Effects of sediment deposit on the hydraulic performance of the urban stormwater drainage system

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Abstract. Sediment deposit is a critical factor strongly affecting the drainage capacity of the conduits due to its cross-section area narrowing and roughness increasing. In this study, a numerical model was applied to investigate the influences of sediment deposit on the hydraulic performance of the drainage conduits. The Nhieu Loc - Thi Nghe (NL-TN) basin, located in Ho Chi Minh City, Vietnam, was selected as a case study. The drainage network of the NL-TN basin was simulated by using the EPA-SWMM model. The effects of sediment deposit were assessed by a non-dimensional comparison of the simulated peak flows of the sediment-deposited conduits and the clean ones. The results indicated that the sediment deposit significantly affects the flow capacity of the conduits and could cause severe inundation. Narrowing of the cross-section area has more impact on the hydraulic performance of the conduit than the increase in the roughness. A 40% increase in the Manning coefficient could decline the peak flow to approximately 80-90%, while a 40% increase in sediment thickness depth could degrade the peak flow by about 60-70% to compare with the peak flow of the clean conduit. The findings could support decision makings on the operation and maintenance of the sewer system and adaptation to extreme rainfall events.

1. Introduction

Sediment deposit is one of the most challenging issues in the operation and maintenance of the urban drainage system. Sediment thickness is the major cause of narrowing the cross-section and increasing the Manning coefficient (due to increasing the resistance) of the conduits that lead to disrupting the flow. Problems that arise include blockage, early surcharge, environmental pollution, and costly removal.

Many previous studies have considered the sediment transport process and its effects on the hydraulic performance of the drainage system. Impact of sediment deposit in the combined sewer and indicated many severe effects of sediment on urban drainage infrastructure was studied by Ashley et al. [1]. The impact of sediment deposit on the hydraulic performance of a pipe in the laboratory scale was evaluated by R. Banasiak et al. [2]. It concluded that sediment deposit strongly impacts the hydraulic capacity of the pipe. Recently, the sedimentation transport in urban drainage conduits by using a mathematical model for two-phase fluid was predicted by Y. H. Song et al. [3]. This research was also
conducted in a laboratory scale. Due to the lack of data available, the evaluation of the effects of sediment deposit on hydraulic performance for a specific urban drainage system by using a numerical model has not been conducted yet.

In this study, a numerical model-based virtual experiment was applied to assess the hydraulic performance of the urban drainage system with multi sediment deposit scenarios. The research was applied for the NL-TN basin, located in Ho Chi Minh City, Vietnam, as a case study. The EPA Storm Water Management Model (EPA-SWMM) was used to simulate the drainage system of the NL-TN basin. A non-dimensional comparison between the peak flow of the drainage pipes with and without sediment deposit was carried out to quantify the effects of sediment deposit.

2. Study area

The NL-TN basin located in the central part of Ho Chi Minh City (HCMC) covers approximately 33.93 km² and includes portions of seven districts of HCMC including District 1, 3, 10, and Phu Nhuan, Tan Binh, Go Vap District. The population of this catchment in 2018 is about 2.356 million people. The topography of the basin is variable, with the north and northwest sections being up to 8.0 m above sea level, while the southern part of the basin averages only 1.3 m above sea level (Figure 1). The elevation-area classification is summarized in Table 1.

![Figure 1. Boundary and DEM of Nhieu Loc – Thi Nghe basin](image)

**Table 1: Elevation – area classification in the NL-TN basin**

| No. | Elevation (m) | Area (ha) | Ratio (%) |
|-----|---------------|-----------|-----------|
| 1   | >5.0          | 1651.98   | 48.69     |
| 2   | 4.0 - 5.0     | 379.31    | 11.18     |
| 3   | 3.0 - 4.0     | 504.03    | 14.86     |
| 4   | 2.0 - 3.0     | 245.23    | 7.23      |
| 5   | 1.5 - 2.0     | 311.33    | 9.18      |
| 6   | 1.3 - 1.5     | 215.04    | 6.34      |
| 7   | <1.3          | 86.00     | 2.53      |
| Total |               | 3392.92   | 100       |
Drainage infrastructure in the basin has been fully upgraded under the HCMC Environmental Sanitation (NL-TN basin) project funded by the World Bank and finished in June 2012. However, flooding has recently occurred in some local areas. The flooding's reasons may be caused by the occurrence of rains exceeding the design frequency and the increased impervious surface area beyond the allowable limit. It could be also caused by sediment deposits due to poor maintenance.

3. Data and Methods

3.1. Data description

Data set requires for the rainfall-runoff process simulation including land-use/landcover (LULC), topography, soil properties, and design rainfall hyetograph. LULC data was achieved from Sentinel satellite images in 2020. Topography data was extracted from the Lidar dataset in 2012, and soil properties were obtained from the soil map of HCMC in 2006. The 5-year design rainfall hyetograph at Tan Son Hoa meteorological station was used. To simulate the flow process in the conduit network, the data of the drainage network (conduit size, drainage profile, and drainage network map) were collected from the HCMC Environmental Sanitation (NL-TN basin) project.

3.2. Methods

EPA-SWMM (Environment Protection Agency – Stormwater Management Model) is a comprehensive and widely accepted model for stormwater simulation, which was first developed in 1971 and extended to Ver 5.14 recently [4]. EPA-SWMM conceptualizes a subcatchment as a rectangular surface that has a uniform slope S and a width W that drains to a single outlet channel. Overland flow is generated by modeling the subcatchment as a nonlinear reservoir, as sketched in Figure 2.

**Figure 2.** Nonlinear reservoir model of a subcatchment (Source: [5])

The runoff generated in the subcatchment is calculated by the formula:

$$ Q = \frac{1}{n} W (d - d_p) \frac{S^{3/2}}{3} $$

(1)

Where: Q is runoff generated in the subcatchment (m$^3$/s); n is a surface roughness coefficient; W is width of the subcatchment (m); d is water layer height (m); S is average slope of the subcatchment (m/m).

The St. Venant equations for governing unsteady free surface flow through a channel or pipe can be expressed as [6]:

$$ \frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} = q $$

(2)

$$ \frac{\partial Q}{\partial t} + \frac{\partial (Q^2/A)}{\partial x} + gA \frac{\partial h}{\partial x} + gAS_f + gAh_L = 0 $$

(3)

Where x is distance (m); t is time (sec); A is flow cross-sectional area (m$^2$); and Q is flow rate.
(m³/s); H is hydraulic head of water in the conduit (Z + Y) (m); Z is conduit invert elevation (m); Y is conduit water depth (m); Sf is friction slope (head loss per unit length); and g is acceleration of gravity (m/sec²)

The necessary input data were collected and processed to setup the EPA-SWMM to simulate the urban stormwater drainage network in the NL-TN basin. There is total 228 sub-catchments, 333 conduits and 228 junctions were included in the simulation model (Figure 3).

![Figure 3. Simulation scheme of urban stormwater drainage network in NL-TN basin](image)

3.3. Development of scenarios

The effects of sediment deposit on the flow capacity were investigated for circular and rectangular cross-section conduits, which are two typical cross-section types of the urban drainage system in the NL-TN basin (Figure 4). Three scenarios were developed including (1) Sediment deposit thickness (2) Manning coefficient; (3) Sediment deposit thickness and Manning coefficient. It assumes that the sediment deposit thickness and Manning coefficient of the filled conduit increasing 10, 20, 25, 30, 35, 40, 45, and 50% to compare with the clean one.

![Figure 4. Demonstration of sediment deposit in two typical cross sections of conduits in NL-TN basin](image)
4. Results and Discussion

To overcome the challenge of observed water level and discharge data unavailable, the numerical model was calibrated by expert experiences based on the shape and lag time of runoff hydrograph shape, and runoff coefficient. This approach may obtain an unreliable calibrated model, but this uncertainty could be eliminated by using a non-dimensional comparison approach to evaluate the scenarios based hydraulic performance of the drainage network.

The rainfall - runoff relation of 5-year design rainfall at the outlet of sub-catchment SA46 and conduit VT64 (see Figure 3, for the position) presented in Figure 5. Figure 5 showed that the shape of runoff hydrographs seems to be homogenous with the simulated runoff hydrographs from other similar catchments. The lag time and runoff coefficient are 45 minutes and 0.85 respectively that is approximate to the values obtained from the experiment formulas. Thus, the model could be good enough for scenarios analysis in case of observed data for calibrating the model unavailable.

Figure 5. Rainfall - runoff relationship at sub-catchment SA46 outlet and conduit VT64

Sediment deposit causes narrowing of the cross-sectional area and increasing the roughness (Manning coefficient) of the conduits that degrade the hydraulic performance of the conduit system. The calibrated numerical model was applied by replacing their inputs with the scenarios developed in section 3.2. A non-dimensional comparison between the simulated peak flows of the sediment-filled conduits and the clean ones was carried out to quantify the effects of sediment deposit on the flow capacity of the conduits.

Where: \( n_{sd}/n(\%) \) is the percentage of the Manning coefficient of the sediment filled and clean conduit; \( Q_{sd}/Q(\%) \) is the percentage of the peak flow of the sediment filled and clean conduit

Figure 6. Relative reduction of peak flows caused by sediment deposit at conduit VT50 (circular cross-section)
Where: \( n_{sd} \) is the percentage of the Manning coefficient of the sediment filled and clean conduit; 
\( Q_{sd}/Q \) is the percentage of the peak flow of the sediment filled and clean conduit

**Figure 7.** Relative reduction of peak flows caused by sediment deposit at conduit VT45b (rectangular cross-section)

**Figure 6** and **Figure 7** plotted the relative reduction of peak flows according to the increase of sediment deposit depth and Manning coefficient at conduits VT50 and VD45b (see **Figure 3** for positions). The results showed that the increase of sediment thickness declines the flow capacity faster than the increase of the Manning coefficient. A 40% increase in the Manning coefficient and sediment thickness depth, the peak flow degrades to approximately 80-90% and 60-70% of the peak flow of the clean conduit, respectively. The hydraulic performance is rapidly degraded in the case of increasing both sediment deposit thickness and Manning coefficient.

The trend of relative reduction of peak flows could be used to plan the dredging schedule of the urban drainage network. The dredging should start when the sediment deposit has significant effects on hydraulic performance and cause serious flooding. For example, the results showed it may be not necessary to dredge the sediment if the deposit thickness depth is below 10% because it does not significantly affect the hydraulic performance of the conduit. In addition, the hydraulic performance degradation could be used to detect the positions of local blockage due to sedimentation or garbage. The numerical model was also applied to assess the potential impacts of sediment deposit on flood risk caused by extreme rainfall events. Further research is necessary to improve the reliability of the results.

**5. Conclusions**

The research demonstrated a non-dimensional analysis of the influences of sediment deposit on the flow capacity of sewer pipes. The preliminary results showed the trend of relative reduction of the peak flow due to sediment deposit. The increase of sediment deposit depth has more impacts on hydraulic performance than increases in the roughness of the conduit. A 40% increase in the Manning coefficient, the hydraulic performance degrades to approximately 80-90 %, while a 40% increase in sediment thickness (compared with conduit depth) could degrade the peak flow to about 60-70% compared with the peak flow of the clean conduit. Further research should be carried out to quantify the impacts of the sediment deposit on hydraulic performance with highly accurate and reliable results. The results could support decision makings on the design, operation, and maintenance of the sewer system and adaptation to extreme rainfall events.

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