upstream stretch. As the urban runoff was released into the drain from property lots and road at different points along the drain, the volume of urban runoff accumulated as it travelled downstream. As such, the model estimated higher water levels at the downstream stretch. Any water congestion at the downstream end would cause overflowing and flooding the surrounding area. However, no overflowing from the front drain was predicted.

For post-development condition without intervention (Figure 7(a)), the water level profiles peaked at 10 minutes after the onset of design storm. The model estimated the highest water level of 0.41 m at the 80 m point. For post-development condition with intervention (Figure 7(b)), the water level profiles peaked at 15 minutes. The model estimated the highest water level of 0.35 m at the same point. Comparing the two sub-figures, it could be deduced that the stretch with 0.3 m of water level and above reduced significantly after the intervention. The former had a downstream stretch of 26 m above 0.3 m of water level, while the latter had only a stretch of 12 m.

### *3.3 Storage*

The reduction in flow and water level described in the previous sub-sections could be explained with the water storage facilities. Urban runoff from both the property lot and road was directed to the water storage facilities before discharging to the front drain. This intervention in flow mechanism created an attenuation effect to the drainage characteristics. According to the facility design, the maximum depth of the storage was 0.3 m. The size of the orifice outlets for the car porch and front road were both 0.05 m (2”) diameter pipes. The detained water depth above 0.3 m would indicate a failed model due to overflowing and flooding. The SWMM simulated water level hydrographs of the facilities are presented in Figure 8.

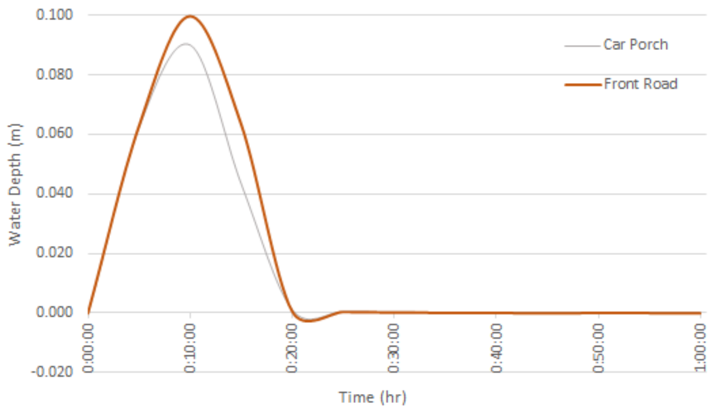



**Fig. 8.** Simulated water level hydrographs in the water storage facilities

Figure 8 shows the detained water depths over a period of 1 hour. The model estimated that the facilities had a peak at 10 minutes after the design rainfall. Since the facility under the road was larger than car porch, the former was estimated to have a maximum water level of 0.1 m. The latter had a maximum water level of 0.09 m. According to the figure, the water depths throughout the design rainfall were under the maximum depth of 0.3 m. The remaining empty storage volume could be reserved for adverse weather patterns.

### *3.4 Discussion*

The estimation of 55% reduction in peak flow was in line with the findings reported by Goorden *et al.,* [12] and Yazdi [13] that ranged between 30 – 95.5%. As such, the reduction from the combined water storage facilities in residential car porch and front road was reasonable. Due to the reduction of flow, the water level profile along the front drain was reduced as well. However, the water filing patterns within the storage structure showed that the storage volumes were not fully optimized.

### *3.5 Limitation*

The findings presented were based on design rainfall, a form of statistically derived rainfall data to reveal modified patterns in flow, water level and storage after the urban runoff passed through the water storage facilities. However, the actual behaviour of the facilities in the field is still lacking. A field test subjected to actual rainfall patterns would provide further validation of the patterns produced in the current investigation.

## 4. Conclusions

This paper argues that features in existing housing estate could be exploited to increase flood resilience for a long-term solution to urban flood mitigation. Car porch and road at the front portion of terrace houses were selected for analyses. It was found that the intervention of diverting urban runoff to the water storage facilities under car porch and front road, instead of directing discharging the urban runoff the drain, had brought forward positive impacts on the flow and water level patterns in the drainage system. The peak hydrograph reduced by 54% due to the intervention. The modified flow hydrograph had delayed the time to peak from 10 to 15 minutes and widened the hydrograph base from 15 to 30 minutes comparing the post-development condition without and with intervention. Subsequently, the water level along the drain reduced as well in relation to the reduced flow. These reduced parameters were suggesting that merging housing features and drainage design was plausible formula to cut down the risk of flooding at the housing estate and downstream waterways elsewhere.

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