Journal of Advanced Research in Fluid Mechanics and Thermal Sciences

Journal homepage:
https://semarakilmu.com.my/journals/index.php/fluid_mechanics_thermal_sciences/index
ISSN: 2289-7879

StormPav Green Pavement as Parking Lot and Stormwater Detention Pond for Flash Flood Mitigation at Taman Uni Garden Kota Samarahan, Sarawak

Lukman Mohd Najib[1], Norazlina Bateni[1,2,*], Darrien Yau Seng Mah[1,2]

[1] Faculty of Engineering, Universiti Malaysia Sarawak, Kota Samarahan Sarawak 94300, Malaysia
[2] Unimas Water Centre, Faculty of Engineering, Universiti Malaysia Sarawak, Kota Samarahan Sarawak 94300, Malaysia

ARTICLE INFO

Article history:
Received 26 December 2024
Received in revised form 16 April 2025
Accepted 24 April 2025
Available online 10 May 2025

Keywords:
Flood mitigation; detention storage; StormPav; SWMM; permeable pavement

ABSTRACT

Flood disturbances have an impact on the economy and society. Previous research has focused on the causes of floods resulting in urbanization, poor drainage networks, maintenance, and climate change. This study aims to develop an integrated stormwater management solution in the Kota Samarahan district's floodplain area in Sarawak, Malaysia. This paper aims to evaluate the causes of the flood and the potential of detention storage, namely StormPav as a sub-surface detention pond storage permeable parking lot to mitigate flood in the study area. The study area has experienced floods almost every year since 2015, during the Northeast Monsoon season in the middle of December and early January. The main outlet received about 2286 m^3 of overflow water when projected with 10 Average Recurrence Interval (ARI) rainfall, causing a flash flood to the commercial building next to the main outlet area. The field study is conducted to evaluate the existing hydraulic drainage network. The existing drainage network of the catchment area is modelled in Stormwater Management Model (SWMM) version 5.1. Next, the scenario with a flood is simulated in SWMM. Finally, flood mitigation using StormPav is assessed using Low Impact Development (LID) control in SWMM. The results show that StormPav reduced peak flow runoff by about 32.55% and 31.15% for 10 ARI and 100 ARI, respectively, with subsurface detention storage.

1. Introduction

Rapid development initiatives have replaced the original vegetation coverings with concrete surfaces in urban regions. As a direct consequence, more runoff was produced, which led to an increase in the number of floods [1,2]. The important component of the problem of flooding in urban areas has been intensified by variables such as changes in precipitation patterns, congested stormwater drainage systems, the development of urban regions, and aging drainage networks [3]. Hence, conventional methods were primarily developed to decrease the peak of the water flow through stormwater management infrastructure. However, they had no aim of reducing the runoff

* *Corresponding author.*
E-mail address: bnorazlina@unimas.my

https://doi.org/10.37934/arfmts.131.1.219229

volume. The problem was typically solved by increasing the system's hydraulic capacity and expanding the number of drainage channel sections already in place [2,4]. Consequently, sustainability has emerged as the primary priority during the process of constructing the infrastructure since the 1990s.

The new permeable road, StormPav Green Pavement System, is constructed from three precast concrete sections to form a modular unit of Grade 50 concrete. This hollow cylinder is equipped with hexagonal plates at the top and bottom, strengthened by the integration of double steel layers, and might also be enveloped by a geotextile layer [5]. The StormPav is constructed on-site by placing it directly on top of flat subgrade soil and assembling it through dry stacking, producing an interlocking paver structure assembly. StormPav is intentionally constructed with a hexagonal shape to optimize its structural support and longevity [5]. This design choice also has the added advantage of enhancing stormwater management's permeability. In which the system's permeability is obtained due to the presence of a drainage system located beneath it. This drainage system serves dual functions, acting as both a microscale subsurface detention storage system and a water-holding mechanism that enhances the capacity of voids [6]. The primary objective of the hollow micro detention design is to serve as a reservoir for rainwater while being capable of a drying mechanism through seepage along the bottom and sides of StormPav during rainfall events [6]. Both the layers include a 40 mm diameter hole at the center and interlocking keys of six grooves. This hole is an open pathway of stormwater infiltration and inflow, respectively. Regarding the lateral flow, the micro detention pond's hollow cylindrical tank incorporates a pair of opposing openings consisting of holes with a diameter of 0.04 m. located close to the bottom section of the cylindrical structure.

Previous research highlighted structural, hydrological, and environmental modeling features but did not include real-world flood scenarios in compliance with local characteristics [5-7]. The study by Bateni *et al.,* [6] indicates that model simulations assessing the hydrological impact of StormPav and other road pavements (Porous Concrete (PC), Porous Asphalt (PA), Permeable Interlocking Concrete Pavers (PICP)) revealed that StormPav achieved greater runoff reduction, the lowest runoff coefficients, and the lowest peak flow rate. Additionally, StormPav exhibited a faster infiltration rate, based on Bateni *et al.,* [6], compared with the permeable concrete and permeable interlocking concrete pavers, whose infiltration losses ranged from 20% to 70%, StormPav's infiltration loss was close to 90%. In terms of the feasibility of implementing StormPav as a flood mitigation solution is well supported by its cost-effectiveness and heat mitigation properties [5]. With a production cost of \$30/m² (\$0.50/ft²), it presents a more economical alternative compared to conventional permeable pavements. Its dry-stacked, precast design allows for rapid installation, reducing both labor requirements and overall costs. Additionally, StormPav functions as a micro-detention pond, reducing the need for large detention basins and smaller drainage systems, which can subsequently lower stormwater impact fees. From a thermal perspective, its light-colored concrete surface absorbs less heat, while its open space design ($0.19 m^3/m^2$) reduces heat retention, contributing to urban heat island mitigation. These features collectively demonstrate the practicality and economic viability of StormPav as a flood mitigation measure.

Besides, the study conducted by Bateni *et al.,* [6] employed the SWMM to clarify the hydrological effects of StormPav. Moreover, the study by Bateni *et al.,* [6,7] aimed to compare StormPav with other permeable pavements by incorporating permeable pavement characteristics into the LID controls section. In another study, researchers investigated the effectiveness of StormPav by utilizing SWMM, specifically the rain barrel feature in the controls section of LID, where StormPav was considered as Rain Water Harvesting (RWH) [8]. Modelling software has been widely used for stimulation without needing to prepare an actual prototype [8].

Building upon these previous approaches, this study adopts a modified modeling technique to address the limitations of the LID control feature in SWMM in implementing new concept of StormPav utilization. This research, therefore, implemented the green parking concept with the StormPav structure as the major body component of the detention storage solution. This entire concept was modeled in SWMM to contribute to the proposed infrastructure substantially. The study is conducted to determine the effectiveness of StormPav as a subsurface storage interceptor to be applied near the outlet.

2. Methodology

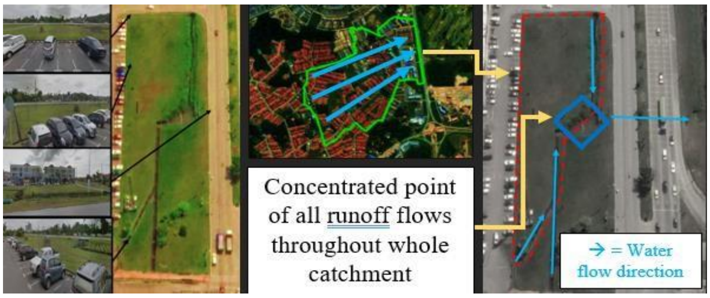
2.1 Study Area

Uni Garden, located in Kota Samarahan, Sarawak, is an urbanized residential area that covers about 69.75 hectares located in front of Universiti Malaysia Sarawak, specifically at 1°27'40.59" north latitude and 110°24'42.56" east longitude. Figure 1, extrapolated from Google Earth Pro, depicts the location of Uni Garden along its border. Almost every year since 2015, the Department of Irrigation and Drainage (DID) of Sarawak has received reports of flash floods in this residential neighborhood whenever extreme rainfall with short duration strikes Uni Garden. Figure 1 shows the severity of the flash flood that occurred on December 7, 2022, in the study area.

Fig. 1. The boundary of Uni Garden and the flood happened on 7 December 2022

2.2 Virtual Implementation of StormPav System

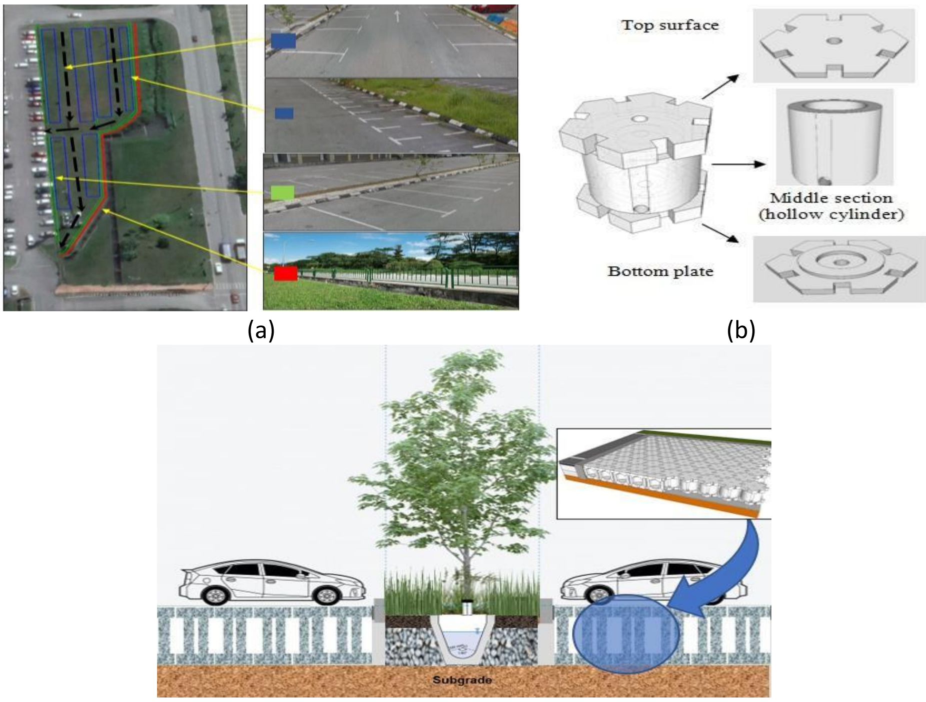
Figure 2(a) illustrates the proposed site for a sustainable parking approach of StormPav as a detention storage and permeable parking lot simulated in SWMM. Located adjacent to downstream of the outlet point with flat topographical condition, the StormPav is virtually installed at the study area to store and direct overflow water in the sub-surface storage. The proposed area covered about 2340 m^2 wide. Figure 2(b) shows the downstream outlet that received and accumulated all the stormwater runoff collected throughout the catchment. The outlet is a point of intersection between the concrete drain and earth drain before the runoff flows through a cylindrical culvert bypassing the Expressway of Kuching- Samarahan. This location is also a starting point for runoffs to overflow.



(a) (b)

Fig. 2. (a) Overview of the proposed site for StormPav application; (b) Boundary of the proposed site for StormPav application

The StormPav applied in this study is simulated with changes in the height of StormPav to provide more detention storage, from 300 mm to 600 mm. The StormPav sub-component was shown in Figure 3(b) As shown in Figure 3(a), the parking lot for the StormPav application is designed to accommodate approximately 80 car parking units and 30 motorcycle parking units. The StormPav structures constructed will cover the proposed area of 2070 m^2 after subtracting with bushes island covers 270 m^2. The bushes' island covers were expected to contain a small drain to flush out runoff infiltrated into StormPav. The implementation concept of this scenario was shown in Figure 3(c).



(a) (b)

(c)

Fig. 3. (a) Proposed layout of green parking approach; (b) StormPav component; (c) Conceptual implementation of StormPav as green parking approach

Theoretically, StormPav is a type of pavement that may be used as a road and detention storage. In connecting the runoff in the drainage system with stacks of StormPav infrastructure, the emergency weir hole (inlet) was installed in the existing adjacent drainage system. The emergency hole will act as the flow director of the excessive water runoffs into the StormPav infrastructure. To make the stormwater water be directed into StormPav faster and significantly alter the outlet's performance, an orifice was placed in the existing drainage system adjacent to the inlet weir. The water directed from the inlet point into the StormPav infrastructure will be merged and fully filled in through the 0.04 m diameter holes opening at the hollow cylinder tank. This approach is expected to reduce overflow risks in the drainage system. The StormPav infrastructure is expected to be designed so that only 30% of storage can be filled in by runoff from the parking area's surfaces. This includes altering the road slope it will expect to direct (runoffs into the drains at the green verge divider) greater than 30% of the rainfall drained in that closed area. This approach can save greater StormPav storage to serve excessive runoffs from the drainage system.

2.3 Modelling of SWMM

Several studies have demonstrated the versatility and reliability of EPA SWMM 5.1 in flood analysis and mitigation planning. The study by Gaborit *et al.,* [9] utilized the model to predict urban catchment runoff, stormwater pond flow, and total suspended solids (TSS). While study by Souza *et al.,* [10] investigated the pollutant removal efficiency of dry detention ponds along drainage mains, the study by Li *et al.,* [11] applied SWMM to model a dual-drainage underground rain barrel system hydrologically. Besides, Bateni *et al.,* [12] simulated a novel porous pavement with subsurface micro-detention storage (PPDS) to assess its effectiveness in stormwater management. Additionally, Moore [13] employed SWMM to simulate an infiltration trench, further showcasing the model's applicability in urban drainage studies. Collectively, these studies highlight SWMM's capability in evaluating stormwater dynamics, pollutant removal efficiency, and the performance of various flood mitigation infrastructures.

Throughout this study, the SWMM model was used to evaluate StormPav's performance as a flood mitigation infrastructure at Uni Garden by referring to the properties of StormPav used in previous studies [5,6,14-16]. SWMM was also used to predict infiltration and evapotranspiration [17]. However, this study used the Storage Unit feature in SWMM instead of the LID control section to model the StormPav flow system due to the limitation of the LID control feature, which can only receive runoff from sub-catchments. While Storage Unit features can receive the water from hydraulic conveyance and allow the water to enter the StormPav system.

The first step involves establishing the hydrology and hydraulics parameters in the site for the existing drainage system model validation. This study examines two distinct modeling situations by using two rainfall curves with different return periods, which are 10-year ARI and 100-year ARI for minor system and major systems, respectively, and implemented for 15 minutes of rainfall duration [14]. The rainfall curves obtained were changed to cumulative curve and act as rain gage input in SWMM. The precipitation that falls into the sub-catchments transforms into runoff, which then flows through the storage system, infiltrates into the subgrade, and eventually collects discharged water at the outfall [6].

The SWMM model's input data encompasses various parameters, such as drainage properties, depth, width, length, and drain flow direction, acquired through on-site visits and on-site measurement [18]. Next, the distribution type of land use surfaces was also considered in SWMM modeling since it influenced the runoff volume generated. Those distributions were identified using a programmed method on the TinEye Lab website that extracted colors from images of Uni Garden which was divided based on the 52 small sub-catchments to ensure accuracy of impervious distribution percentage. The images of all 52 sub-catchments were prepared in PNG format before were processed by using TinEye Lab website.

These procedures were carried out before entering the input data and information for StormPav implementation. Then, based on Bateni *et al.,* [6], validation of this study used the Nash-Sutcliffe

Efficiency (NSE) index to evaluate SWMM's capability to model StormPav as well as Percent Bias (PBIAS) method [19]. Both of these methods were used to compare the cumulated precipitation (mm), peak runoff (m^3/s) and runoff coefficient for both manual calculation and SWMM results. Based on Moriasi *et al.,* [20], the Nash-Sutcliffe Efficiency (NSE) ranges from $-\infty$ to 1.0, with 1.0 representing optimal performance. Where, the values between 0.0 and 1.0 indicate acceptable model performance, while values below 0.0 suggest that the observed mean provides a better prediction than the model, indicating poor performance. On other hand, for Percent Bias (PBIAS), the ideal value is 0.0, with lower magnitudes reflecting higher model accuracy. A positive PBIAS indicates model underestimation, whereas a negative PBIAS signifies overestimation.

After the validation phase, then the values and information of StormPav can be inserted in SWMM model. Several properties (Table 1) are keyed in the SWMM model to analyze the performance of StormPav as a storage unit and weirs that act as inlets and outlets for StormPav. The Figure 4 shows the whole drainage system of Uni Garden in SWMM (left side) along with StormPav unit being considered in the model (right side).

Table 1
StormPav and weir parameters applied in SWMM

Parameters	Value/component used
Storage unit	
Invert level [m]	5.25
Maximum depth [m]	0.75
Storage curve	Tabular
Tabular curve	StormPavCurve
StormPavCurve	
Depth (m)	Area (m^2)
0.1	1253.54
0.2	1253.54
0.3	1253.54
0.4	1253.54
0.5	1253.54
0.6	1253.54
Weir 1& 2	
Type	Sideflow for both weir
Height [m]	0.4 and 0.1 respectively
Length [m]	1 for both weir
Inlet offset [m]	1.6 and 0.5 respectively
Outlet offset [m]	0.2 and 1.71 respectively

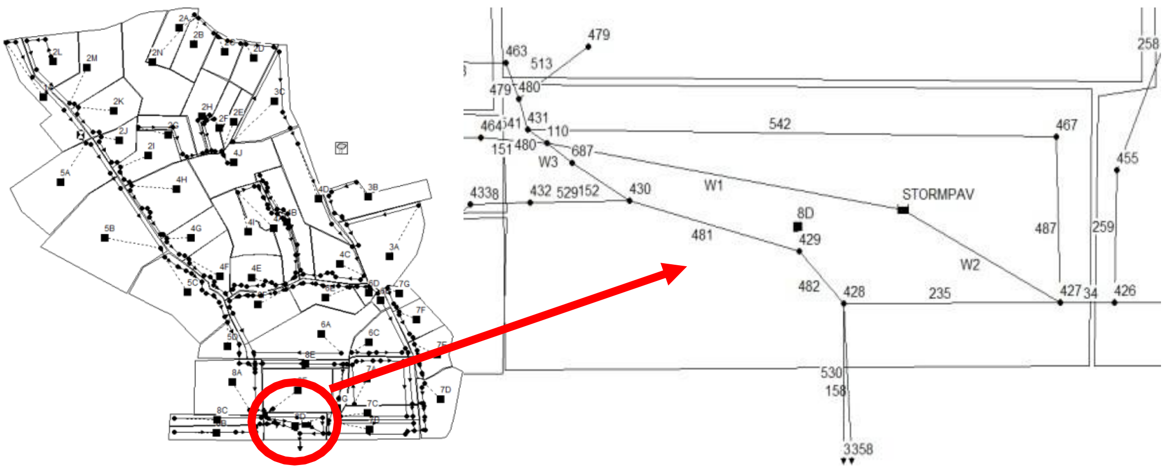


Fig. 4. The StormPav infrastructure is applied virtually on-site through SWMM

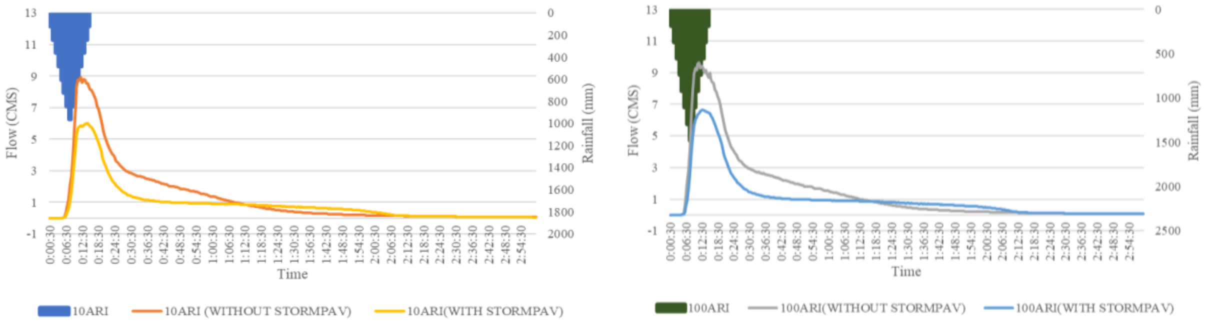
3. Results and Discussion

StormPav infrastructure was implemented at the downstream sub-catchment, and sub-catchment 8D was located adjacent to the outlet as a storage unit feature. The stormwater runoff in the drainage system that exceeded 1.6 m height was transferred into StormPav infrastructure through Weir 1 at node 110. It bypassed the rise in the drainage system's water level, thereby preventing overflow and flooding. Then, the excess discharge in the StormPav infrastructure will flush out through outlet Weir 2 and end at node 427. Meanwhile, the water that is not flushed out will undergo an infiltration process through the subgrade underneath. Based on Bateni *et al.,* [5] that studies StormPav of 300 mm height, the StormPav system demonstrated a significant decrease in runoff, reducing it by approximately 60% to 70%. Moreover, there was also a substantial decrease in infiltration, with a loss of nearly 90%. Hence, the StormPav can serve as the detention pond storage for the overflow runoff from the existing drainage in the catchment.

Despite StormPav's practicability, there is a concern regarding mosquito development in the structure. Most mosquito eggs hatch within 24 to 72 hours of coming into contact with water, developing into larvae. Before entering the pupal stage, the larvae develop for 7 to 10 days. It takes one to three days before adult mosquitoes emerge from the pupal stage. The study by Bateni *et al.,* [15] reported that mosquito larvae required 9.8 to 23.3 days to mature into adults, depending on the temperature. According to Bateni *et al.,* [15], the larvae growth was discovered in stagnant water within the hollow cylindrical component of StormPav as early as eight days. The study also showed the capacity of the proposed StormPav to rapidly transmit and bypass water into the soil in less than two hours to infiltrate 14 liters (L) of water. It took less than two hours for the soil with no stagnant water to remain in the empty section, eliminating the retention period needed for larvae development. Since mosquito larvae needs around eight days to mature, the high permeability rate of HSG soil groups A and B (122.45 mm/hr and 168.12 mm/hr respectively) may prevent any possible growth of mosquitoes.

In this simulation, the StormPav infrastructure was not connected to sub-catchment 8D or affected by its hydrological aspect scenarios. The StormPav performance is evaluated based on the stormwater runoff reduction from the SWMM link. Link 158 was used for analysis as it was located at the end of the Uni Garden drainage system network. The resulting hydrographs consisting of rainfall series and reduction in runoff flow for link 158 are presented in Figure 5 for the duration of 10 and 100-year ARIs of storm events. In which the hydrographs of the StormPav with different rainfall magnitudes were compared against those resulting from the existing condition without StormPav. The uniform interval of 15-minute time steps was used to generate the hydrographs. Figure 5 revealed that the peak flow for 10 and 100-year ARI storm events without StormPav implementation were 8.91 m^3/s and 9.63 m^3/s, respectively. StormPav infrastructure decreased the peak flow to 6.01 m^3/s and 6.63 m^3/s for 10 and 100-years ARI, respectively. Hence, the StormPav implementation will result in 32.55% and 31.15% peak flow reduction at link 158 for 10 and 100-year ARI, respectively. Both of these reduction percentages were calculated by using (1).

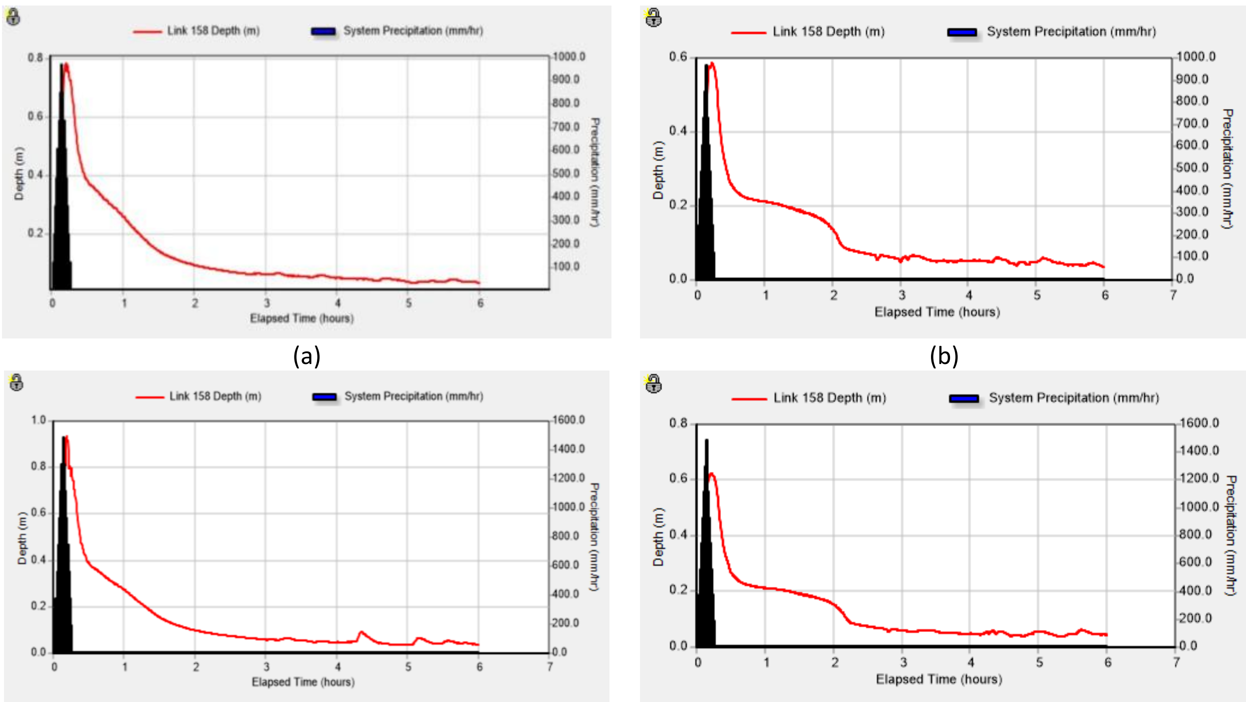
$$\text{Percentage of reduction (\%)} = \frac{\text{Existing Peak flow} - \text{Reduced Peak Flow}}{\text{Existing Peak Flow}} \times 100\% \tag{1}$$



(a) (b)

Fig. 5. The link 158 hydrographs simulation resulted from SWMM software for (a) 10 and (b) 100 ARI events with and without StormPav implementation

Figure 6 shows the variation of water level in the drainage system. The maximum water depth in link 158 in the model without StormPav is about 0.79 m during peak flow (00:12:00) for 10 ARI and 0.93 m during 00:11:30 for 100 ARI, respectively. With StormPav, for both 10 and 100-year ARI, the water level was 0.59 m (during 00:14:00) and 0.63 m (during 00:13:00), respectively. The reduction in water level is about 25.32% and 32.26%, comparably. The reduction is due to the effectiveness of StormPav as a detention pond storage to store the overflow water about 1.6 m high at the drainage outlet. Figure 7 shows the water level profile in the adjacent drainage with the implementation of StormPav, which has significantly reduced in comparison to the existing condition of the overflow drainage system. The result eventually shows a tremendous increase in the water level of the drainage system, which can be prevented and reduce the risk of overflow and flood.

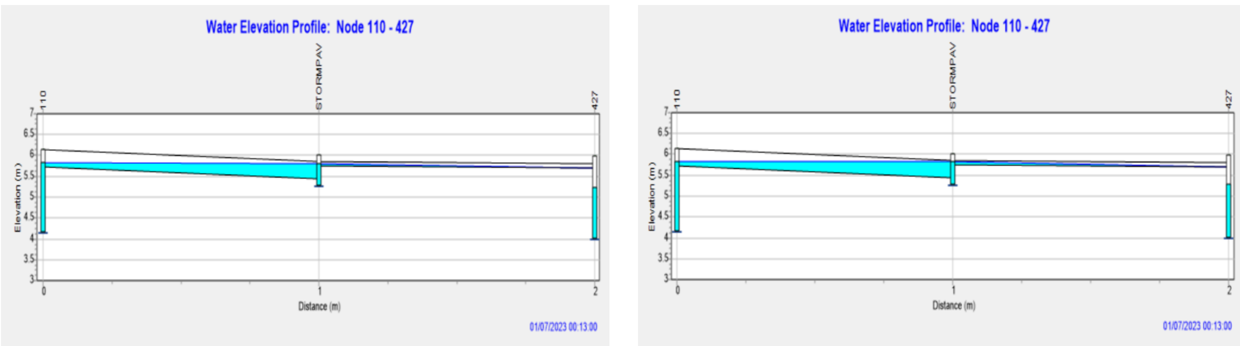


(a) (b) (c) (d)

Fig. 6. The water depth resulted from SWMM software for both 10 and 100 ARI events; (a) 10-year ARI and 15-minute design rainfall (without StormPav); (b) 10-years ARI and 15 minutes design rainfall (with StormPav); (c) 100-years ARI and 15-minute design rainfall (without StormPav); (d) 100-years ARI and 15 minutes design rainfall (with StormPav)

The StormPav can control peak flow and balance the water level profile in the existing drainage. Even though the storage unit cannot reduce the post-development runoff volume resulting from the large impervious area covers. However, it can temporarily retain the rainwater and be released back to the drainage network system when the water reaches the outlet weir level (0.5 m height from the 5.25 m ground invert level of StormPav). Several dimensions were applied to determine the most appropriate weir opening, resulting in the best water profile control in the existing drainage system. Smaller weir sizes allow less total inflow and outflow of the water and increase the risk of overflow since the water has less time to be stored, and the amount of time for water that has been stored in the StormPav will be longer. This is an important aspect since an extended peak flow time can contribute to an overall increase in peak flow during an event, especially when assessing a sizable watershed [21]. On the contrary, a larger dimension of the weir facilitates a larger passage of water into the StormPav, reducing the StormPav's detention time to achieve maximum storage. This was proven through the use of the discharge formula for the rectangular sharp-crested shaped weir used in previous studies by (2) below [22-24]. At which the Q in the formula represents the discharge flows through the weir in m^3/s, Cd represents the discharge coefficient, the variable g denotes the gravity in m^2/s, B denotes the weir's width in m, and H represents the head over the weir crest in m. The studies by Ben said and Ouamane [25], and Kumar *et al.,* [26], which studied labyrinth weirs that implemented rectangular shapes as their basis, also indicate that the study revealed that the rectangular labyrinth shape demonstrated a higher discharge capacity compared to the trapezoidal shape.

$$q = \frac{2}{3} c_d \sqrt{2ghBH^{\frac{3}{2}}} \tag{2}$$



(a) (b)

Fig. 7. The modelling of StormPav implementation for 10 ARI and 100 ARI; (a) 10-year ARI and 15-minute design rainfall; (b) 100-year ARI and 15-minute design rainfall

StormPav is not only anticipated to give additional storage (70% of StormPav's system storage) to change the water flows, but it is also anticipated to give alterations in terms of the behavior of the water runoffs, the time step of the flow decremental value in the drain system, giving sufficient and optimal time for the water to flush out instead of overflowing at the outlet point. It overtakes the incremental water stage in the drainage system, preventing it from reaching the maximum drainage height and overflowing. The primary objective of the design of the water-holding system is to improve the design of void and detention capacity, achieving an increase of up to 70% and 0.90 m^3/m^2 (30 L/unit), respectively [6]. In this study, a maximum of 749.30 m^3 (749,300 L) of water can be stored in the StormPav system. A range of 624.41 m^3 (624,410 L) to 749.30 m^3 (749,300 L) will be stored before the water flows through the outlet.

4. Conclusions

In this paper, the modified design of the StormPav looks to be an alternative to detention storage with potential functions as a road system and stormwater management infrastructure. In conclusion, the following are some of the most important factors to be concluded.

i. The evaluation was carried out with SWMM modeling. The modeling suggested that the adoption of StormPav has resulted in a 32.55% and 31.15% reduction of peak flow at the outflow link for 10 ARI and 100 ARI, respectively.
ii. Based on the results of a model simulation that evaluated the hydrological impact of StormPav, it is feasible to determine that StormPav divided the time of water accumulation at the outlet and prevented the risk of outlet failure.
iii. StormPav demonstrated that the water runoffs were bypassed into the StormPav structure and given external storage downstream.

References

[1] Li, Qian, Feng Wang, Yang Yu, Zhengce Huang, Mantao Li, and Yuntao Guan. "Comprehensive performance evaluation of LID practices for the sponge city construction: a case study in Guangxi, China." *Journal of Environmental Management* 231 (2019): 10-20. https://doi.org/10.1016/j.jenvman.2018.10.024

[2] Zhu, Zhihua, Zhihe Chen, Xiaohong Chen, and Guo Yu. "An assessment of the hydrologic effectiveness of low impact development (LID) practices for managing runoff with different objectives." *Journal of Environmental Management* 231 (2019): 504-514. https://doi.org/10.1016/j.jenvman.2018.10.046

[3] Webber, James L., Mike J. Gibson, Albert S. Chen, Dragan Savic, G. Fu, and David Butler. "Rapid assessment of surface-water flood-management options in urban catchments." *Urban Water Journal* 15, no. 3 (2018): 210-217. https://doi.org/10.1080/1573062X.2018.1424212

[4] Haris, H., M. F. Chow, F. Usman, L. M. Sidek, Z. A. Roseli, and M. D. Norlida. "Urban stormwater management model and tools for designing stormwater management of green infrastructure practices." In *IOP Conference Series: Earth and Environmental Science*, vol. 32, no. 1, p. 012022. IOP Publishing, 2016. https://doi.org/10.1088/1755-1315/32/1/012022

[5] Bateni, N., S. H. Lai, R. Ahmad Bustami, M. A. Mannan, and D. Y. S. Mah. "A review on green pavement hydrological design and recommended permeable pavement with detention storage." In *IOP Conference Series: Materials Science and Engineering*, vol. 1101, no. 1, p. 012014. IOP Publishing, 2021. https://doi.org/10.1088/1757-899X/1101/1/012014

[6] Bateni, Norazlina, Sai Hin Lai, F. J. Putuhena, Darrien Yau Seng Mah, Md Abdul Mannan, and Ren Jie Chin. "Hydrological performances on the modified permeable pavement with precast hollow cylinder micro detention pond structure." *KSCE Journal of Civil Engineering* 23, no. 9 (2019): 3951-3960. https://doi.org/10.1007/s12205-019-2271-8

[7] Bateni, Norazlina, Lukman Mohd Najib, Khairisya Roslan, Mah Yau Seng, Inawati Othman, H. Maseri, and M. D. Mannan. "Environmental Performance of the Stormpav Permeable Pavement Using the Stormwater Management Model (SWMM)." *International Journal of Integrated Engineering* 15, no. 6 (2023): 52-63. https://doi.org/10.30880/ijie.2023.15.06.006

[8] Dullah, Salinah, Hidayati Asrah, Movierawanna Bernard, and Jane Ann Jumi. "Preliminary Modelling of Hydrological Performance for Green Roof Drainage Layer using Response Surface Methodology." *Journal of Advanced Research in Applied Sciences and Engineering Technology* 55, no. 1 (2026): 105-124. https://doi.org/10.37934/araset.55.1.105124

[9] Gaborit, E., François Anctil, Geneviève Pelletier, and Peter A. Vanrolleghem. "Exploring forecast-based management strategies for stormwater detention ponds." *Urban Water Journal* 13, no. 8 (2016): 841-851. https://doi.org/10.1080/1573062X.2015.1057172

[10] Souza, Fernanda Pereira, Maria Elisa Leite Costa, and Sergio Koide. "Hydrological modelling and evaluation of detention ponds to improve urban drainage system and water quality." *Water* 11, no. 8 (2019): 1547. https://doi.org/10.3390/w11081547

[11] Li, James, Seyed Alinaghian, Darko Joksimovic, and Lianghao Chen. "An integrated hydraulic and hydrologic modeling approach for roadside bio-retention facilities." *Water* 12, no. 5 (2020): 1248. https://doi.org/10.3390/w12051248

[12] Bateni, Norazlina, Sai Hin Lai, Frederik Josep Putuhena, Darrien Yau Seng Mah, Md Abdul Mannan, and Ren Jie Chin. "Hydrological impact assessment on permeable road pavement with subsurface precast micro-detention pond." *Water and Environment Journal* 34 (2020): 960-969. https://doi.org/10.1111/wej.12613

[13] Moore, Shaelynn. "Low Impact Development Mitigation for Base Flood Elevation Disparity between Adjacent Properties." *University of New Orleans Theses and Dissertations* (2021).

[14] Bateni, Norazlina, Lai Sai Hin, Md Abdul Mannan, Jethro Henry Adam, Kuryati Kipli, and Rosmina Ahmad Bustami. "Performance of Permeable Pavement with Subsurface Micro Detention Storage as Rainwater Harvesting Device." In *ICCOEE2020: Proceedings of the 6th International Conference on Civil, Offshore and Environmental Engineering (ICCOEE2020)*, pp. 139-146. Springer Singapore, 2021. https://doi.org/10.1007/978-981-33-6311-3_16

[15] Bateni, Norazlina, Nur Sakinah Mohd Fathil, Rosmina Ahmad Bustami, Saihin Lai, M. A. Mannan, and Darrien Yau Seng Mah. "Environmental assessment of stormpav green pavement for stormwater management." *Journal of Sustainability Science and Management* 17, no. 6 (2022): 182-192. https://doi.org/10.46754/jssm.2022.06.014

[16] Bateni, Norazlina, Sai Hin Lai, F. Putuhena, Y. S. Mah, and A. Mannan. "A rainfall simulator used for testing of hydrological performances of micro-detention permeable pavement." *International Journal of Engineering & Technology* 7, no. 3.18 (2018): 44-48. https://doi.org/10.14419/ijet.v7i3.18.16671

[17] Alamdari, Nasrin. "Evaluating the effects of stormwater control measures on percolation in semi-arid watersheds using a high-resolution stormwater model." *Journal of Cleaner Production* 375 (2022): 134073. https://doi.org/10.1016/j.jclepro.2022.134073

[18] Kuok, King Kuok, and Po Chan Chiu. "Hydrological Modelling and Evaluation of Detention Ponds Transformed from Roundabout to Mitigate Urban Flooding." *Journal of Engineering Science and Technology* 17, no. 6 (2022): 4398-4409.

[19] Turco, Michele, Radka Kodešová, Giuseppe Brunetti, Antonín Nikodem, Miroslav Fér, and Patrizia Piro. "Unsaturated hydraulic behaviour of a permeable pavement: Laboratory investigation and numerical analysis by using the HYDRUS-2D model." *Journal of Hydrology* 554 (2017): 780-791. https://doi.org/10.1016/j.jhydrol.2017.10.005

[20] Moriasi, Daniel N., Jeffrey G. Arnold, Michael W. Van Liew, Ronald L. Bingner, R. Daren Harmel, and Tamie L. Veith. "Model evaluation guidelines for systematic quantification of accuracy in watershed simulations." *Transactions of the ASABE* 50, no. 3 (2007): 885-900. https://doi.org/10.13031/2013.23153

[21] Juiani, Siti Fairuz, Nor Azazi Zakaria, Aminuddin Ab. Ghani, Khairul Rahmah Ayub, Chun Kiat Chang, Mohd Fazly Yusof, Syafiq Shaharuddin, Nor Ariza Azizan, and Muhammad Zaki Mohd Kasim. "Bio-ecological Drainage System (BIOECODS): A Sustainable Green University Drainage System." In *Handbook of Best Practices in Sustainable Development at University Level*, pp. 207-231. Cham: Springer International Publishing, 2022. https://doi.org/10.1007/978-3-031-04764-0_12

[22] Alwan, Husam H., L. A. Saleh, Fadhil M. Al-Mohammed, and M. A. J. J. Abdulredha. "Experimental prediction of the discharge coefficients for rectangular weir with bottom orifices." *Journal of Engineering Science and Technology* 15, no. 5 (2020): 3265-3280.

[23] Caroline, L. L., and Nasser R. Afshar. "Effect of types of weir on discharge." *Journal of Civil Engineering, Science and Technology* 5, no. 2 (2014): 35-40. https://doi.org/10.33736/jcest.137.2014

[24] Pandey, Rahul, S. K. Mittal, and M. K. Choudhary. "Flow characteristics of sharp crested rectangular weir: a review." *International Journal of Innovative Science, Engineering & Technology* 3, no. 3 (2016): 171-178.

[25] Ben Said, Mosbah, and Ahmed Ouamane. "Performance of rectangular labyrinth weir–an experimental and numerical study." *Water Supply* 22, no. 4 (2022): 3628-3644. https://doi.org/10.2166/ws.2022.005

[26] Kumar, Munish, Parveen Sihag, N. K. Tiwari, and Subodh Ranjan. "Experimental study and modelling discharge coefficient of trapezoidal and rectangular piano key weirs." *Applied Water Science* 10, no. 1 (2020): 43. https://doi.org/10.1007/s13201-019-1104-8