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Short Communication

SWMM5 Modelling of Staggered Flume with Internal Orifice-Weir Plate

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Abstract *- A new approach uses soft computing to model an orifice-weir system inside open-source drainage software. As climate change alters urban runoff patterns, innovative nature-based engineering solutions like staggered detention ponds are increasingly necessary. Still, intricate hydraulics typically demand high-end simulation tools many working engineers lack access to. For this reason, a basic setup emerges through adjustments in SWMM 5, modifying a weir element with defined bottom entry spacing to reflect both orifice and overflow behaviour at once. Verified using experimental data from a hydraulic flume alongside hand-based calculations, the model lines up with expected mass balance behaviour. The experimental results match theoretical mass conservation principles, and empirical testing identifies an optimal discharge coefficient of 0.40 for the structure. Though flow and water level outputs stay close to observed values when inflow is high, lower inflows see the model fall short on predicting actual depths. One core constraint stands out, which the setup cannot capture, hydraulic jumps forming further down. Despite this, the approach offers engineers a practical way forward, fitting complex water control features into everyday drainage planning without demanding advanced tools. What matters most is practical forecasting for how much stormwater systems can be handled, built on straightforward methods.*

Keywords *- Climate change, Drainage, Flood, Stormwater pond, Sustainable development, Urban runoff.*

1. Introduction

This paper proposes a new soft computing-based method for modelling combined orifice and weir plate in Storm Water Management Model version 5 (SWMM5), which was not addressed before. Although SWMM5 can model orifices and weirs separately, simulating a combined structure remains a methodological gap.

Nature-based interventions, which depend on natural processes, have been suggested in order to achieve sustainable flood management [1, 2]. Based on this theory, an ordinary stormwater detention pond can be retrofitted using an orifice-weir plate system, thus creating two ponds from a large pond (Figure 1). Consequently, further investigation is required to evaluate the performance of this combined structure and its integration into computer modelling environments.

A conventional detention pond is designed to attenuate surface runoff during storm events while remaining dry during non-rainy periods [3, 4]. By incorporating the proposed combined orifice-weir plate, the pond achieves a staggered layout that enhances its overall water storage capacity. The dividing plate features an orifice at its base and acts as a weir at its crest. During minor storm events, inflow to the upstream pond discharges through the bottom orifice (Outlet 1), which effectively restricts flow. A second obstruction at the downstream end of the pond, featuring another orifice (Outlet 2), further attenuates the discharging water.

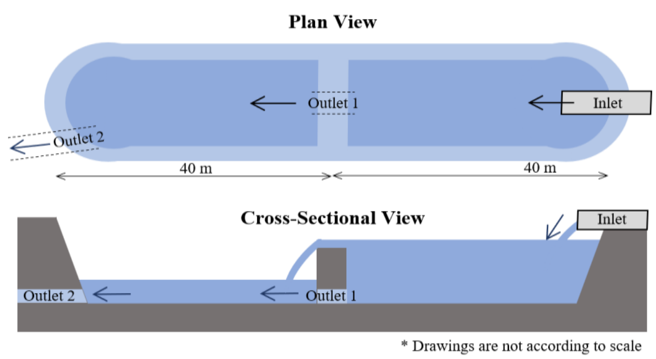


Fig. 1 Proposed staggered stormwater detention pond with an internal orifice-weir plate in addition to an outlet at the end of pond. Presented in the figure, the top figure shows the plan view, and the bottom figure shows the cross-sectional view of pond.

During intense storm events, the water level in the upstream pond can rise rapidly as inflow exceeds the capacity of Outlet 1. To manage this, the combined orifice-weir plate permits overtopping once the upstream pond reaches its maximum capacity, while discharge simultaneously continues through the bottom orifice. These dual flow mechanisms create a significant water level differential, maintaining a high stage in the upstream pond and a lower stage in the downstream pond.

When treated as a closed system from inlet to outlet, the pond adheres to the principles of conservation of mass and momentum [5]. Accordingly, the mass and momentum of the water remain constant. As a result, the flow rate, Q, upstream of the structure is equal to the flow rate downstream, as represented in Equation 1 and Equation 2:

$$Q_{inlet} = Q_{outlet} \tag{1}$$

And

$$Q_{combined\ orifice-weir} = Q_{orifice} + Q_{weir} \tag{2}$$

Orifices and weirs are common hydraulic structures [6], [7] with well-established theoretical foundations. When operating individually, the flow through each structure can be estimated using Equation 3 and Equation 4:

$$Q_0 = C_{do}\, A_o \sqrt{2gh_o} \tag{3}$$

where
Q_o = flow rates through orifice (m^3/s);
C_{do} = discharge coefficient (unitless);
A_o = cross-sectional area of orifice opening (m^2);
G = gravitational acceleration (m/s^2);
h_o = height of water from water surface to the centroid of orifice (m).

$$Q_w = \frac{2}{3} C_{dw} \sqrt{2g}\, b\, h_w^{3/2} \tag{4}$$

where
Q_w = flow rate over a broad-crested weir (m^3/s);
C_{dw} = discharge coefficient (unitless);
b = crest thickness (m);
h_w = stage from water surface to crest height (m).

The discharge coefficient (C_d) is a dimensionless correction factor used in flow measurement. A C_d A value approaching 1.0 indicates high flow efficiency, while lower values indicate higher flow resistance. In Equations 3 and Equation 4, C_d is an empirical variable usually determined through laboratory experiments. For orifices, typical C_d values range from 0.60 to 0.62 for sharp edges and 0.80 to 0.82 for thick edges [8]. For weirs, C_d is typically 0.60 for sharp-crested designs and 0.10 to 0.55 for broad-crested designs [9]. For a combined structure featuring a sharp-crested rectangular weir with bottom orifices, C_d values have been reported in the range of 0.605 to 0.638 [10].

Alongside physical experiments, advanced computer simulations such as Computational Fluid Dynamics (CFD) [11] and Artificial Intelligence (AI) techniques [12, 13], have been utilized to predict C_d values for orifice-weir configurations. However, these methods demand highly specialized expertise and involve significant computational complexity, making them impractical for typical practicing engineers. Conversely, while SWMM5 is an accessible, widely used public-domain software, there is currently no documented research on its application for simulating these combined structures.

2. Materials and Methods

The study started with a flume experiment which flow data was collected. Manual calculation was applied next to check on the consistency of collected data. Lastly, the experiment was simulated using hydraulic modelling (Figure 2).

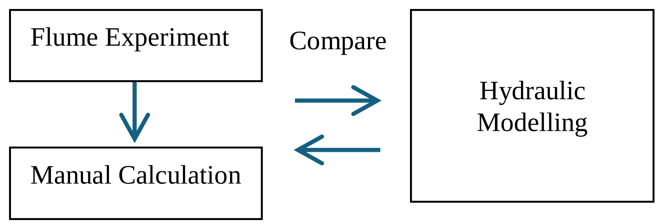


Fig. 2 Flowchart of methods

2.1. Flume Experiment

To mimic the elongated dry pond, a 5 m long hydraulic flume (0.075 m wide, 0.175 m high, with a 0.009 m/m slope) was utilized (Figure 1).

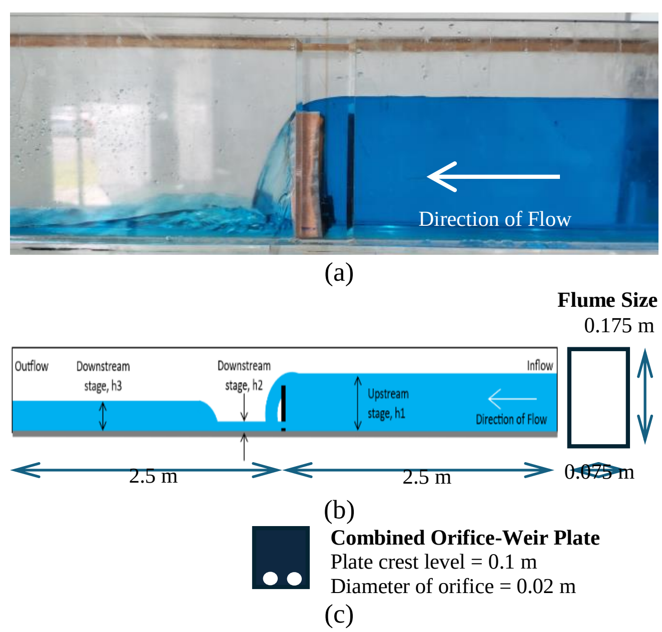


Fig. 3 Flume experiment, (a) Photo of the experiment being conducted, (b) Schematic diagram of longitudinal profiles of flume, and (c) Front view of combined orifice-weir plate.

A combined orifice-weir plate (0.075 m wide and 0.1 m high) was installed in the middle of the flume. The top edge of this plate functioned as a weir (Figure 3(a) and Figure 3(b)), while two orifices (each 0.02 m in diameter) were located at the base (Figure 3(c)).

Once the water flow stabilized in each run, three water stage readings (h1, h2, and h3) were recorded (Figure 3(b)). The flow rate was measured gravimetrically by timing the collection of 5 kg of water at the discharge end of the flume.

For each run, flow rates were measured twice: with water running through emptied flume (as inflow) and with the orifice-weir plate in-placed (as outflow). The resulting data are presented in Table 1.

2.2. Manual Calculation

The total flow rate through the combined orifice-weir plate was calculated as the sum of Equation 3 and Equation 4. Geometric parameters (A_o and b) were measured directly from the apparatus, while the remaining parameters correspond to the recorded water stages (h_o and h_w). Finally, the C_d was determined by comparing the experimentally measured flow rates with the calculated theoretical values.

2.3. Hydraulic Modelling

SWMM5 was used to replicate the physical flume experiments detailed in Section 2.1. Because SWMM5 is a drainage modelling software, it does not process inflow boundary conditions in the same manner as CFD software.

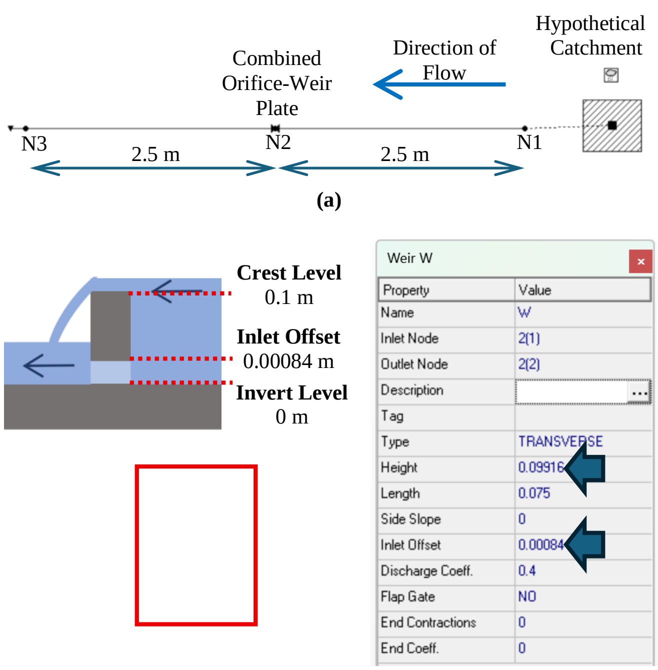


Fig. 4 Hydraulic modelling with SWMM5, (a) Developed model, and (b) Model representation of combined orifice-weir plate.

Instead, adhering to standard SWMM5 modelling practices, a hypothetical catchment (10 m^2 or 0.001 ha, with a 0.2% slope) and synthetic rainfall events were created to generate the necessary inflow for the simulation (Figure 4(a)).

Using the Rational Method ($Q = CIA/360$), with a runoff coefficient of $C = 1$ (fully impervious) and a hypothetical catchment area of $A = 0.001$ ha, the required rainfall intensities (I) were calculated. Based on the experimental inflow (Q_{in}) values, the intensities were determined to be 220, 140, 110, and 95 mm/hr, respectively, accurately replicating the flume inflows in the model.

An open rectangular conduit (nodes N1-N2-N3) was modelled to replicate the physical hydraulic flume. SWMM5 includes built-in orifice and weir elements as separate components. However, initial attempts to model both structures simultaneously yielded anomalous flow data.

To resolve this, only the weir component was utilized, but an inlet offset was specified corresponding to the orifice area (A_o). This created a flow space underneath the structure that successfully simulated the physical orifices (Figure 4(b)) and produced representative flow data.

To maintain the correct physical dimensions, the total crest elevation of 0.1 m was achieved by summing the inlet offset (0.00084 m) and the effective weir height (0.09916 m).

A summary of the modelling parameters is presented in Figure 5. The upstream and downstream boundaries are depicted at the top and bottom of the schematic, respectively, with the central section representing the simulated flume.

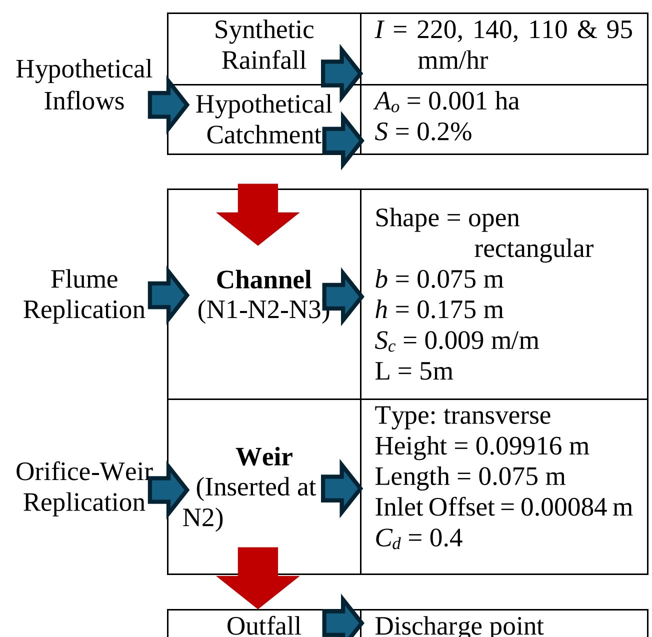


Fig. 5 Hydrological and hydraulic parameters in the developed model

3. Results and Discussion

3.1. Experimental Flow Data

The measured Q_{in} and Q_{out} values closely matched, confirming the mass conservation principle expressed in Equation 1. With the weir crest level set at 0.1 m, four experimental runs produced upstream water stages, h1 (refer to Figure 3(b)), in the range of 0.110–0.135 m (Table 1). Because these stages exceeded the crest level, water flowed simultaneously through the orifice and over the weir during these runs.

Immediately downstream of the orifice-weir plate, the water stages, h2, were relatively shallow, in the range of 0.010–0.025 m. Hydraulic jumps were observed in all four runs where the rapid flow transition elevated the subsequent downstream stages, h3 to higher levels, in the range of 0.030–0.051 m.

Table 1. Measured data from flume experiments

Run	Inflow, Q_{in} (m^3/s)	*h1* (m)	*h2* (m)	*h3* (m)	Outflow, Q_{out} (m^3/s)
1	0.0006024	0.135	0.025	0.051	0.0006369
2	0.0003868	0.125	0.020	0.040	0.0003891
3	0.0003046	0.120	0.015	0.025	0.0003104
4	0.0002563	0.110	0.010	0.030	0.0002608

3.2. Calculated Flow Data

The theoretical flow rates through the combined orifice-weir plate were calculated by applying C_d values in the range of 0.40–0.65. These calculated values were then plotted against the experimental laboratory data, as shown in Figure 6.

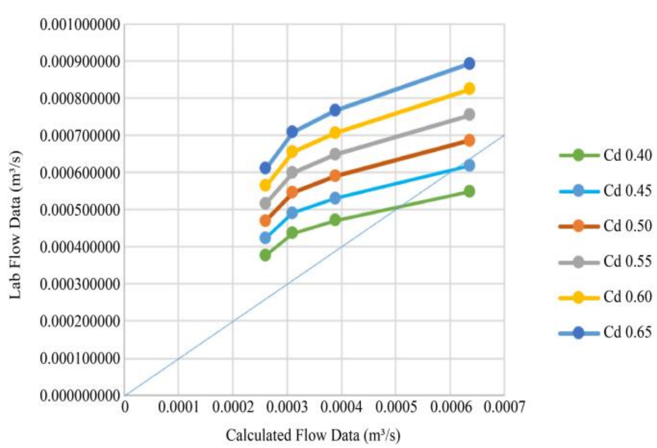


Fig. 6 Plots of laboratory measured and calculated flow rates due to combined orifice-weir plate

The calculated results showed a better match with the experimental data at lower C_d values (0.40–0.45) compared to higher values (>0.50). Across the six trials, with calculated flow rates between 0.0002 to 0.0007 m^3/s, a C_d of 0.40 produced the lowest Root Mean Square Error (RMSE) of 0.0001, whereas a C_d of 0.65 yielded the highest RMSE of 0.0004.

3.3. Modelled Flow Data

Four simulation runs were modelled to match the number of physical experiments. The calculated rainfall intensities, *I* were input as rainfall data to generate runoff over the 0.001 ha hypothetical catchment. This runoff was then routed into the modelled channel, passing through the combined orifice-weir structure using the calibrated discharge coefficient of 0.40. The modelling results are presented graphically in Figure 7.

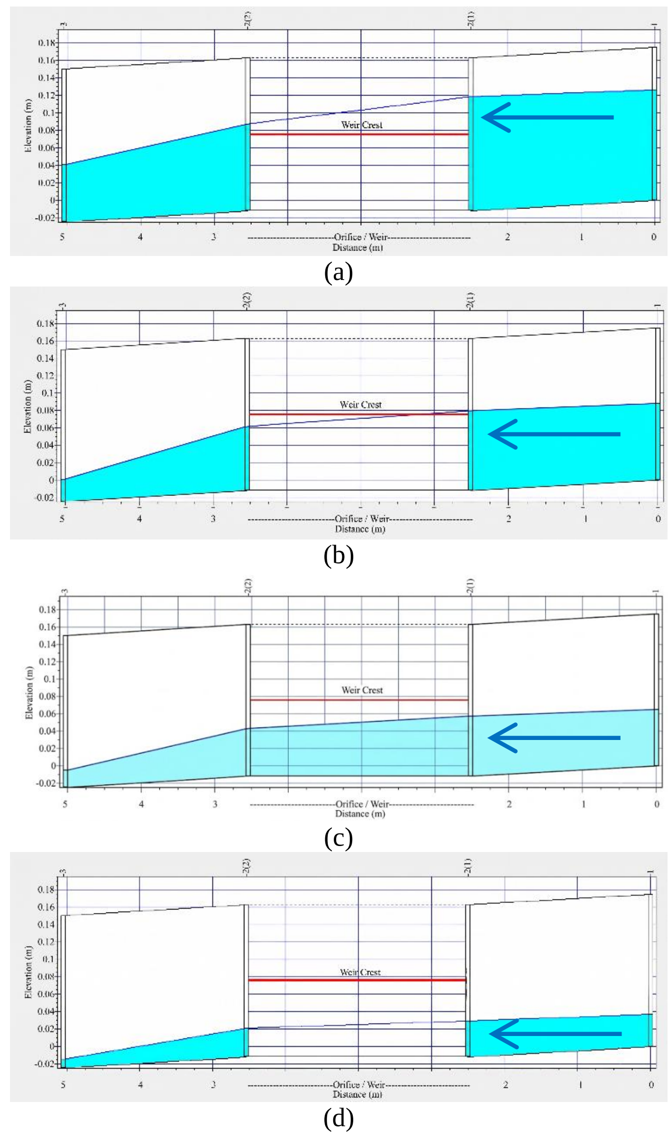


Fig. 7 Modelled longitudinal water profiles, (a) Run 1, (b) Run 2, (c) Run 3, and (d) Run 4.

Generally, under high inflow conditions (Run 1), the modelled water surface profiles matched the laboratory observation, successfully reproducing stages h1 and h3. However, SWMM was unable to simulate the hydraulic jump, effectively bypassing the shallow intermediate stage h2. This pattern was consistent across all modelled cases. As inflow rates decreased in the subsequent simulations, the model underpredicted the stages for the remaining three runs. Most notably, in Run 3 and Run 4, the model failed to replicate the flow over the weir, inaccurately simulating only orifice flow.

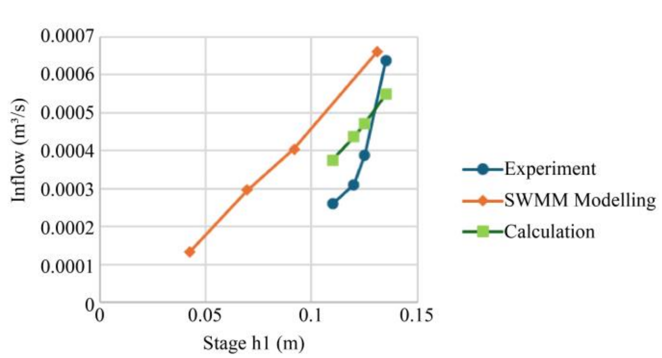
3.4. Comparison

A summary of experimental, modelled and calculated peak flow data is presented in Table 2.

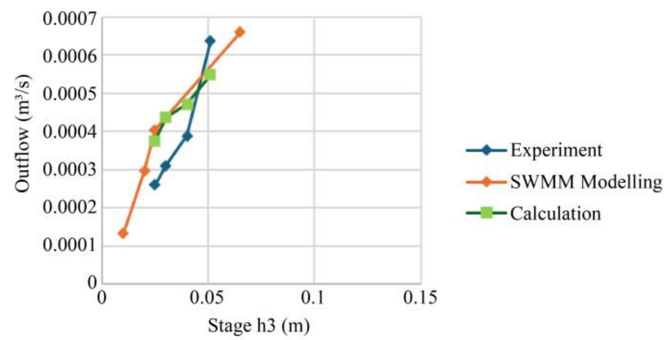
Table 2. Comparison of flow data for inflows and outflows

Run	Experiment		Model		Calculation	
	h1 (m)	Q_{in} (m^3/s)	h1 (m)	Q (m^3/s)	h1 (m)	Q (m^3/s)
1	0.14	0.00064	0.13	0.00066	0.14	0.00055
2	0.13	0.00039	0.09	0.00040	0.13	0.00047
3	0.12	0.00031	0.07	0.00030	0.12	0.00044
4	0.11	0.00026	0.04	0.00013	0.11	0.00038
Run	Experiment		Model		Calculation	
	h3 (m)	Q_{out} (m^3/s)	h3 (m)	Q (m^3/s)	h3 (m)	Q (m^3/s)
1	0.05	0.00064	0.07	0.00066	0.05	0.00055
2	0.04	0.00039	0.03	0.00040	0.04	0.00047
3	0.03	0.00031	0.02	0.00030	0.03	0.00044
4	0.03	0.00026	0.01	0.00013	0.03	0.00038

The flow rate and stage relationships were plotted to compare the experimental, calculated and modelled datasets (Figure 8). The modelled flow rates downstream of the orifice-weir plate ranged 0.00013–0.00066 m^3/s, compared to the laboratory measurements of 0.00026–0.00064 m^3/s. The percentage differences ranged 4–97%, with RMSE calculated as 0.00007. Run 1 exhibiting the most accurate modelled flow rate compared to the rest of the trials. Regarding the upstream stage, h1, the model predicted values in the range of 0.04–0.13 m, compared to the observed stages of 0.11–0.13 m, resulting in percentage differences in the range of 3–160% and an RMSE of 0.045. Similarly, for the downstream stage, h3, the model predicted depths in the range 0.01–0.07 m against the observed range of 0.03–0.05 m, yielding differences between 22% and 150% and an RMSE of 0.014.



(a)



(b)

Fig. 8 Plots of flow rate and stage relationships, (a) Inflow-upstream h1, and (b) Outflow-downstream h3.

3.5. Discussion

The primary intention of this approach is to provide a practical, soft-computing strategy for practicing engineers who need to design complex, dual-function stormwater structures but lack access to computationally intensive 3D and CFD tools. For the accurate representation of the composite orifice weir in SWMM5, an existing transverse weir component can be modified through the addition of an inlet spacing (bottom entry spacing) to represent the orifice part of the structure. An ideal value of 0.40 for the C_d has been obtained from experimental analysis for the structure described in this study.

In addition to this, this model performs better in cases of higher inflows, where there is good agreement between the water surface profiles and mass balance principles. Although this methodology proves quite effective, it has several distinct methodological drawbacks that prevent its universal application. First, the inability of SWMM5 to simulate highly turbulent energy exchange, including hydraulic jumps, limits its effectiveness.

Thus, this software fails to consider shallow intermediate water stages (h2) that exist just after the plate. Moreover, this software is not very accurate when low inflows happen, as the software fails to predict the upstream water stages correctly. At the times of low inflows, there is no weir overtopping process; however, the model simulates only orifice flow. Thus, these limitations are responsible for huge inaccuracies that can reach even 160%. These drawbacks are caused by using a hypothetical catchment when artificial rainfall and inflow values are used to match the flume. It is obvious that variables in this hydrological system, especially the catchment width and slope, cause physical distortions in the hydraulic flow simulation. To enhance the reliability of this approach, future studies will need to concentrate on improving the predictive ability of the model. Since this current model can perform much better when the inflow is high, it will be greatly advised that future studies involve bigger inflow data sets. Future research will also need to investigate other possible ways of applying boundary conditions in SWMM5.

4. Conclusion

The current study presented an efficient and practical method of incorporating the complicated multi-functional orifice-weir plate structure within conventional SWMM5 flood control models. From the experimental, theoretical and simulation results, it was observed that the current model performed excellently well with respect to matching the three data sets, especially at high inflow values.

But then again, the study reveals some limitations with the methodology adopted, especially the inability of the SWMM5 to simulate localized hydraulic jumps and a predisposition towards underestimating upstream water levels, especially at low flows. Nevertheless, even with the current limitations and the bias brought about by the assumption of catchment boundary conditions, the current setup remains as an accessible option for engineers when designing staged detention pond and other stormwater systems.

Data Sharing

The datasets and computer models (SWMM5) generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

Acknowledgments

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