SUSTAINABLE URBAN DRAINAGE SYSTEM MODEL FOR THE NHIEU LOC – THI NGHE BASIN, HO CHI MINH CITY

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Abstract. In recent years, Ho Chi Minh City has been faced with stark challenges in urban flooding affected by the impact of climate change in associated with the rapid urbanization and inadequate urban planning. Although many flood mitigation solutions were invested and implemented such as upgrading drainage systems, transport infrastructure, flood control pumps, etc. the problem remains unsolved and even worse. The purpose of this study is to propose a calculation model of the sustainable urban drainage system (SuDS) integrated with of GIS and remote sensing technology to assess and predict flooding degree in a specific basin in HCMC. Further, the results of this calculation model are just a pre-testing and pre-simulation of the proposed model for future studies on the application of sustainable urban drainage techniques, including rainwater harvesting, green roofs, urban green space and pervious pavement.

1. Introduction
The subjective cause of flooding in Ho Chi Minh City (HCMC), typically in Nhieu Loc – Thi Nghe Basin, evaluated by many experts, is the ineffective operation of drainage system. Besides that, many recent studies demonstrated that there is a link between the urbanization process and the risk of flooding in HCMC, with the most obvious feature is the expansion of the impervious surface area [1, 2]. Although structural solutions to urban flood mitigation like upgraded infrastructure and building flood gates, there is an increase in the trend of urban flooding in Ho Chi Minh City in recent years. In the latest report of the Ho Chi Minh City Department of Construction about flood situation, the number of flooded roads by rain in HCMC increased from 17 routes (2019) to 35 routes (2020) [3]. Since 2013, due to the impact
of climate change, heavy rains of over 100mm in the period of 1-2 hours appear more and more, leading to an increase in flooding points [4].

![Figure 1 Location of flooded points on November 25, 2018 (rainfall up to 401mm)](image)

There are some reasons to explain the flood issue in HCMC, but it classified in 02 groups:

- **Objective reasons:** Climate change and urbanization rate are major causes. There was a significant increase in heavy rains and tides recently. Within 40 years (1962-2001), HCMC had 09 spots of rain lasting 3 hours, rainfall over 100mm. Over the past 10 years (2002 - 2020), there have been more than 30 rains. Thereby, it shows that over time the rainfall increased both the frequency and rainfall. In addition, HCMC is affected by high tides. From 2008 up to now, the tidal peak exceeds + 1.5m, and the frequency of tidal peaks is increasing due to the effects of climate change [4]. Moreover, the urbanization problem is more and more expand due to overpopulation in HCMC, leading to reduce the percentage of pervious surface. This is a result of the current urban flood situation [4].

- **Subjective reasons:** Some reasons such as overload of the drainage system, canal system have not been dredged, and especially ineffective management. Before 1975, the sewerage planning designed to meet a population of 2 million people, however, the population in HCMC is over 10 million at the present, leading to a 5-fold increase in the amount of wastewater [4]. Besides, most of the rivers and canals in HCMC have not been dredged, causing sedimentation, flow congestion, and discharge outlets, which limit drainage capacity. One of the most remarkable reasons is ineffective management in mitigating the flood in HCM, for example, a lack of synchronization in drainage system construction and awareness on environmental protection (littering and canal encroachment) [4].

The Government has also implemented structural measures such as improving and upgrading rainwater drainage systems in flooded roads, but still flooded, such as Phan Xich Long, Truong Son, Song Hanh, Highway 22, Phan Van Hon, Nguyen Anh Thu, To Ngoc Van streets [3]. Therefore, radical demand has been given to transfer to the renewed solution with more sustainability and efficiency. Sustainable Urban Drainage Systems (SuDS) technologies have widely implemented as an application of eco-engineering with the principle of fully applying the framework and functions of natural ecosystems. With ecological engineering, the process of urban flooding is slowed down by using storage, increasing the natural permeability of rainwater through the vegetation, and at the same time
improving the landscape and environmental quality [5]. With the above characteristics, SuDS is used as a solution to support flooding mitigation in Ho Chi Minh City under the existing conditions. In order to create a good SuDS scheme or flooding mitigation model, a series of drainage techniques is usually combined from prevention, source control, site control and regional management. However, in this study, source control techniques were focused to illuminate its impact, particularly rainwater harvesting, green roofs, urban green space, and pervious pavement.

The purpose of this paper is to propose a calculation model of sustainable urban drainage system (SuDS) integrated with of GIS and RS technology to assess and predict flooding degree in a specific basin in HCMC. Further, the results of this calculation model are just a pre-testing and pre-simulation of the proposed model for future studies on the application of SuDS techniques, including rainwater harvesting, green roofs, urban green space and pervious pavement.

2. Literature review

2.1. Sustainable Urban Drainage System

Sustainable Urban Drainage System (SuDS) is a term that is commonly referred as a sustainable approach to urban drainage system in developed countries, especially in the context that traditional drainage systems are not able to adapt with the fast urbanization development since traditional systems are only designed to meet the degree of discharge volume with a certain population size [5]. At the Rio International Conference on Earth - 1992, the concept of SuDS has received international consensus as part of the Sustainable Development Strategy because the SuDS solution achieves the goal of sustainable development, which balances factors such as economic development, community and environmental safety. This resolution must be applied to the planning strategy as well as to embellishment areas. Alternative measurements as well as new solutions for managing stormwater from irregular rains, are being studied and developed in recent decades, such as Low Impact Development (LID) in North America, Water Sensitive Urban Design in Australia and Sustainable Urban Drainage Systems (SUDS) in UK [5]. A wide range of benefits of SuDS applications in UK and Europe was depicted in Table 1.

![Figure 2 Procedures for applying water management techniques in SUDS systems][8]

One of the more important concepts of SuDS design is the use of source control in SuDS schemes, and source control components should be upstream of any pond, wetland or other SuDS features. Many components of source control may be found within private lands or areas of the highway. The main type
of source control as well as four techniques used in this study, and the performance of these four techniques was also presented in Table 2.

### Table 1. Some cases of effective application of SuDS

| No | Location | SuDS components | Outcome |
|----|----------|-----------------|---------|
| 1  | Streatham Common South London Borough of Lambeth | De-paving (pervious pavement), Tree planting, Kerb inlets | Pavement SuDS, where inserted with verges, replaced concrete dished channels. They delay the drainage of surface water into the sewage system. Modelling undertaken has shown that in a one in 100 year, six-hour storm case, the grass verge can potentially eliminate 6 m of surface water runoff [6]. |
| 2  | Reedworth Street London Borough of Lambeth | Permeable paving | The initiative has enhanced the permeability of front gardens and improved streetscape aesthetics [6]. |
| 3  | Swan Yard London Borough of Islington | Bioretention planter (rainwater harvesting) | Previously, rainwater from the roof was released directly into the street. Diverting and disconnecting downpipes to feed rainwater into bioretention planters and water butts for irrigation was the most productive way to introduce SuDS. In a thermoreally hard paved yard, the planting adds a small element of self-sustaining biodiversity [6]. |
| 4  | Mendora Road London Borough of Hammersmith & Fulham | Permeable paving retrofit | Mendora Road requires the construction of permeable paving on either side of the road inside the parking bays, with underground storage supported on one side by geocellular structures and aggregate on the other, with a flow control outlet to the current sewer system [6]. |
| 5  | London Borough of Newham | Temporary permeable paving installation | The joint void was filled with 2-6mm clean stone to provide a permeability rate of 18,750 L/s/ha, to cope with any storm event [6]. |
| 6  | Hammersmith London Borough of Hammersmith & Fulham | Green roofs, Bioretention basin, Detention basin, Permeable paving | - The works were delivered at the same cost as conventional landscape improvement when compared to other housing estate works.  
- The landscape has been turned into a multifunctional space.  
- 142m² of green roof has been installed, improving biodiversity.  
- Running off from an impermeable surface of 900m2 has been moved to a SuDS [6]. |
| 7  | The Withys, Wareham | Rainwater harvesting (RWH) and grey water recycling (GWR) | Each dwelling had a pitched roof with clay tiles and provided a total catchment area of the site of 185m². As such 6,000l rainwater tanks were specified for each dwelling which were split for rainwater storage and surface water retention. These storage tanks provided a split storage capacity allowing 3,000L of surface water runoff from the 3-property development to be retained and discharged at a controlled rate, and 3,000L of harvested rainwater to be stored for non-potable |
applications within the development properties, including toilet flushing for 4 toilets and laundry [7].

The RWH system collects water from the 2,300m² catchment area of the shallow pitch membrane roof with symphonic drainage and conveys it to two 23,000L precast concrete storage tanks. The combination of the high annual rainfall and large catchment area yields up to 1,850m³ of rainwater every year, with an estimated efficiency of 70% [7].

Table 2 Performance of source control techniques [9].

| Technique                  | Peak flow reduction | Volume reduction | Water quality treatment | Amenity potential | Ecology potential |
|----------------------------|---------------------|------------------|-------------------------|-------------------|-------------------|
| Green roofs               | High                | Medium           | Poor                    | Poor              | Poor              |
| Rainwater harvesting      |                     |                  |                         |                   |                   |
| Permeable paving          |                     |                  |                         |                   |                   |
| Green Open Space          |                     |                  |                         |                   |                   |

It can be seen that the techniques selected for site study show shift effectiveness in flood peak control, and this is also the main goal of applying SuDS to the basin.

2.2. Stormwater management model (PCSWMM) and SUDS

Stormwater management strategy is a critical indicator to reflect the effectiveness of SUDS. In order to assess the performance of stormwater management practices, hydrological modelling has been found it is a common approach with its ability to calculate the runoff volume reduction and flood mapping through two processes is infiltration and evapotranspiration [11, 12]. Currently, there have been many hydrological - hydraulic computer models and software such as XP-SWMM, StormCAD, MIKE HYDRO River, etc. Among them, the PCSWMM software (PCSWMM is an advanced modelling software for EPA SWMM 5 stormwater, wastewater, and watershed systems) shows strong and powerful simulation capabilities for urban areas and this has been proven in many studies, especially in the context of the Nhieu Loc - Thi Nghe Basin - the central part of Ho Chi Minh City [13, 14].

In this study, requirements of data input were given to solve the issue of the topic paper, particularly applying GIS and remote sensing technology to analyze and create the initial information of PCSWMM towards measures the proficiency of sustainable urban drainage technology approaches (Table 3).

Table 3. Data input for PCSWMM
| No | Required data (PCSWMM) | Used methods | Reference |
|----|------------------------|--------------|-----------|
| 1  | DEM                    | LiDAR image used to produce digital elevation model (DEM) – representation of elevation data | [15, 16] |
|    |                        | GIS is used as a potential technology to improve the geometry accuracy of the drainage system as well as easy to connect between objects such as conduits and junctions. |         |
| 2  | Drainage geometry      | The drainage features consisting of the channel shape and dimension, geometry at nodes, and channel surface condition were also collected and analyzed by these technologies. | [17]    |
|    |                        | The land cover map was used to classify the effects of land cover on catchment hydrological behaviour. Remote sensing and GIS technology used integrated to create input data served for modelling. |         |
| 3  | Land cover             | In PCSWMM, SuDS techniques as LID (Low Impact Development), and introduced under a large number of design variables and parameters to which the user must assign values. These include parameters of size (surface area, layer depths, and capture ratio), surface parameters (freeboard depth, outflow face width, slope, and roughness), soil parameters (moisture limits and hydraulic conductivity), pavement parameters (void ratio and permeability), storage parameters (void ratio and native soil conductivity), drain parameter (discharge coefficient and exponent, roof drain capacity, and drain mat roughness), and clogging parameter. In order to easy to connect between these values and PCSWMM, GIS and RS technology is used. | [21, 22, 23] |
| 4  | SuDS techniques        | Rainfall data used to drive the model and produce runoff so accurate estimation of rainfall data is very important to determine the success of the model. The rainfall intensity can be used to estimate water runoff and discharge. | [17]    |
| 5  | Rainfall Data          |                                                        |           |

### 3. Study Area and Methods

#### 3.1. Study area

According to the Master Plan of Drainage System in HCMC to 2020 released in 2001, Nhieu Loc – Thi Nghe sub-basin covering an area of 33.2 km2 is one of the central drainage catchments in HCMC and comprises whole or part of seven districts including 1, 3, 10, Phu Nhuan, Tan Binh, Go Vap, and Binh Thanh. The Nhieu Loc – Thi Nghe sub-basin has topography surrounding the canal, is completely independent from other sub-basins. The highest elevation of the sub-basin is up to + 8m, concentrating in the North-Northwest and the lowest area below + 1.3m, concentrated in Cau Bong and Van Thanh canals, which are often flooded during high tide periods. In addition, the Nhieu Loc – Thi Nghe sub-basin is also influenced by the semi-diurnal regime of the East Sea, which blocks the drainage of wastewater in the periods of tidal peaks.

Nhieu Loc - Thi Nghe sub-basin has high urbanization rate due to ground filling, filling low-lying areas, narrowing the area of parks, lawns, green trees, increasing construction area, concreting of yards, pavement, etc. These factors have changed the coverage factor, narrowed the natural permeability area,
reduced the amount of rainwater infiltration, leading to an increase in the runoff coefficient, increasing the possibility of flooding the sub-basin.

![Figure 3: Location of Nhieu Loc – Thi Nghe Basin](image)

According to a survey report of the Ho Chi Minh City Technical Infrastructure Management Center, there was a constant rise in flooded points in HCMC from 2012 to 2018, especially in some areas of Nhieu Loc – Thi Nghe Basin such as Go Vap district, Binh Thanh district, District 9.

![Figure 4: Points flooding in Ho Chi Minh City (2012-2018)](image)

3.2. Data processing

a) The sewer networks
Sewer network is a combination of all kinds of infrastructure works such as conduit, junction, Orifice etc. used to collect and transport wastewater (domestic, production, rainwater, etc.) to the water treatment plants or directly to receiving water bodies through outfall to ensure hygiene, prevent pollution and flooding. Sewer network data was collected from the Ho Chi Minh City Technical Infrastructure Management Center, then digitized through GIS tools and as input data for the model.

b) Rainfall data
Rainfall data used as drive the model and produce runoff so accurate estimation of rainfall data is very important and determines the success of the model. The rainfall intensity can be used to estimate water runoff and discharge. Rainfall data from the rain gauge stations near the study area were collected. There were three (3) rain gauge stations near the study area (Mac Dinh Chi, Cau Bong, Tan Son Hoa and Ly Thuong Kiet), and also materials used for rainfall design for PCSWMM (Figure 5). Calculation and simulation of flooding need longer range of available rainfall data. Therefore, input data was collected from year 2016 to 2020 with hourly rainfall, total rainfall in time series during rainy events.

Figure 5 Rain gauge station map in NL-TN

c) Digital Elevation Model (DEM)
The digital elevation model (DEM) represents land elevation data, which are crucial to create slope and catchment delineation of surface flooding. Available LiDAR datasets used in the study include the LiDAR point cloud available with 1-m resolution aerial imagery that was collected from the Department of Natural Resources and Environment of Ho Chi Minh City.
d) Land cover
Land use map was used for identifying the effects of land cover in the hydrologic behavior of the catchment. With this study, remote sensing technology (using Planet image with resolution of 3m) is used to classify the land use into types of surfaces such as roofs, roads, parks, rivers, lakes, bare soil. Corresponding to each type of surface will have a different impervious coefficient, runoff coefficient. The runoff coefficient in an urban catchment area is highly influenced by the impervious and pervious surface characteristics, as they participate in a big part in generating discharge and affect the amount of rainwater entering a drainage system.

| Surface description                  | Manning’s n | Reference |
|-------------------------------------|-------------|-----------|
| Asphalt                            | 0.012       | [24]      |
| Concrete                            | 0.013       | [25]      |
| Vitrified clay                      | 0.015       | [26]      |
| Cast iron                           |             | [26]      |
| Parks & Cemeteries, Heavy Turf      | 0.4         | [25]      |
| Woods (Light underbrush)            | 0.4         | [25]      |
| River, Lakes and streams            | 0           | [25]      |
| Bare soil                           | 0.035       | [25]      |

e) Sustainable Urban Drainage System (SuDS) techniques
SuDS comprises a variety of different components, each offers a different approach to managing water quality, runoff volume and velocity, and providing amenities and other benefits. The configuration of SuDS components varies between sites and they can be installed in sequence as a “management train” in order to provide benefits incrementally across a catchment [5]. For this study, the authors choose 4 techniques on source control as Table 5.

| SuDS techniques | Image description |
|-----------------|-------------------|
4. Results and Discussion

4.1. Proposed model
Based on the catchment characteristics, drainage management status, and similar studies, the author's proposed model for measuring the efficiency of SUDS techniques in the NL-TN basin, including input data types, processing processes and software (Figure 7) and are partially detailed by individual processes.

Figure 7 Proposal model for measuring the efficiency of SUDS techniques
In each section, data generation processes are built to clarify the sources and input data set construction techniques for PCSWMM software.

- **Section 1:** Building database, prepare steps for ensuring the accuracy and saving time when integrating with PCSWMM.
- **Section 2:** Providing the information for running PCSWMM – hydrologic and hydraulic software. It depends on user’s purpose, the 1D, 2D modelling will be selected or integrated to run.

4.2. Results of pre-feasibility
a) DEM map, slope map, sub-basin and land cover map
With the elevation data from lidar image, GIS algorithm used integrated to build the DEM map, slope map for Nhieu Loc - Thi Nghe basin (30 sub-basin generated). Using Planet image with resolution of 3m conducting supervised classification building land use maps of the study area.

![Figure 11 DEM map, slope map, sub-basin and land cover map of the NL-TN Basin](image)

The average slope of the NL-TN basin is low from 4-6 degrees and the watershed drains have equal slope without too much difference. The impermeable surface area in the sub-basins is mostly over 50%. The increasing impermeable surface is responsible for changes in the flooding process in the basin.

| ID | NAME  | AREA (ha) | SLOPE (%) | IMPERV (%) | IMPERV (HA) | PERV (ha) | NIMPERV | NPERV  |
|----|-------|-----------|-----------|------------|-------------|-----------|---------|--------|
| 1  | SUBCM1| 60.08     | 4         | 52         | 31.24       | 28.84     | 0.013034| 0.024150|
| 2  | SUBCM2| 94.45     | 5         | 70         | 66.12       | 28.34     | 0.012345| 0.027602|
| 3  | SUBCM3| 75.65     | 6         | 53         | 40.09       | 35.56     | 0.012861| 0.029095|
| 4  | SUBCM4| 35.94     | 6         | 50         | 17.97       | 17.97     | 0.012244| 0.020417|
| 5  | SUBCM5| 20.45     | 5         | 51         | 10.43       | 10.02     | 0.013150| 0.027133|
| 6  | SUBCM6| 35.79     | 4         | 79         | 28.27       | 7.52      | 0.012719| 0.034572|
| 7  | SUBCM7| 88.98     | 5         | 61         | 54.28       | 34.70     | 0.013071| 0.028689|
| 8  | SUBCM8| 183.62    | 6         | 66         | 121.19      | 62.43     | 0.012426| 0.029493|
| 9  | SUBCM9| 291.81    | 5         | 68         | 198.43      | 93.38     | 0.012778| 0.033168|
| 10 | SUBCM10| 65.03    | 5         | 47         | 30.56       | 34.47     | 0.012930| 0.029968|
b) The sewer network
Sewer network data is synchronized in a common format (GIS) from some different data format as CAD, GIS, EXCEL (data sources from the Ho Chi Minh City Technical Infrastructure Management Center). After the data process, classification was implemented, this data was selected, grouped, and converted to the input data of PCSWMM including Conduits, Junctions, Orifices, Outfalls, Raingage to simulate urban flooding.

Table 7. The number of used objects for PCSWMM

| Objects          | Number |
|------------------|--------|
| 1 Subcatchments  | 30     |
| 2 Conduits       | 2825   |
| 3 Junctions      | 2807   |
| 4 Orifices       | 1527   |
| 5 Outfalls       | 39     |
| 6 Raingage       | 3      |
| 7 Pump           | 1      |

Figure 12 Drainage data design for PCSWMM
c) Flood Mapping of the Nhieu Loc – Thi Nghe
After the flood simulation by PCSWMM with the mentioned input data and the rainfall on 06/08/2020, the results pointed out that there were 10 flooded routes from 0.07m to 0.3m (Figure 13).

d) Proposed location for applying SuDS techniques
In order to optimize the effectiveness of applying the SUHD soft techniques, the public participatory survey was done to get the information reality and exactly. This is a basis for mapping source control technology (SUHD techniques) including water harvesting, green roofs, urban green space, and pervious pavement.

| Table 8. The number of survey sites in the NL-TN Basin |
|-------------------------------------------------------|
| District 1 | District 3 | District 10 | Binh Thanh District | Go vap District | Phu Nhuan District | Tan Binh District |
| Number | 13 | 45 | 08 | 70 | 25 | 34 | 29 |

Figure 13: Flood map of NL-TN basin on 06/08/2020
Figure 14 Survey sites map in the NL-TN Basin

5. Conclusions
The model for sustainable drainage for NL-TN was tested with different SuDS techniques combined with GIS and RS technology. The results of pre-feasibility and the justification can be applicable for the selection of SuDS' techniques in assisting to assess peak flow control. Apart from flooding mitigation, these initial results should be examined in the future studies on SuDS application to bring underlying benefits such as water quality treatment, reducing the speed and reduce runoff from stormwater features in the NL-TN. Further, this approach offers an opportunity to strengthen green spaces for the city, connect and expand network trees, thereby creating community benefits (improving the living environment, increasing the quality of community life, increasing property values, land prices and prosperity of the local economy).

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