

Original Article

Comparative Performance Evaluation of Home-Based On-Site Stormwater Detention Systems across Different Terrace Housing Types using SWMM Simulation

Johnny Ong King Ngu¹, Hushairi bin Zen², Darrien Yau Seng Mah³, Frederik Josep Putuhena⁴

^{1,2}Faculty of Engineering and Technology, i-CATS University College, Sarawak, Malaysia.

³UNIMAS Water Centre, Faculty of Engineering, Universiti Malaysia Sarawak, Sarawak, Malaysia.

⁴Fakultas Teknologi dan Desain, Universitas Pembangunan Jaya, Banten, Indonesia.

¹Corresponding Author : johmynok@icats.edu.my

Received: 10 January 2026

Revised: 12 February 2026

Accepted: 15 March 2026

Published: 28 April 2026

Abstract - Urban flooding remains a persistent challenge in tropical regions, primarily driven by rapid urbanization and the expansion of impervious surfaces that restrict natural infiltration. To address this, decentralized stormwater management practices such as home-based on-site detention systems have been adopted to reduce surface runoff at the property scale. This study compares the performance of a modular on-site detention system, the StormPav system, modelled beneath six common terrace housing types in Malaysia, namely double-storey corner, double-storey intermediate, single-storey corner, single-storey intermediate, semi-detached, and bungalow units. Using the Storm Water Management Model, 72 simulation scenarios were developed to evaluate the influence of housing typology, contributing catchment ratio, and storm duration on peak discharge reduction. Design storms of 5, 10, and 15 minutes corresponding to an intensity of 10-year Average Recurrence Interval were simulated. The results show that the StormPav system effectively mitigates peak discharge for all housing types, with significant improvements when the contributing catchment ratio exceeds 50%. Among the configurations tested, the double-storey corner unit demonstrated the highest detention efficiency, achieving a 30–35% reduction in post-development peak discharge compared with pre-development conditions. The novelty of this work lies in the systematic evaluation of a modular on-site detention system across diverse terrace typologies using the stated public-domain software, providing comparative insights into decentralized stormwater performance that can inform urban flood mitigation strategies in tropical environments. The findings highlight the potential of decentralized on-site detention systems to enhance flood resilience in tropical terrace developments.

Keywords - Catchment ratio, OSD, Stormwater management, Sustainable development, Urban runoff.

1. Introduction

This paper describes a systematic comparison of Stormwater–Green Pavement System, or in short StormPav as a home-based On-Site Detention (OSD) across six representative terrace housing types commonly found in Malaysian developments. These terrace houses usually have a close range of lengths but vary in the widths from single- to double-storey houses. Each housing type, therefore, has a different roof area.

The OSD could be installed at the front or back portion of a house. Its placement is critical to follow the flow path, starting from the roof as a collection point and channelling the stormwater to the OSD. It is unlikely to connect all roof areas to OSD as it requires undesired complex piping. Practically, only parts of the roof are connected to the intended OSD. As such, the main objectives are to evaluate the influences of housing typology and contributing catchment ratio on its

detention performance by using the Storm Water Management Model (SWMM) version 5.1. OSD systems temporarily store stormwater within individual property boundaries and release it at a controlled rate, thereby reducing the load on downstream drains during critical storm periods [1-3].

StormPav is one of such an OSD system which integrates interlocking storage modules below a structural surfacing layer to provide subsurface detention while supporting vehicular loads [4].

When applied to a property lot, the StormPav concept enables the capture of roof and paved runoff directly into a compact storage volume located beneath a residential driveway or porch, minimizing site disturbance and preserving usable surface area.



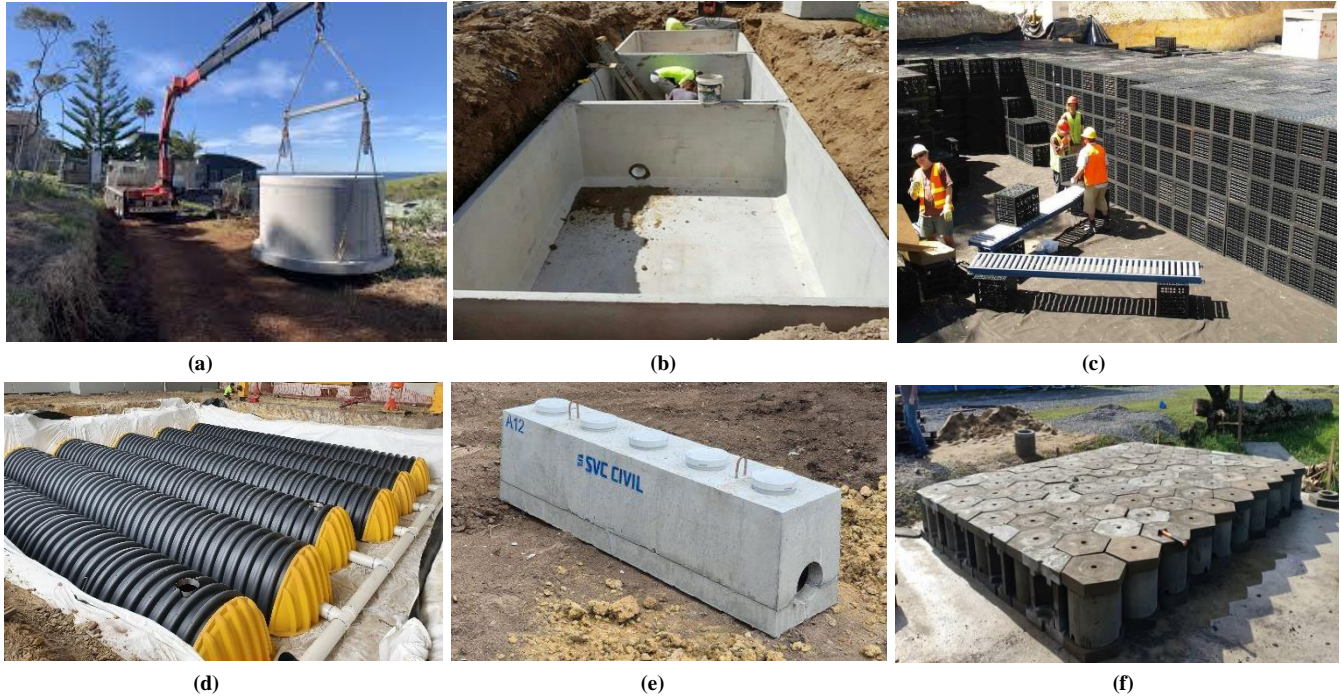


Fig. 1 Examples of OSD, (a) Precast concrete tank [5], (b) Precast concrete modular units [6], (c) High-strength plastic modular units [7], (d) Pipe packages [8], (e) Concrete vault [9], and (f) StormPav modular units.

In areas like Sarawak, Malaysia, for instance, these high-intensity, short-duration convective storms are frequent and often result in swift drainage of conventional drainage systems, causing localized flooding within residential neighbourhoods. This emphasizes a critical need for lot-scale interventions that can effectively reduce peak flows and supplement centralized drainage infrastructures. A variety of OSD forms have been developed, as shown in Figure 1. Each offers different trade-offs between storage efficiency, constructability, and maintenance requirements. OSDs can be used to cater for community scale, in which stormwater from properties of a community is directed to a large structure. These large structures can be observed in Figures 1(a) to 1(d). Despite this, the structures could be designed smaller to fit into a property lot. Figure 1(a) appears as a circular tank, and such a tank also comes in various shapes and sizes. Figure 1(b) depicts three rectangular tanks called modular units, which depend on the site condition and intended storage capacity. Figure 1(c) depicts smaller plastic modular units. No matter whether concrete or plastic, these modular units ease the construction of large structures on site, but resemble the readily fabricated units, stacking them together as storage cells. The OSDs depicted in Figures 1(d) and 1(e) are elongated structures. The former sub-figure depicts pipe packages, which also come in various materials and sizes. The latter shows a concrete vault with storage chambers, each regulated by a small opening connected to them along the vault.

Put as the last, Figure 1(f), shows the StormPav modular units. Each modular unit has three concrete pieces, which

consist of a top cover, a bottom cover, and a hollow cylinder. These pieces are like systems in Figure 1(b) and Figure 1(c), which require connecting many units to form a single storage. But this OSD is the smallest among the examples. The modular units are not sealed but rest freely, which contradicts systems in Figures 1(d) and 1(e). This feature allows replacement of any damaged unit and maintenance of the system by removing the pieces to remove accumulated sediment or debris.

Although these presented OSDs come in different shapes and sizes, their fundamental design links catchment area to detention volume [10, 12]. In this case, the size of the roof area serves as the primary determinant for the volume of runoff that must be managed. Most of the literature, on the other hand, concentrated on lot-scale assessments rather than comparative analyses across various residential layouts. Housing typology, which includes roof area and connectivity to OSD, is influencing the proportion and timing of runoff delivered to an OSD unit. Therefore, the same modular units may exhibit varied hydrological performance when installed under different housing configurations. Understanding these differences is crucial for developing robust design guidance for home-based OSD.

2. Materials and Methods

2.1. StormPav

StormPav consists of interlocking modular units with a high void ratio that provides temporary stormwater storage while supporting vehicular loads. A single modular unit is

laboratory tested to support up to 10 tons of load. Its dimensions are presented in Figure 2. The cover, both top and bottom, has a surface area of 0.1624 m² with a service inlet of 0.04m. Each cover is 0.075 m high. The cylinder has an inner diameter of 0.28 m and a wall thickness of 0.06 m. Each cylinder is 0.3 m high. The hollow cylinder functions as a storage chamber to hold water at a capacity of 0.19 m³/m² of pavement area. The service inlet can drain stormwater up to 10,000 mm/hour.

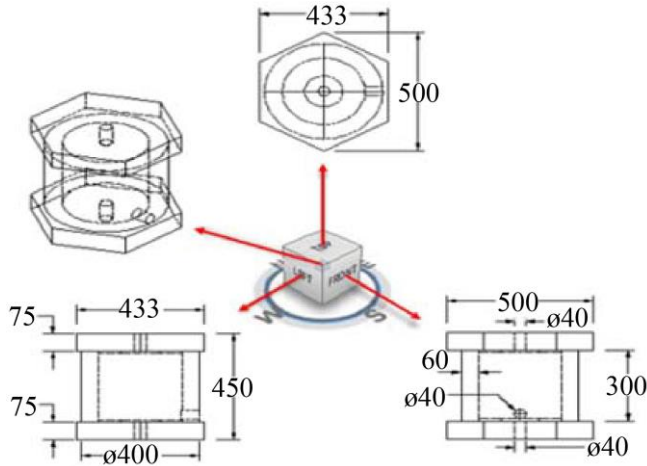


Fig. 2 Dimensions of a single StormPav modular unit

This configuration allows the StormPav system to capture and detain runoff from both the roof and driveway areas without reducing usable land space. The rate of roof runoff that enters the OSD can be estimated using the Rational Method, as in Equation 1:

$$Q_c = \frac{CIA}{360} \quad (1)$$

Where

- Q_c = inflow (m³/s);
- C = runoff coefficient (unitless);
- I = rainfall intensity (mm/hr);
- A = catchment area (hectares).

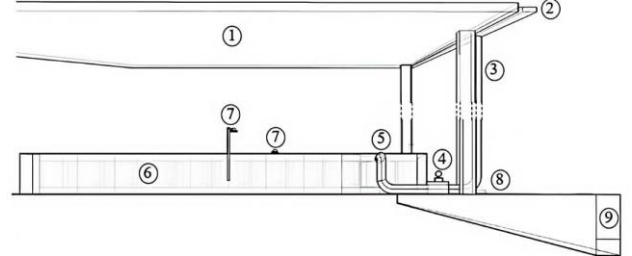
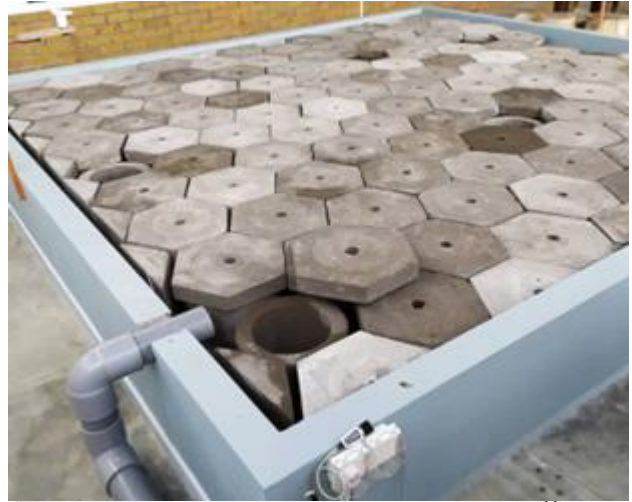
The detained water is subsequently released at a controlled rate through a small orifice outlet connected to the external drainage network. The rate of discharge from OSD can be estimated using Equation 2, which was derived from Bernoulli's principle:

$$Q_o = C_d A_o \sqrt{2gh_o} \quad (2)$$

Where

- Q_o = outflow (m³/s);
- C_d = orifice coefficient of discharge (unitless);
- A_o = area of orifice outlet (m²);
- g = gravity acceleration (m/s²);
- h_o = water head (m).

A conceptual layout of the StormPav home-based OSD used in this study is shown in Figure 3.



- ① House side canopy, made of spandex, area 95 m², slope 3:100
- ② Roof gutter, made of PVC, 0.1 m x 0.1 m
- ③ Downpipe, made of PVC, 0.1 m in diameter
- ④ Electromagnetic flowmeter
- ⑤ Inlet to tank, 0.1 m in diameter
- ⑥ Stormwater detention tank, 4.40 m x 4.70 m x 0.45 m in size
- ⑦ Ultrasonic water level detector
- ⑧ Outlet pipeline, made of PVC, 0.05 m in diameter
- ⑨ House perimeter drain

Fig. 3 StormPav on-site detention system and schematic layout beneath a typical residential lot

2.2. Study Area

The experimental site was located in Kota Samarahan, Sarawak, Malaysia, a growing suburban district approximately 20 km southeast of Kuching City. Over the last decade or so, the district has seen significant urban development, leading to a notable loss of green spaces converted into impervious residential and commercial areas. This urbanized landscape has contributed to more frequent localized flooding incidents during intense rain events.

Kota Samarahan experiences a humid equatorial climate, characterized by high annual rainfall, uniform temperatures, and high humidity throughout the year. Rainfall is dominated by short, high-intensity convective storms, especially during

the Northeast and Southwest monsoons. These climatic conditions make the district an ideal location for evaluating home-based OSD system performance under tropical rainfall.

2.3. Rainfall Characteristics

In this study, design storms corresponding to a 10-year Average Recurrence Interval (ARI) were adopted to represent the standard design condition for residential drainage systems in Malaysia, as recommended by the Urban Stormwater Management Manual for Malaysia, Manual Saliran Mesra Alam Malaysia (MSMA) [12]. The rainfall intensities were determined from the Intensity–Duration–Frequency (IDF) curves developed for the Kuching–Samarahan region. Three design storm durations, namely 5, 10, and 15 minutes, were selected to represent the range of critical rainfall durations that commonly trigger flash flooding in the study area.

2.4. Housing Typology and Catchment Representation

Six common terrace housing types found in Malaysian urban developments were selected to evaluate the influence of lot configuration on the performance of the home-based OSD system. The housing types include double-storey corner, double-storey intermediate, single-storey corner, single-storey intermediate, semi-detached, and bungalow units. These typologies represent a broad range of roof areas, lot dimensions, and driveway layout commonly used in contemporary housing schemes in Sarawak.

Each housing type was modelled to reflect its geometric characteristics and the proportion of impervious surfaces contributing to stormwater runoff. The contributing catchment ratio (C^R) was defined as the percentage of the total roof and paved surface area draining into the OSD system. Four catchment ratios, namely 30%, 40%, 50%, and 60%, were applied in the analysis to simulate varying levels of roof area and its connectivity for each housing type.

Physical and hydraulic parameters for each housing type, such as roof area, lot size, runoff coefficient, storage volume, and orifice diameter, were derived from field measurements and experimental investigations conducted under local tropical conditions. These parameters were incorporated into the drainage model to ensure a realistic simulation of home-based OSD performance in Malaysian conditions.

2.5. SWMM Model Configuration

SWMM, which was developed by the United States Environmental Protection Agency (EPA), was employed to simulate the hydrological behavior of each residential lot under varying storm conditions [13]. Each lot was represented in the model as a simplified sub-catchment–storage–outlet system corresponding to the inflow area, the StormPav modular detention chamber, and the orifice outlet structure. The overall conceptual layout of the computational configuration is shown in Figure 4.

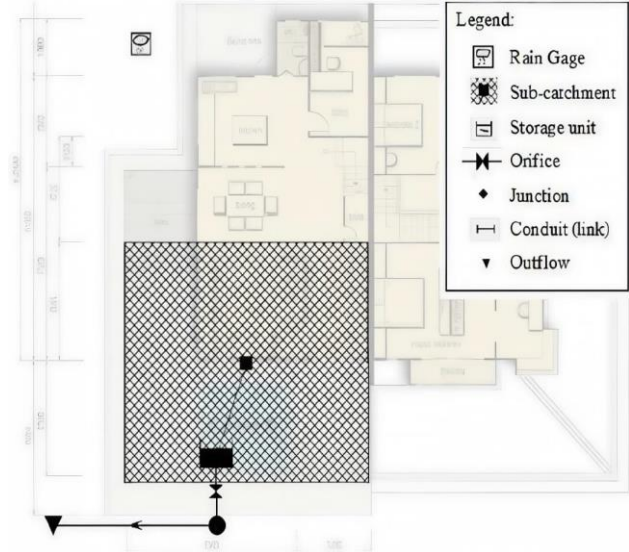


Fig. 4 Developed SWMM computational configuration for the StormPav on-site detention system

Rainfall data derived from the 10-year ARI design storms were input into the “Rain Gage,” which was linked to “Catchment”. The runoff generated from the catchment was computed through Equation 3:

$$Q_a = W \frac{1.49}{n} (d - d_p)^{5/3} S_c^{1/2} \quad (3)$$

Where

- Q_a = catchment flow (m^3/s),
- W = catchment width (m),
- S_c = catchment slope (m),
- n = Manning’s roughness value (unitless),
- d_p = maximum depression storage (m), and
- d = depth of water over the catchment (m).

Runoff from roof and driveway surfaces was directed into the OSD, which was modelled as a “Storage Unit”, where temporary detention occurred before outflow through the “Orifice”. The hydraulic routing was simulated using the dynamic wave method, as in Equation 4, which accurately represents surface and subsurface flow interactions in small-scale systems.

A computational time step of 1 second was adopted to ensure numerical stability, especially under high-intensity rainfall conditions.

$$Q_b = \frac{\partial A}{\partial t} + \alpha mA^{(m-1)} \frac{\partial A}{\partial x} \quad (4)$$

Where

- Q_b = routed drain flow (m^3/s),
- A = cross-sectional area of the drain (m^2),
- x = distance along the flow path (m),
- t = time step (s),
- α = flow geometry due to drain (unitless), and
- m = surface roughness of drain (unitless).

Table 1. Input parameters used in the SWMM model configuration for home-based OSD simulation

Parameter	Symbol	Value / Range
Sub-catchment area	A_s	Based on housing type (60–250 m ²)
Runoff coefficient	C	0.80–0.90
Storage depth	h_s	0.25 m
Orifice diameter	d_o	0.055 m
Manning’s roughness	n	0.013
Simulation time step	Δt	1 s
Routing method	–	Dynamic wave

The key input parameters governing the model are summarized in Table 1. These include sub-catchment area, runoff coefficient, storage depth, orifice diameter, and Manning’s roughness coefficient for conduit flow. The values were obtained from field measurements and previous calibration studies. The runoff coefficient (C) was set between 0.80 and 0.90, typical for impervious residential surfaces in Malaysia. The storage depth (h_s) was defined as 0.25 m. This value represents the effective height of a single StormPav modular cell. The orifice diameter (d_o) was set as 0.055 m, which was obtained from the field calibration in the past.

2.6. Simulation Scenarios

In total, 72 simulation scenarios were formulated to assess the performance of the StormPav OSD system under different housing configurations and rainfall conditions. The scenarios encompassed combinations of six housing types, four contributing catchment ratios ($C^R = 30\%, 40\%, 50\%, \text{ and } 60\%$), and three storm durations (5, 10, and 15 minutes). This factorial design allowed for a systematic evaluation of how the lot geometry, inflow area, and storm characteristics impact detention efficiency and outflow behavior.

Table 2. Simulation matrix

Housing Type	Contributing Catchment Ratios (C^R)	Storm Durations (min)	Total Runs
Semi-detached	30, 40, 50, 60	5, 10, 15	12
Double-storey corner	30, 40, 50, 60	5, 10, 15	12
Double-storey intermediate	30, 40, 50, 60	5, 10, 15	12
Single-storey corner	30, 40, 50, 60	5, 10, 15	12
Single-storey intermediate	30, 40, 50, 60	5, 10, 15	12
Bungalow	30, 40, 50, 60	5, 10, 15	12
Total	—	—	72

Each simulation was performed using the hydrological and hydraulic parameters described earlier in Table 1, ensuring consistency across all runs. The combinations of housing types, contributing catchment ratios, and storm durations adopted in the analysis are summarized in Table 2. The rainfall intensities corresponding to the 10-year ARI and storm durations were applied to each model configuration. The resulting outflow hydrographs at the system outlet were measured for analysis.

2.7. Performance Indicators

The performance of the StormPav OSD system was evaluated using three key indicators derived from the simulated outflow hydrographs: peak discharge reduction (ΔQ_p), storage utilization (U_s), and attenuation ratio (R_a). These indicators provide a quantitative measure of the system’s ability to reduce flood peaks, utilize available storage, and delay discharge relative to inflow conditions.

A higher value of ΔQ_p signifies a higher rate of attenuation. Basically, it measures the proportion of peak discharge at the inflow hydrograph subtracted by the value of peak discharge in the outflow hydrograph to the peak inflow discharge, expressed in Equation 5.

$$\Delta Q_p = \frac{Q_{pi} - Q_{po}}{Q_{pi}} \times 100 \tag{5}$$

Where

Q_{pi} = peak inflow discharge (m³/s); and
 Q_{po} = peak outflow discharge (m³/s).

The U_s reflects the extent to which the detention capacity was effectively utilized during storm events of different durations and rainfall intensity. This indicator assesses the fraction of the total detention storage volume that was effectively utilized during a storm event, expressed in Equation 6.

$$U_s = \frac{h_m}{H_t} \times 100 \tag{6}$$

Where

h_m = maximum water depth in the storage unit (m);
 H_t = total available storage depth (m).

R_a is an indicator that represents the proportion of discharge reduction in comparison with the volume of detention storage. In a higher value of R_a , it demonstrates increased detention capability. This indicator quantifies the time lag between peaks of inflow hydrographs and outflow hydrographs. It captures the extent of delay that occurs due to the time it takes for water to flow through the OSD system.

Therefore, this indicator captures how long it took to completely drain the OSD system and how effective the OSD was in releasing water in a timely manner, expressed as Equation 7.

$$R_a = \frac{T_{po}}{T_{pi}} \tag{7}$$

Where

T_{pi} = time to peak for inflow hydrograph (s);

T_{po} = time to peak for outflow hydrograph (s).

These three design indicators were then extracted from all the simulation scenarios for further analysis. They were used to evaluate the impact of housing type, catchment ratio, and duration of storm on the overall detention performance of the StormPav system.

3. Results and Discussion

3.1. Overview of Simulation

The simulated runoff hydrographs at the outfall for the semi-detached (Figure 5), double-storey corner (Figure 6), double-storey intermediate (Figure 7), single-storey corner (Figure 8), single-storey intermediate (Figure 9), and bungalow (Figure 10) houses were plotted. Each subfigure presents the hydrographs corresponding to 5-, 10-, and 15-minute 10-year ARI design storms. The simulation results demonstrate that the StormPav OSD system successfully attenuated the peak discharge and delayed the time to peak for all housing types. It is thus not unexpected that shorter storm durations result in sharper peaks and higher outflow intensity, whereas longer durations yield broader hydrographs with lower peak discharges and longer recession limbs. These results demonstrate that storm duration and roof area ratio jointly influence the detention performance and discharge timing of small-scale modular OSD systems.

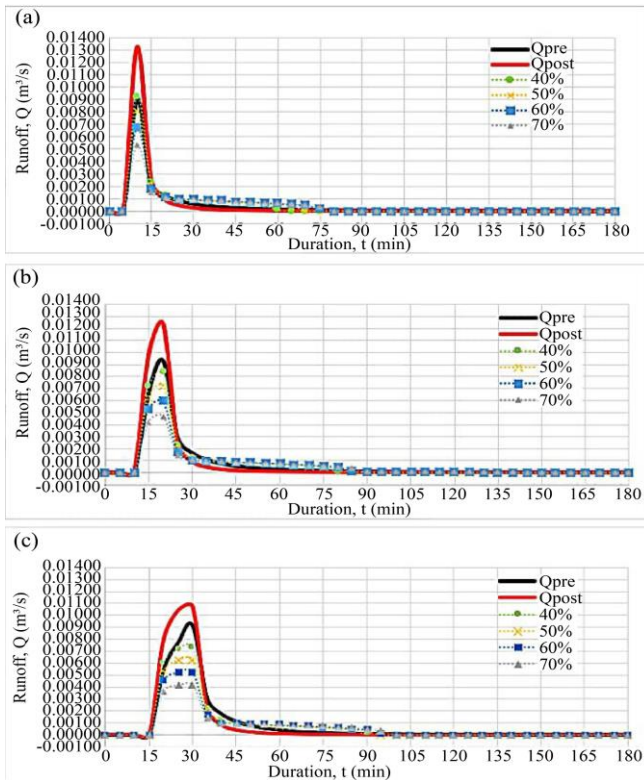


Fig. 5 Simulated runoff hydrographs at outfall for semi-detached house subjected to 5-, 10-, and 15-minute 10-year ARI design storms

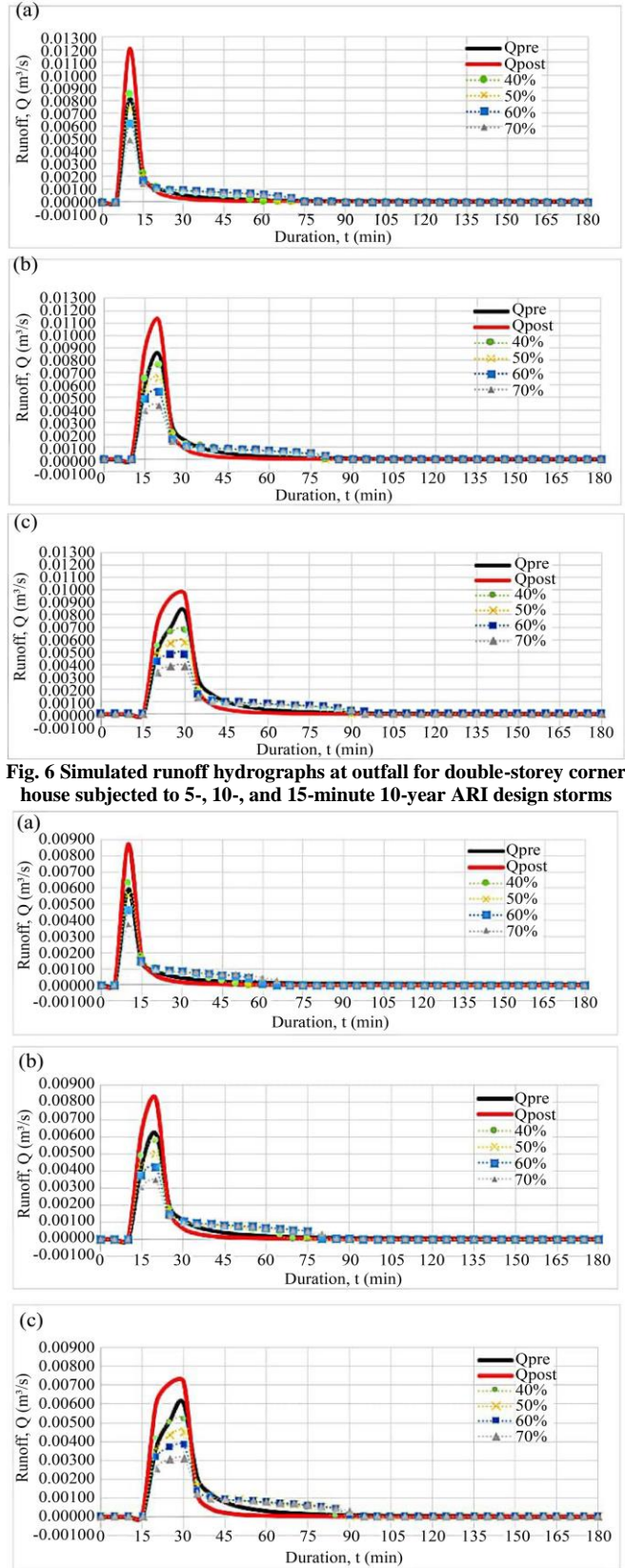


Fig. 6 Simulated runoff hydrographs at outfall for double-storey corner house subjected to 5-, 10-, and 15-minute 10-year ARI design storms

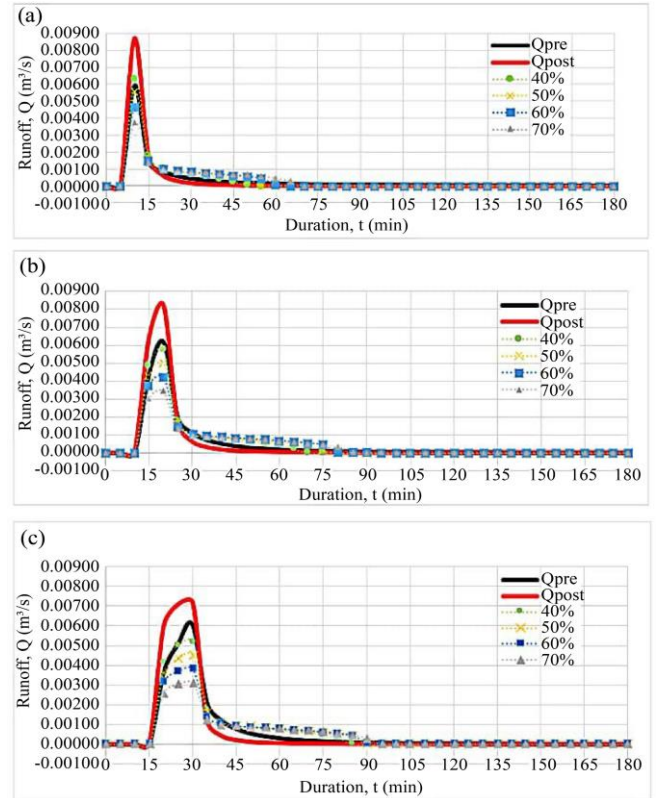


Fig. 7 Simulated runoff hydrographs at outfall for double-storey intermediate house subjected to 5-, 10-, and 15-minute 10-year ARI design storms

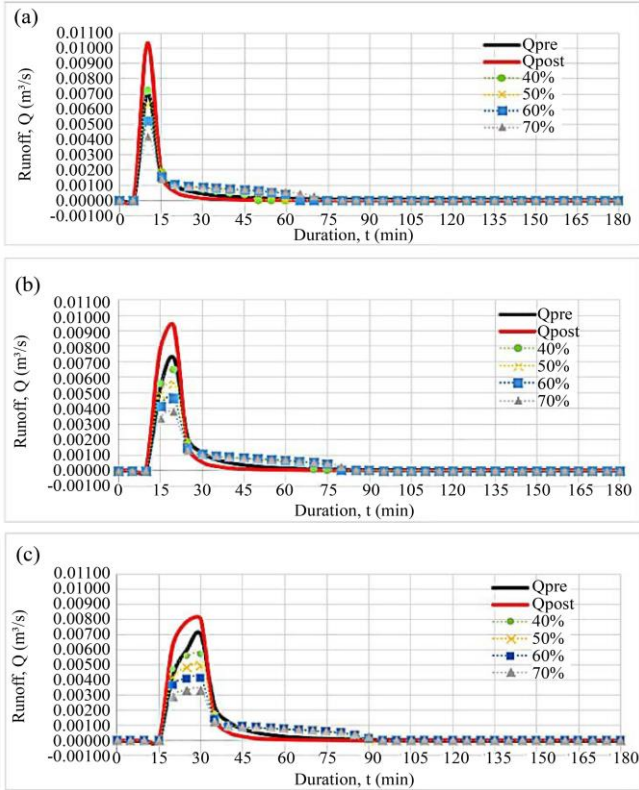


Fig. 8 Simulated runoff hydrographs at outfall for single-storey corner house subjected to 5-, 10-, and 15-minute 10-year ARI design storms

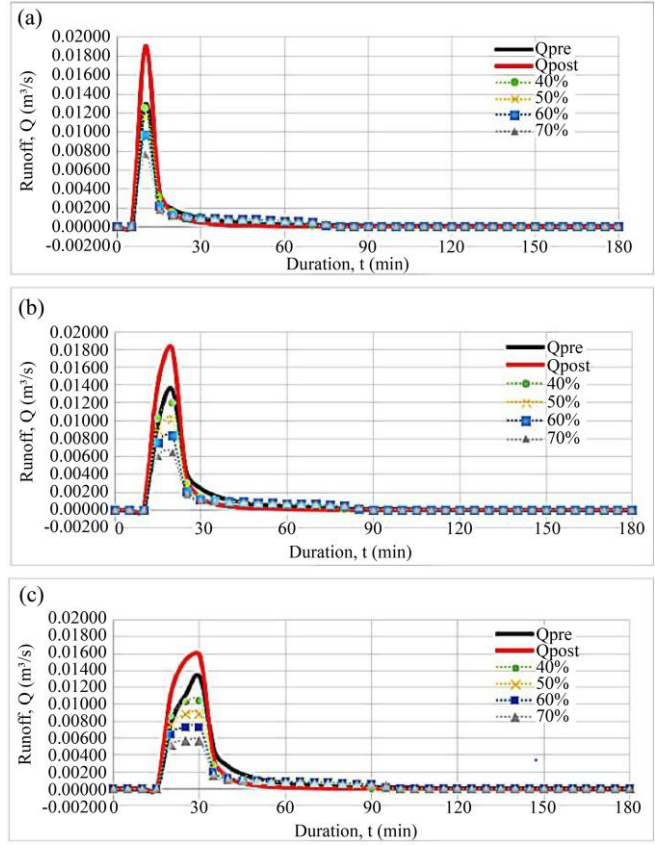


Fig. 10 Simulated runoff hydrographs at outfall for bungalow house subjected to 5-, 10-, and 15-minute 10-year ARI design storms

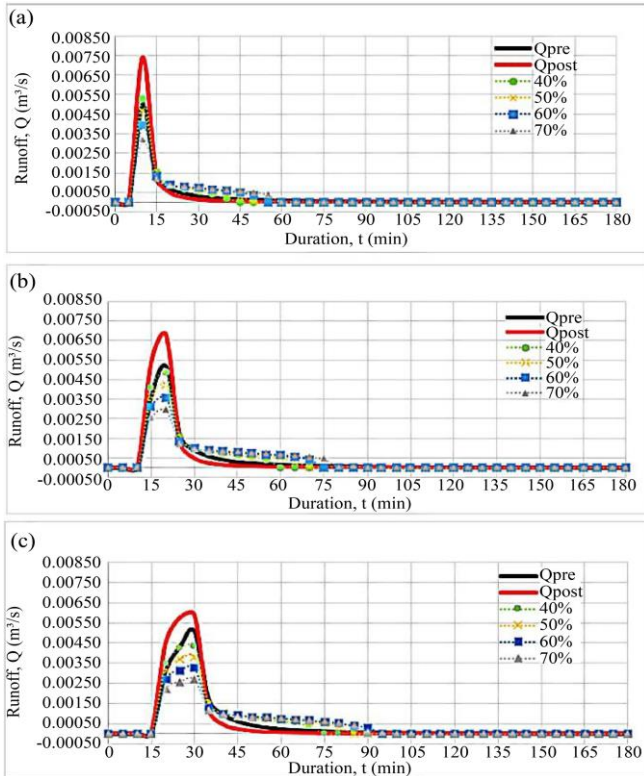


Fig. 9 Simulated runoff hydrographs at outfall for single-storey intermediate house subjected to 5-, 10-, and 15-minute 10-year ARI design storms

In general, the outflow hydrographs exhibited a distinct delay in peak discharge relative to inflow, demonstrating the detention capacity of the modular StormPav system. From these results, a maximum time lag of 2–5 minutes is generally seen to take place, depending on storm duration and the use of storage units. Systems installed in the larger housing types with higher catchment ratios demonstrate higher consistent attenuation effects, and therefore, the detention efficiency increases proportionately with the proportion of impervious area contributing to the storage system.

3.2. Influence of Housing Typology

From Figures 5 to 10, it can be observed that housing typology has a notable impact on the shape and magnitude of the outflow hydrograph. Across all typologies, the double-storey corner unit demonstrates the largest peak discharge reduction with approx. 30-35% reduction compared to pre-developed flow conditions. This improvement is due in part to larger inflow volumes, which are available to the detention effect as well as more favourable hydraulic gradient between the sub-catchment and OSD unit.

Alternatively, intermediate housing units (single- and double-storey) demonstrate a relatively lower attenuation performance with a reduction in the range of 15-25% depending on storm duration, while these typologies generally

have smaller contributing roof areas and less driveway connection to the OSD system, resulting in smaller inflow volume being available for detention. The semi-detached and bungalow typologies have an intermediate result, with larger lot sizes and therefore greater lot contribution; however, a relatively lower efficiency due to longer flow path lengths and greater dispersion of the contributing surfaces.

It is therefore evident from the results that the hydrological performance of decentralized OSD systems cannot be generalized to all residential layouts, and that the system efficiency strongly depends on lot geometry, impervious connectivity, and relative storage capacity.

3.3. Effect of Contributing Catchment Ratio

The contributing catchment ratio (C^R), as presented in Table 3, was one of the key parameters found to affect the OSD performance. Increasing the contributing catchment ratio from 30% to 60% resulted in a steady rise in detention efficiency across all the housing type scenarios. The peak discharges after development were reduced to less than the pre-development values when the catchment ratio was higher than or equal to 50%, indicating the effectiveness of the hydrological control provided by this design parameter.

This trend can be attributed to the increased contribution of surface runoff flowing into the detention module, allowing full use of the available storage volume. However, beyond a contributing catchment ratio of 60%, the marginal benefit seems to diminish, as seen from Table 3.

The increase in the contributing catchment ratio seems to reach a point of diminishing returns, where additional inflow leads to only a limited reduction in peak discharge. These results indicated that a minimum contributing catchment ratio of about 50% should be provided in order to ensure satisfactory OSD.

Table 3. Effect of contributing catchment ratio (C^R) on peak discharge reduction (ΔQ_p) for different housing types

Housing Type	ΔQ_p (%) at $C^R = 30\%$	ΔQ_p (%) at $C^R = 40\%$	ΔQ_p (%) at $C^R = 50\%$	ΔQ_p (%) at $C^R = 60\%$
Semi-detached	18.4	23.5	30.2	33.8
Double-storey corner	22.1	28.7	34.6	37.9
Double-storey intermediate	15.8	20.4	25.6	28.2
Single-storey corner	19.2	24.3	29.8	32.5
Single-storey intermediate	14.7	18.5	23.1	26.0
Bungalow	20.3	25.8	31.0	34.7

This is in accord with the recommendation of the decentralized stormwater design guidelines [10, 11], which highlight the balance between provision of storage and its contributing inflow for lot-scale detention.

3.4. Discussion

3.4.1. Influence of Storm Duration

The durations of the storms were found to affect the OSD performance in the following way. Short-duration (5-min) high-intensity storms produced the highest inflow peaks, resulting in higher storage utilization and rapid chamber(fill) of the OSD. The 15-minute duration storms had lower peak intensities but prolonged durations, causing moderate values of storage utilization.

All the housing types had maximum peak reduction for a 10-minute duration design storm. These results illustrate the importance of varying rainfall duration to assess and achieve good performance of small-scale OSD during its design phase.

3.4.2. Storage Utilization and Detention Efficiency

A total storage utilization (U_s) of the Storm Pav system was recorded, ranging from a minimum of 65% to a maximum of 95% in all the cases simulated, providing a reasonable performance of the activation of detention capacities. This, nevertheless, is explained by the influence of the housing typologies, as the lower values obtained were for larger units, such as the bungalows and semi-detached ones, as the amount of storage was not completely utilized under moderate storms. In contrast, near-completely utilized system volumes could be recorded in the case of corner units for a lower storm duration, highlighting the appropriate design and implementation of the system, considering the match between the available storage space and the inflow volumes.

The combined overall attenuation ratio (R_a) values recorded, defined as the ratio of the post-development to the pre-development peak discharge, are as follows, ranging from 0.65 to 0.85 for all the analyzed cases. The lower the value, the larger the performance of the storage system. Combining the previously obtained results, it is observed that the performance of the systems resulting from the application of the StormPav configuration as an appropriate OSD enables the attainment of considerable flood-mitigation potentials regardless of and especially under the high-intensity rainfall scenarios characterizing tropical environments. The results of the present analysis and comparison are in line with the performance values reported in recent studies dealing with lot-scale detention systems at a similar scale [4, 6, 10].

3.4.3. Comparison

The results presented in the present study provide a supportive confirmation of the significance of housing typology and site-specific hydraulic parameters in a decentralized design of stormwater. Previous research works with similar approaches in terms of lot-scale detention

systems had reported a peak reduction performance usually varying between 20 and 30%, depending on the applied storage capacity and the catchment area contributing to the inflow at the design storm, [4, 6] which, as already mentioned, place the observed peak reduction values at the present analysis up to 30-35% for some housing configurations at the same order of magnitude and slightly higher than previously reported in comparable studies dealing with modular detention systems.

The higher performance achieved at the present analysis seems to be attributed to the hydraulic characteristics exhibited by the StormPav configuration. The relatively high void ratio provided by the different modular storage chambers in a limited footprint ensures the attainment of high detention volumes under residential pavements without the need for additional land areas. Besides, the controlled outlet orifice ensures the regulation of discharge rates and delays in the runoff release, which, in turn, leads to an effective peak flow attenuation.

Practically speaking, the results show that the corner and semi-detached house types provide the most favourable configurations for the adoption of home-based OSD systems, as they typically feature larger contributing catchment areas and enhanced hydraulic connectivity towards the detention chamber. The intermediate units, on the other side, might necessitate larger modular volumes or the addition of supplementary drainage features to achieve similar performance in terms of runoff detention. However, the results can offer practical guidance to local authorities and developers looking to optimise the implementation of decentralized stormwater management strategies in tropical residential developments.

3.4.4. Maintenance and Economic Considerations

The practical adoption of a home-based OSD, however, also necessitates the consideration of maintenance accessibility and economic viability along with hydraulic performance. The StormPav system, in this sense, has multiple advantages and strengths. Unlike conventional underground detention tanks or concrete vacuum systems, the modular nature of the StormPav system enables the removal of individual units for cleaning, facilitating access to and inspection of the sediment or debris that may have collected within the storage chamber. Thereby, the StormPav system facilitates maintenance procedures, particularly in residential settings where access to underground structures often poses challenges.

The routine maintenance of the system should involve regular inspection of the service inlet opening and the outlet orifice in order to ensure unobstructed flow conditions. When considering the presence of sediment within the hollow cylindrical chambers, a deposition or accumulation over time can occur due to the runoff from the roof and driveway

surface. However, the modular nature of the StormPav system provides the opportunity to locally clean the sediment without the need for full system excavation. Thereby, the StormPav maintenance requirements are relatively low compared to the sealed underground detention structures.

Lastly, from an economic perspective, the modular precast configuration can also offer additional construction benefits. The prefabricated units can be installed during the construction phase of residential driveways, minimizing construction time and labour costs when compared with cast-in-place detention structures. Moreover, as the system is integrated beneath existing pavement areas, it does not require additional land allocation, which is particularly important in high-density terrace housing developments where the available space is limited. The characteristics of the StormPav thus indicate a cost-effective decentralized stormwater management solution for residential applications.

3.4.5. Study Limitations and Transferability

Despite the promising results obtained from the simulations, several limitations should also be noted. First, the analyses were conducted based on numerical simulations using representative housing configurations, rather than long-term field monitoring data. While the SWMM model has been extensively validated for urban drainage applications, the actual performance of such stormwater management systems may vary due to factors such as sediment accumulation influence, construction variability, and drainage connectivity within residential developments.

Second, the study focused primarily on the system performance of individual property-scale detention solutions and did not consider the cumulative hydrologically interconnected effects of large-scale implementation across entire neighbourhoods or urban catchment areas. The decentralised OSD system's effectiveness may be different if multiple systems interact within a broader urban drainage network.

Lastly, while the economic feasibility and maintenance requirements of the StormPav system were discussed qualitatively, detailed life-cycle cost assessments were not specifically performed in this study. Future research should include a combination of extended monitoring and cost-benefit analysis to assess further the operational sustainability of modular OSD systems in tropical urban settings.

4. Conclusion

This study evaluated the hydrological performance of the StormPav home-based On-Site Detention (OSD) system under different housing configurations, contributing catchment ratios, and storm durations using the SWMM hydrologic-hydraulic simulation model. A total of 72 simulation scenarios were developed to represent six residential housing typologies in a tropical urban setting. The

results confirmed that the StormPav system effectively attenuates post-development peak discharge and delays time to peak for all tested configurations.

Better detention efficiency was found for corner and semi-detached houses of approximately 30–35% for peak discharge reduction. Analyzing the results shows that the storage detention efficiency improves with the increase in the contributing area catchment ratio up to an optimum value of approximately 50%, beyond which the improvement is marginal. A higher input peak was generated for short-duration and high-intensity storms, resulting in greater storage utilization and a lower input peak for long-duration storms with longer times to outflow recession periods.

Overall, the results demonstrate that decentralized home-based OSD systems with proper design, when added to urban catchments, can have promising contributions to mitigate urban flooding and sustainable stormwater management of residential developments. Future studies should include field calibration under varying rainfall conditions and conduct cost–benefit analyses to support the integration of modular OSD systems into local drainage guidelines. Although field testing was conducted, this study was limited to selected housing configurations and simulation scenarios. Future

research should focus on long-term field monitoring under varying rainfall conditions and residential layouts to validate the model predictions presented in this study. In addition, comprehensive cost–benefit analyses and neighbourhood-scale hydrological assessments would further support the integration of modular OSD systems into urban drainage planning and regulatory guidelines. Such efforts would help strengthen the role of decentralized stormwater detention systems in improving urban flood resilience in tropical residential developments.

Funding Statement

The authors would like to acknowledge the financial support provided by Universiti Malaysia Sarawak via the Postgraduate Research Grant Scheme for the project entitled “Field Testing of On-Site Detention Using StormPav Green Pavement System,” Project ID: UNIMAS/F02/PGRG/1911/2019.

Acknowledgment

The authors would like to acknowledge the article processing charge provided by i-CATS University College for this paper.

References

- [1] C.H.J. Bong et al., “Detention Properties of Subsurface Stormwater Modules Under Tropical Climate,” *International Journal of Integrated Engineering*, vol. 15, no. 6, pp. 72-78, 2023. [[CrossRef](#)] [[Google Scholar](#)] [[Publisher Link](#)]
- [2] Pedro de Paula Drumond, Priscilla Macedo Moura, and Márcia Maria Lara Pinto Coelho, “Improving the Understanding of On-Site Stormwater Detention Performances,” *Urban Water Journal*, vol. 20, no. 10, pp. 1271-1289, 2023. [[CrossRef](#)] [[Google Scholar](#)] [[Publisher Link](#)]
- [3] Mirelle Lopes Dias et al., “Evaluating the Performance of On-Site Stormwater Detention based on the Technical Guidelines for Developing Stormwater Projects in Belo Horizonte (MG, Brazil),” *RBRH*, vol. 30, pp. 1-16, 2025. [[CrossRef](#)] [[Google Scholar](#)] [[Publisher Link](#)]
- [4] Norazlina Bateni et al., “Environmental Performance of the StormPav Permeable Pavement using the Stormwater Management Model (SWMM),” *International Journal of Integrated Engineering*, vol. 15, no. 6, pp. 52-63, 2023. [[CrossRef](#)] [[Google Scholar](#)] [[Publisher Link](#)]
- [5] Raincycle, 2026. [Online]. Available: <https://raincycle.com.au/what-do-osd-tanks-look-like/>
- [6] Senior Resources Group, OSD on Site Detention, 2026. [Online]. Available: <https://www.srgroup.com.my/showproducts/productid/3653212/osd-on-site-detention/>
- [7] Ausdrain, Onsite Detention Tanks, 2023. [Online]. Available: <https://ausdrain.com/onsite-detention/>
- [8] Atlan Stormwater, Atlan Stormwater Detention Tanks, 2026. [Online]. Available: <https://atlanstormwater.com/au/stormwater-detention/>
- [9] SVC Civil, Stormwater Detention Systems, 2026. [Online]. Available: <https://svc.com.au/products/stormwater-detention-systems/>
- [10] Thivanka Dharmasena et al., “Performance Assessment of a Constructed Wetland using a Numerical Modelling Approach,” *Ecological Engineering*, vol. 173, 2021. [[CrossRef](#)] [[Google Scholar](#)] [[Publisher Link](#)]
- [11] Azadeh Hosseinzadeh et al., “A New Multi-Criteria Framework to Identify Optimal Detention Ponds in Urban Drainage Systems,” *Journal of Flood Risk Management*, vol. 16, no. 2, pp. 1-19, 2023. [[CrossRef](#)] [[Google Scholar](#)] [[Publisher Link](#)]
- [12] Government of Malaysia Department of Irrigation and Drainage (DID), *Urban Stormwater Management Manual for Malaysia* (MSMA), 2nd ed., Putrajaya, Malaysia: Government of Malaysia, 2012. [[Google Scholar](#)]
- [13] Hossein Ahmadi et al., “Automated Calibration of SWMM for Improved Stormwater Model Development and Application,” *Hydrology*, vol. 12, no. 6, pp. 1-26, 2025. [[CrossRef](#)] [[Google Scholar](#)] [[Publisher Link](#)]