Development of a Computer Model of a Drainage System with Uncertainties in External Inflow and Channel Cross-section

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Abstract: In urban development, stormwater drainage is an important aspect of infrastructure planning and design. Computer modeling has often been used to assist the design of the drainage system. With this type of modeling, external inflows to the system and channel configurations are important model inputs. As such, it is challenging to develop a model when there are uncertainties in external inflows and channel cross-sections.
This paper presents the development of a computer model of a drainage system in Singapore. In the development, it is necessary to resolve the uncertainties in the external inflow at various points along the drainage system, as well as the uncertainties in channel cross- sections. The software package Stormwater Management Model (SWMM) was used and the model has been developed and calibrated with on-site measured data. The results show that the external inflows have significant effects on the simulated hydrographs, while channel cross-sections do not affect the simulated hydrographs. On the other hand, the channel cross-sections have significant effects on the simulated water levels in the drainage channels.

Keywords: Modelling, Stormwater, Uncertainty

1. Introduction

In urban development, storm water drainage is an important aspect of infrastructure planning and design. Computer modeling has often been used to assist the design of the drainage systems. For example, Jang et al. (2007) used SWMM to simulate the hydrologic assessment of natural catchments and verified its applicability in both pre- and post-development considerations [3]. Kim et al. (2014) used numerical simulation to assess three alternatives of a drainage design in response to the use of an underground storage facility as an underground cistern for drainage [4]. In many of the publications, peak discharge of stream-flows, times to peak are important results to be analyzed. Models of runoff are used not only for forecasts and predictions of runoff, but also as inputs to the environmental processes. Numerical models are also widely used as a research and education tool to gain further understanding of the processes and to test hypotheses ([5]). On the other hand, model results are highly dependent on model inputs ([1], [2]). In particular, external inflows to the system and channel configurations are important model inputs. As such, it is challenging to develop a model if there are uncertainties in external inflows and channel cross-sections.

This paper presents the development of a computer model of a drainage system in Singapore. In the development, it is necessary to resolve the uncertainties in the external inflows at various points along the drainage system, as well as the uncertainties in channel cross- sections.

2. Methodology

This paper presents the case study of a catchment in Singapore with a total area of approximately 182 ha. The drainage system of the catchment was built for draining the surface runoff and external inflow resulting from industrial activities. The system was also subjected to tidal influence downstream.

In this catchment, rainfall and runoff data were monitored at nine stations over a period of one year from August 2012 to August 2013. Figure 1 shows the layout of the nine monitoring stations in the catchment. The data being monitored at the nine stations are summarized in Table 1. Rainfall was measured at six stations, discharge at three stations, and water level at all stations.

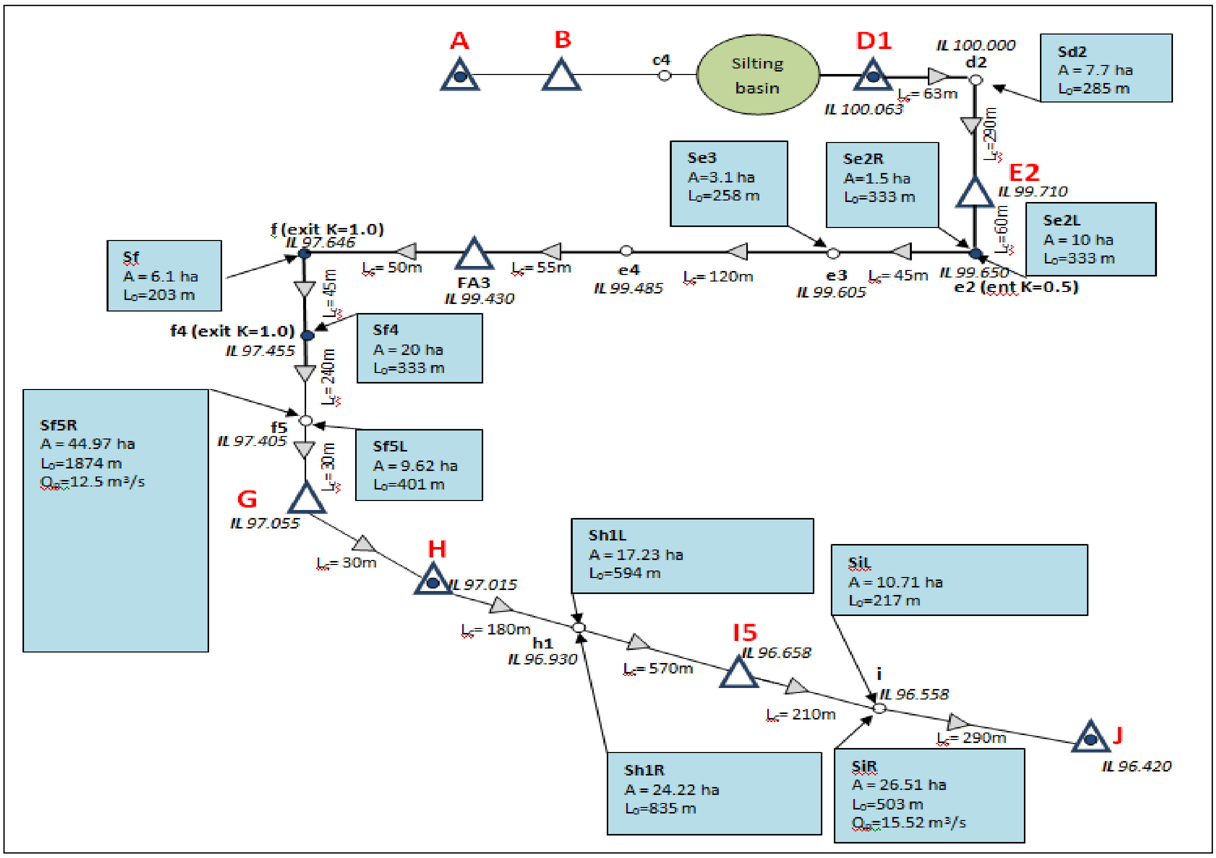

Figure 1: Layout of the monitoring stations

Table 1: Parameters being monitored at the different stations

Station	Rainfall	Discharge	Water level
B	X		X
A	X		X
C (silting basin)			X
D1	X	X	X
E2	X	X	X
G	X		X
H			X
I5		X	X
J	X		X

Using the package Storm water Management Model (SWMM) developed by the US Environmental Protection Agency (USEPA) [5], a computer model of the catchment has been developed. The model consists of 12 subcatchments, 18 drain sections and a silting basin. In the model, considering the flat topography of the site, the slopes of the subcatchments were set at the value of 0.1%. Both ends of the drainage system were subjected to tidal influence. According to SMWW manual, the recommended values of Manning's n for an impervious concrete surface for overland flow (N-Imperv) is 0.013 and for a pervious surface (N-Perv) is 0.024. The recommended value of Manning's n for concrete conduits or channels is 0.015. The depths of the depression storage on both impervious and pervious areas (i.e. Dstore-imperv and Dstore-perv) were set at 0 mm ([5]).

Of all the measured data (August 2012-August 2013), the event on 15 December 2012 had the heaviest recorded rainfall. Hence, the computer model was calibrated and verified using the data on this date from 12:30 to 18:00. Figure 2 shows the rainfall data recorded at all stations, namely A, B, D1, E2, G and J.

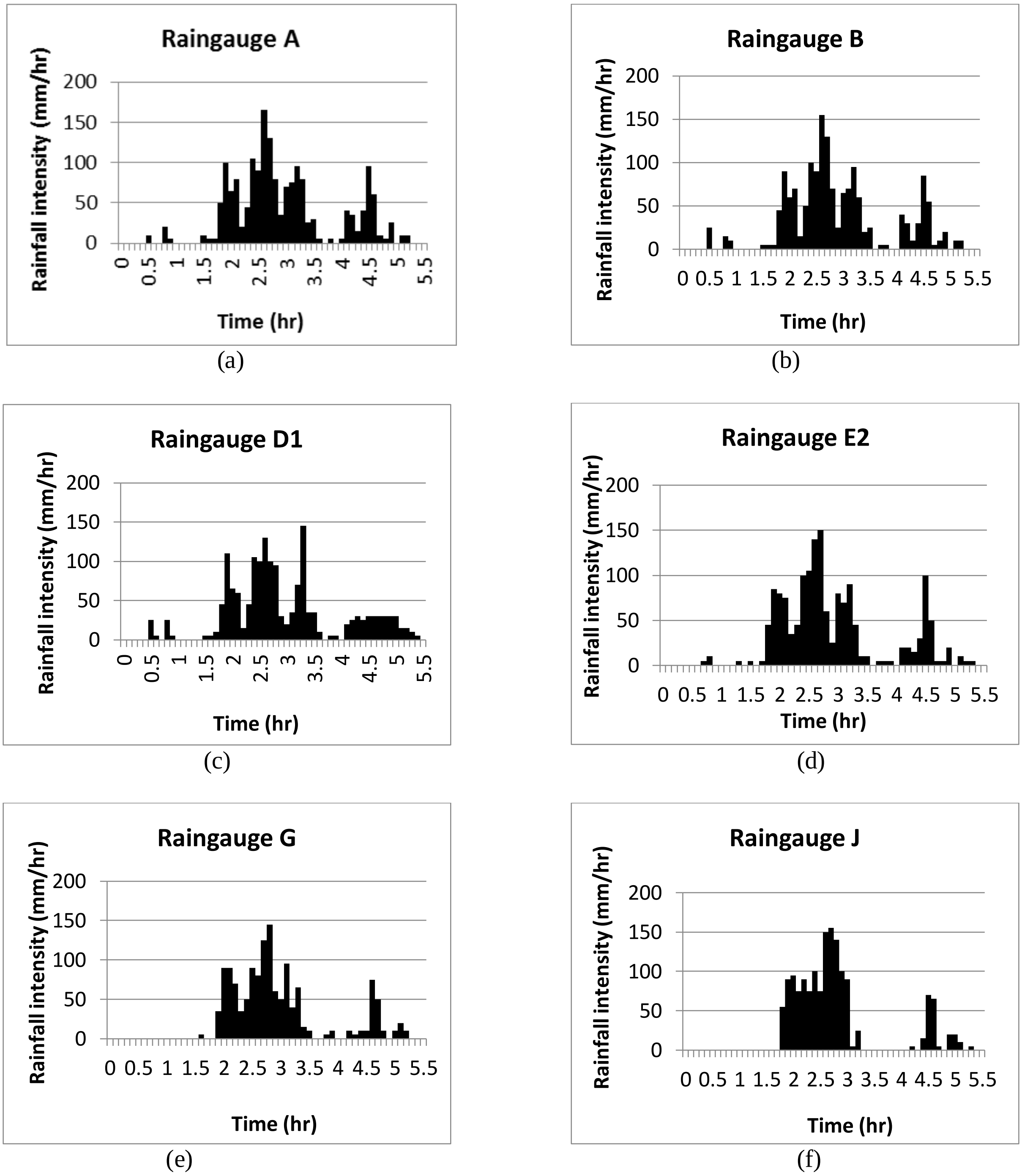

Figure 2: Rainfall recorded at six stations on 15 December 2012 from 12:30 to 18:00 hrs

To calibrate the model, the measured water levels at Stations A and J, which correlate with the tidal inputs, were applied at Nodes A and J in the model, respectively. Since there was no direct measurement of the external inflows, the first step in the model calibration was to determine the probable external inflow by assigning fixed values to all the other model parameters.

To determine the probable external inflow rates, Table 2 contains the values of process flow at nodes f4, f5 and I5 at various percentages of the design flow rates. These flow rates were then used as input for the model to determine the probable external inflows that would correspond to the discharge data collected on 15 December 2012.

The model also considered two sets of channel configurations that correspond to the design scenario and the measured channel configuration at the time of the monitoring. The design and measured channel configurations are shown in Table 3 and Table 4.

The simulated hydrographs were then compared with the measured hydrographs. The probable external inflow is taken as the flow rate with which the simulated hydrograph best fits the measured hydrograph.

Three values of runoff coefficients were considered in the simulations (C = 0.7; 0.8; and 0.9).

Table 2: External inflows (in m^3/s) at various model nodes and at various fractions of the design flow rates

% of design external inflow	Node f4	Node f5	Node I5	Total External Inflow (m^3/s)
100%	15.95	12.50	15.52	43.54
90%	13.48	11.25	13.97	39.19
80%	12.42	10.00	12.42	34.83
70%	10.86	8.75	10.86	29.08
0%	0	0	0	0.0

Table 3: Design cross sections of the channels

Channel section	Reach	Shape	Length (m)	Bottom width (m)	Height (m)	Side slope (H:V)
Section 1						
20m temporary earth drain	c4→ B → A	Trapezoid, open	190	5.5	3.75	1.93
Section 2						
4m drain	D1→d2→E2 →e2	Rectangle, closed	413	4	3	0
4m drain	e2→f	Rectangle, closed	270	4	3	0
6.5m culvert	f→ f4	Rectangle, closed	45	6.5	4	0
8m-wide canal	f4→f5→G → H	Rectangle, open	300	8	6	0
26m-wide canal	H→h1→I5→i→J	Rectangle, open	1250	26	6	0

Table 4: Measured cross sections of the channels

<table>
<tr><th>Channel section</th><th>Reach</th><th>Shape</th><th>Length (m)</th><th>Bottom width (m)</th><th>Height (m)</th><th>Side slope (H:V)</th></tr>
<tr><td colspan="7">Section 1</td></tr>
<tr><td>20m temporary earth drain</td><td>c4→ B→A</td><td>Trapezoid, open</td><td>190</td><td>4.7</td><td>2.8</td><td>1.30</td></tr>
<tr><td colspan="7">Section 2</td></tr>
<tr><td>4m drain</td><td>D1→d2→E2 →e2</td><td rowspan="5">Same as design</td><td rowspan="6">Same as design</td><td colspan="3" rowspan="4">Same as design</td></tr>
<tr><td>4m drain</td><td>e2→f</td></tr>
<tr><td>6.5m culvert</td><td>f→ f4</td></tr>
<tr><td rowspan="2">8m-wide canal</td><td>f4→f5→G</td></tr>
<tr><td>G→H</td><td>11.8</td><td>4</td><td>0</td></tr>
<tr><td>26m-wide canal</td><td>H→h1→I5→i→J</td><td>Trapezoid, open</td><td>12</td><td>6</td><td>1.94</td></tr>
</table>

3. Results

3.1 Model calibration

In the calibration, the probable flow rates and runoff coefficient were determined based on the comparison of the measured and simulated hydrographs at Station I5.

a. Effects of external inflows

Figure 3 shows the simulated hydrographs at Station I5 with different values of the external inflows. The results showed that the simulated hydrograph that best fits the measured hydrograph is the one with 80% of the design flows.

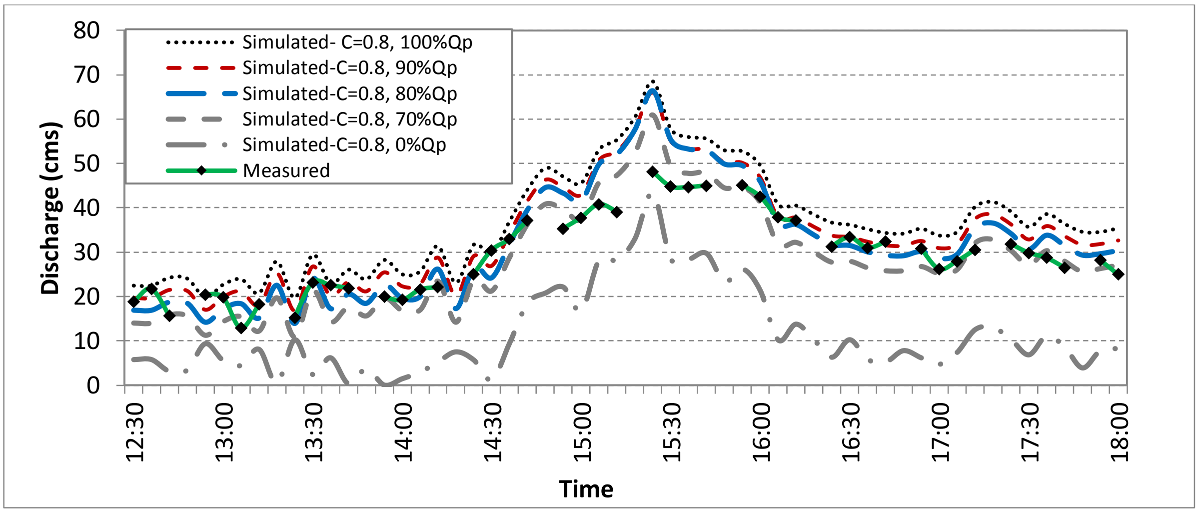

Figure 3: Comparison of measured and simulated discharges at various external inflows at Station I5 for the 15 December 2012 event

b. Effects of runoff coefficient

Figures 4 and 5 show the simulated hydrographs with C = 0.7; 0.8; and 0.9. From the figures, it is apparent that runoff coefficient has negligible effect on the simulated hydrographs and the simulated water levels.

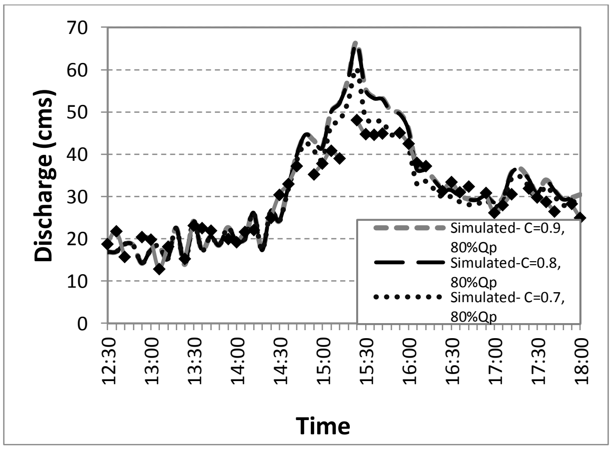

Figure 4 : Variation of the simulated hydrographs with different values of runoff coefficient.

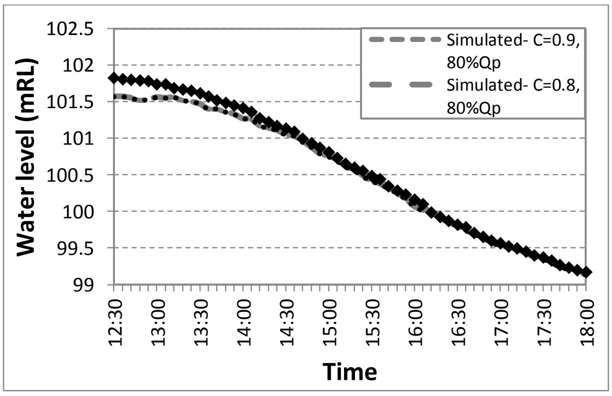

Figure 5: Variation of the simulated water levels at Station I5 with different values of runoff coefficient

c. Effects of channel cross-sections input

The simulated hydrographs during the event on 15 December 2015 using the input of cross sections as the design condition are shown in Figure 6. While the simulated hydrographs from the two simulations with the design and measured cross sections were similar, the change in cross sections has more impacts on the simulated water levels (as shown in Figure 7).

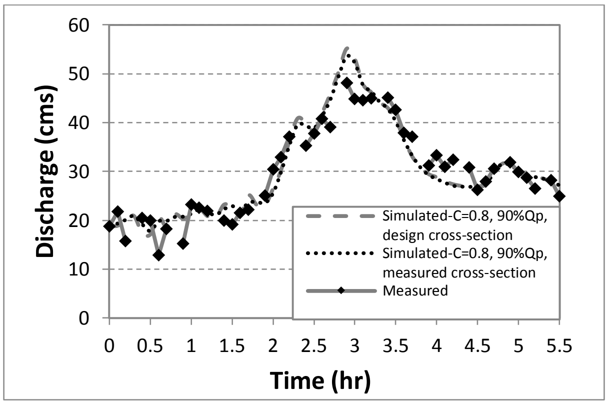

Figure 6: Variation of the simulated hydrographs at Station I5 with design and measured channel cross sections

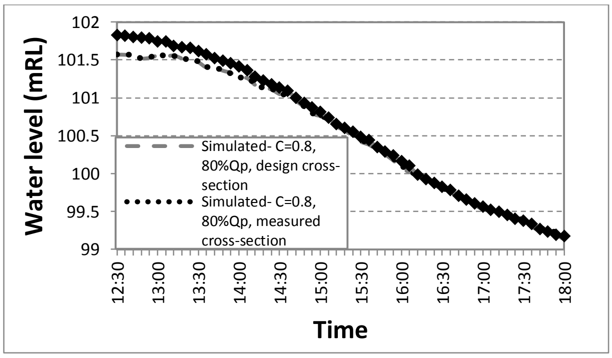

Figure 7: Variation of the simulated water levels with design and measured channel cross sections

3.2 Model verification

Using the calibrated probable external inflow and runoff coefficient, the simulated discharge and water levels at Stations A, B, D1, E2, G, H and J are shown in Figures 8-16. The simulation was based on 80% design external inflows, runoff coefficient of 0.8 and design channel cross-sections.

Figures 10 and 12 show that the simulated discharges agree well with the measured discharges at Stations D1 and E2.

Figures 8 and 16 show that the simulated water levels match perfectly with the measured water levels at Stations A and J. This was because the measured water levels had been used as input values for the computer model. Figures 9, 11, 13, 14 and 15 show reasonable agreement between simulated and measured water levels for Stations B, D1, E2, G and H.

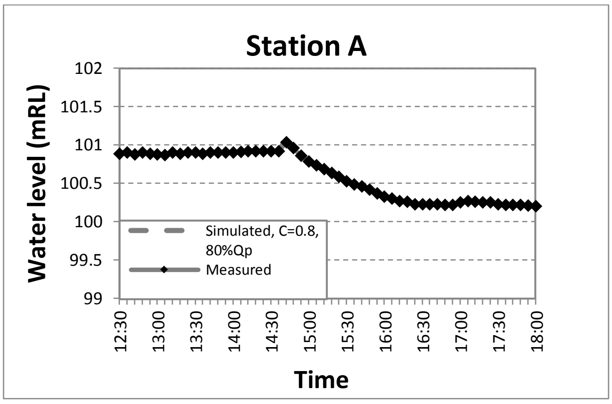

Figure 8: Comparison of the simulated and measured water levels at Station A for the 15 December 2012 event

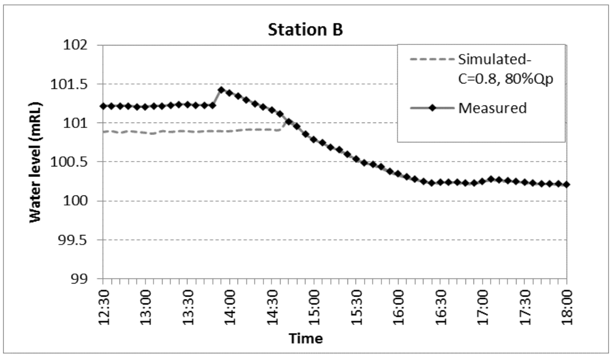

Figure 9: Comparison of the simulated and monitored water levels at Station B for the 15 December 2012 event

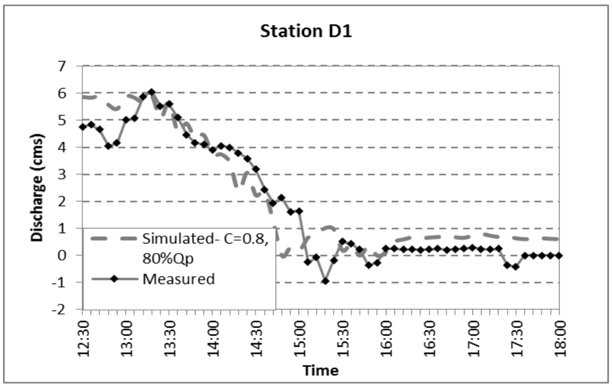

Figure 10: Comparison of simulated and measured discharges at Station D1 for the 15 December 2012 event

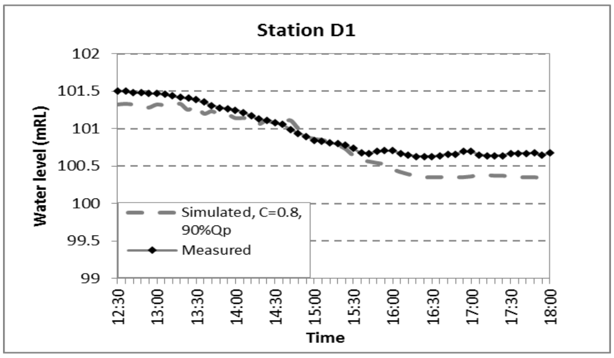

Figure 11: Comparison of simulated and measured water levels at Station D1for the 15 December 2012 event

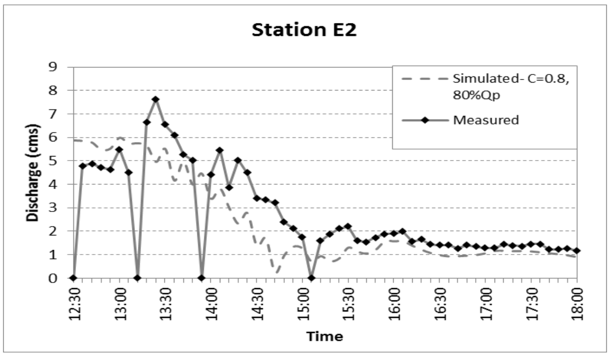

Figure 12: Comparison of simulated and measured discharges at Station E2 for the 15 December 2012 event

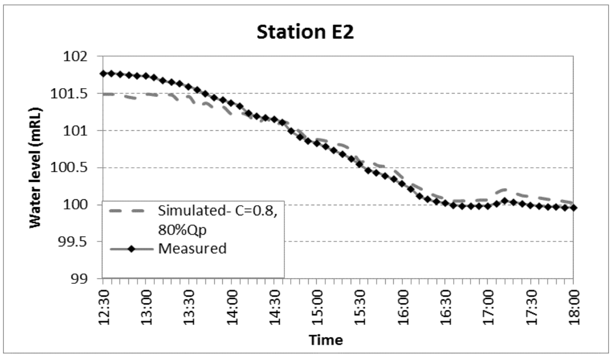

Figure 13: Comparison of simulated and measured water levels at Station E2 for the 15 December 2012 event

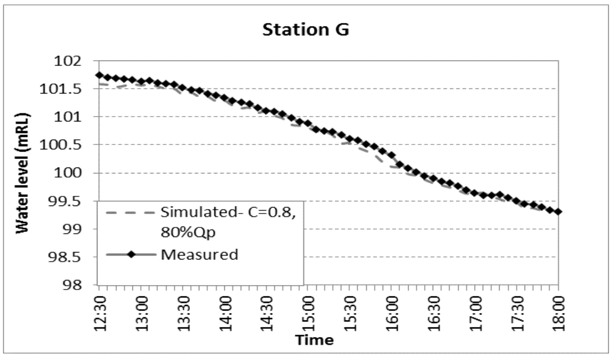

Figure 14: Comparison of simulated and measured water levels at Station G for the 15 December 2012 event

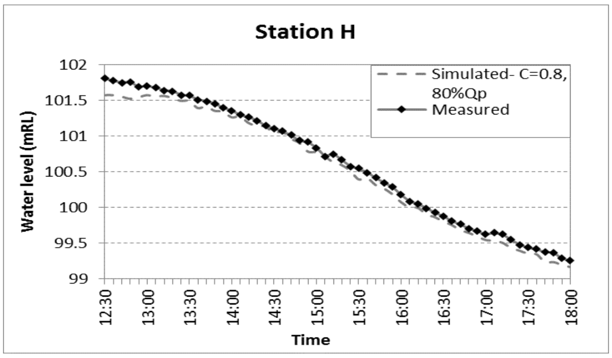

Figure 15: Comparison of simulated and measured water levels at Station H for the 15 December 2012 event

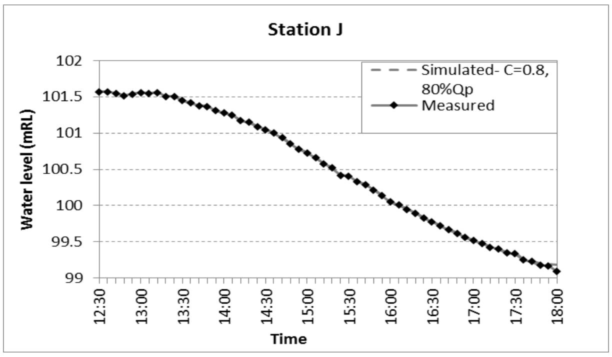

Figure 16: Comparison of simulated and measured water levels at Station J for the 15 December 2012 event

4. Conclusions

Using the Storm water Management Model (SWMM) software, a computer model has been developed for a drainage system in Singapore and subjected to tidal influence. The model was calibrated using the measured rainfall, discharge and water level data for the 15 December 2012 event. The results show that external inflows have significant effects on the simulated hydrographs, while channel cross-sections do not have any impact. On the other hand, channel cross-sections have significant effects on the simulated water levels in the drainage channels.

The model was then verified using the discharge and water level data at the other eight stations. The simulated discharges and water levels agreed reasonably well with the corresponding measured data at all stations.

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