Storm water management approach to increase the quality of urban streetscape in Sudirman Street, Bogor City

C N Ainy[1*], D Harlan[2], and H Hanan[3]

[1] Landscape Architecture Department, Bandung Institute of Technology, Jln. Ganesha No 10 Bandung 40132, Indonesia.
[2] Research Division of Water Resources Engineering, Bandung Institute of Technology, Jln. Ganesha No 10 Bandung 40132, Indonesia.
[3] Architecture Department, Bandung Institute of Technology, Jln. Ganesha No 10 Bandung 40132, Indonesia.

[*]Email: nurulainyherish@gmail.com

Abstract. The storm water management approach is still scarce in developing countries. Streetscape is one of the city's elements that suitable for storm water management because of the dominance of impervious surface. Storm water runoff will cause damage of streetscape facility and river biodiversity in the long term due to the pollutant consist on it. This study focuses on the use of hydrological analysis to determine the main problem regarding the drainage capacity and the design solution with storm water management approach. The case study takes place in Sudirman Street, Bogor City. There are two types of drainage basins in Sudirman Street and delineated to two different catchment areas. The result of study shows that both of existing channels have enough capability to accommodate peak runoff until 5-year storm, yet the flash flood still occurs during the heavy rain. This is leading to conclusion that the existing inflow design is not effective to convey the runoff into existing drainage. So, the design solution is utilizing green area in the streetscape as a green infrastructure that give a multiple benefit to the environment such as filter, infiltrate, and convey storm water runoff slowly to the main drainage.

Keywords: drainage capacity, hydrological analysis, runoff, storm water, streetscape

1. Introduction

The International Geosphere-Biosphere Programme (IGBP) identifies three main components of global change: land-use/cover change, changes in atmospheric composition, and climate change [1]. Current environmental problems as we face them because of climate change are encouraged to have green spaces in the city [2]. Streetscape is one of the city's elements that plays important role I the environmental quality because it has 25% area of the city [3], yet it has the dominance of impervious surface. Directly Connected Impervious (DCI) areas are areas where a runoff is directed into a storm sewer, Swale, or creek with no opportunity for the runoff to encounter absorptive soil or vegetation. These areas are the most damaging to stream health and flooding because all precipitation is translated immediately into a runoff in the stream system [4]. To prevent water pollution, site designers must now address storm water management practices not only for the finished development, but for the construction site as well, from the time the site is first disturbed [5].

Hydrological analysis is very critical step to ensure the sustainability of site towards storm water runoff. Storm water management approach in Indonesia still unpopular while we need more responsive

design to encounter the climate changes effect. Widening the drainage capacity more and more was the quickest solution and ended up failing to solve the problem regarding storm water runoff in the streetscape. It is essential to conduct the computation of the existing drainage capacity to determine the main problem. There are multiple benefits to enhance our hydrological analysis with the calculation of storm water runoff discharge: first, it will help to find the cause of storm water runoff that occurs due to the lack of capacity or not; second, it will be easier to design the drainage system with the proper capacity. This paper will focus on calculation practice on both benefits. Therefore, it will be very beneficial for designer to design the environment in a more sustainable way. Sudirman Street, in Bogor City, has been selected as the study area. As a one of the main road in the Bogor City, it faces so many problems due to the development of the city and the effect of climate change. Storm water runoff affects the damage of streetscape's facility and decrease user comfortability. Thus, with this study it will help to determine the main problem and the design solution to reduce storm water runoff in the Sudirman Street.

2. Methods

2.1. Study area
This study was conducted in Sudirman Street, Bogor City (approximately 6°24'49" S- 6°35'39.24" S, 106°47'44" E- 106°47'46" E). Bogor has high annual precipitation compared with other city in the same region about 3500-4000 mm/year. It has historical street which is part of road development in the Colonial Era (1808) called Groote Post Weg now the name is changed to Jalan Sudirman and classified into Secondary Artery Road (Figure 1). In the South of Sudirman Street, there is Bogor Botanical Garden, the largest green open space that classified as a City Forest [6].

Figure 1. Map of study area.

2.2. Data collection
The main data for this study is the maximum precipitation (Figure 2) for over the past 10 years (2006 - 2015). These data were collected by Department of Meteorology, Climatology, and Geophysics located in Bogor Botanical Garden (06°35'55.7" S- 106°47'44.1" E). Beside the maximum precipitation, the other data were land cover, topography, flow direction, and the size of existing drainage. Land cover data were obtained from Google Earth to determine the runoff coefficient. Topography, flow direction, and the size of existing drainage were obtained from the secondary data and field observation were used to determine the catchment area and computed the runoff discharge.
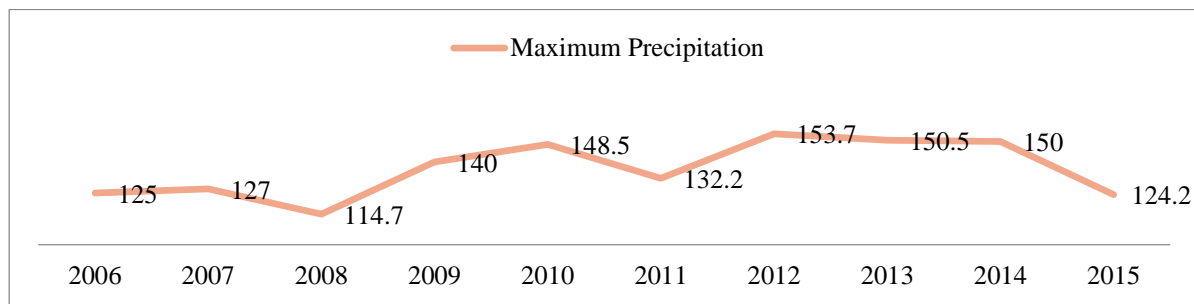
Figure 2. Maximum precipitation/month (mm) from year 2006-2015.

2.3. Runoff discharge

2.3.1. Manning equation

The flow in open channels is a function of a velocity and the cross-sectional area of flow. Velocity is a function of slope, surface roughness, and cross-sectional shape. The Manning Formula is used to compute velocity [7]:

$$R = \frac{A}{P} \tag{1}$$

$$v = \frac{1}{n} \; R^{\frac{2}{3}} \; S_o^{\frac{1}{2}} \tag{2}$$

Two other arrangements of the Manning Formula are convenient in conveyance design. Discharge (**Q**) can be expressed in terms of the Manning Formula using the following formula [7]:

$$Q = \frac{1}{n} R^{\frac{2}{3}} S_o^{\frac{1}{2}} A \tag{3}$$

Remarks:
R = the hydraulic radius (m)
A = the cross-sectional area (m^2)
V = velocity of flow (m/s)
S_o = longitudinal slope of the hydraulic grade line (m/m)
N = Manning's coefficient for friction

2.3.2. Gumbel method

The Gumbel method is used to determine predicted 5-years rainfall in the study area based on the maximum rainfall data in the last 10 years. The formulas used are as follows [8]:

$$X_T = \overline{X}(1 + KC_v) \tag{4}$$

$$K = (y_T - y_n)/S_n \tag{5}$$

Remarks:
X_T= the probable maximum precipitation with a return period of T years
C_v = coefficient of variation
Xbar = mean maximum precipitation
K = frequency factor

σ_n = standard deviation of data

y_T = -lnln(T/T-1)

y_n, σ_n = expected mean and standard deviations of reduced extremes to be found from Gumbel's table.

2.3.3. Mononobe rainfall intensity

The intensity of rainfall is defined as the mean of the rainfall intensity assumed to fall uniformly over the catchment area; to determine the duration and frequency of the units, the commonly used unit is mm/hr. The Mononobe formula is used to calculate rainfall intensity each time based on daily rainfall. Here is the formula used [9]:

$$I = \frac{R_{24}}{24}(\frac{24}{t})^{2/3} \tag{6}$$

Remarks:

I = Rainfall intensity (mm/jam)

R_{24} = Rainfall in 24 hours (mm)

t = Rainfall duration (jam)

2.3.4. Rational method

Many methods to compute runoff has been developed over the years and the first and most enduring of these are the Rational Method. The Rational Method is used to compute the peak runoff (**Qp**) following a rainfall event. It makes no attempt to estimate runoff before or after the peak, but simply estimates the one quantity of flow that is greatest [10]. The formulas are:

$$Q = kCIA \tag{7}$$

Remarks:

Q = peak runoff (m^3/s)

K = coefficient (0.278)

C = runoff coefficient

I = rainfall intensity (mm/jam)

A = drainage area (m^2)

3. Results and Discussion

3.1. Hydrological analysis

3.1.1. Drainage capacity

Before computing the capacity of the drainage, field observations were conducted to know the size of the drainage and catchment area delineation. There are two types of drainage in the study area, both are open channel drainage, but different in material and size. Drainage Type 1 lies in the west of road while Drainage Type 2 lies in the east of the road. The catchment areas were determined based on the area where the flow of water entering the drainage; so, it is divided into two catchment areas. One is for the catchment area in Drainage Type 1 (180717 m^2) and the other one is for catchment area Drainage Type 2 (56775 m^2). The highest point is in the south with elevation 258 m above sea level (asl) and the lowest point is in the north with elevation 233 m asl. The length of Drainage Type 1 is 1439 m and Drainage Type 2 is 1404 m (Figure 3).

The result of field observation about the size of existing drainage and the boundary of the catchment areas could be seen in Figure 4. The material of the channel will affect Manning Coefficient of Friction. Drainage Type 1 has 0.023 coefficients because it made from gravel bottom, sides dry rubble. Drainage Type 2 has 0.012 coefficient because the material is made from concrete, formed and trowel finish [7]. For the slope of Drainage Type 1 is 0.017 m/m and Drainage Type 2 is 0.018 m/m. Based on that, the result of computation using Equation (1), (2), and (3) is the capacity of Drainage Type 1 is 6.56 m^3/s and Drainage Type 2 is 0.85 m^3/s.
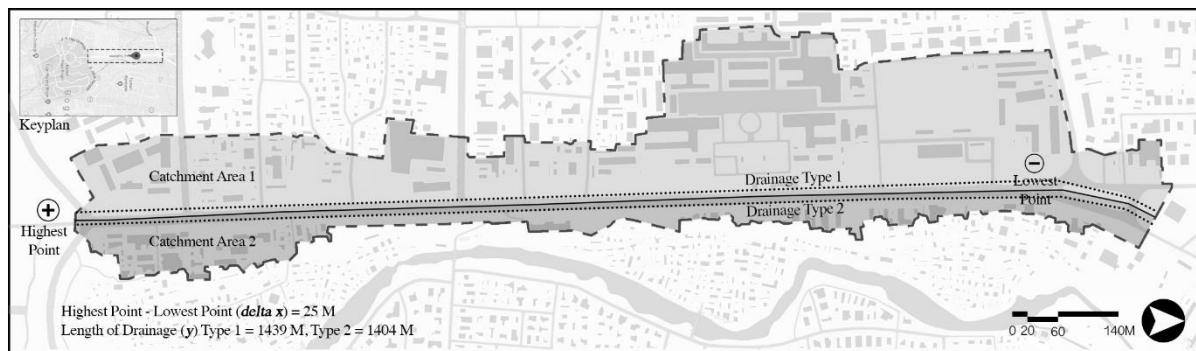

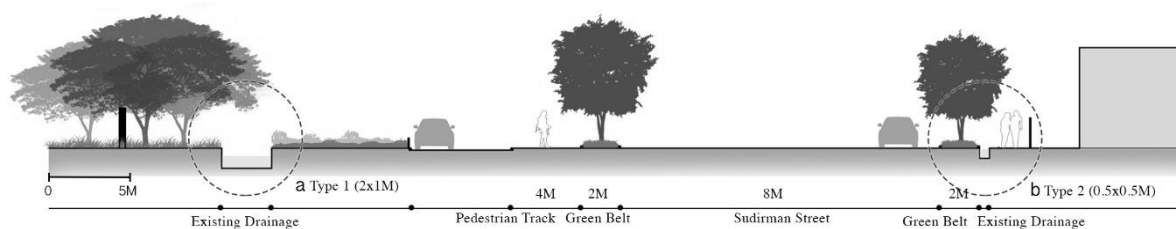**Figure 3.** Catchment area and drainage map.

Figure 4. Typical existing street section.

3.1.2. Runoff discharge

Rainfall data processing is needed before computing the runoff discharge. Gumbel Method (4) is one of the methods to predict the rainfall. In this study, the trend of rainfall is predicted in 5-years rainfall. The result is rainfall in the study area (**Xt**) will reach 151.03 mm/day in the 5-years rainfall. Then, this data will be processed on Mononobe Formula (6) to determine the rainfall intensity per hour. The result is rainfall intensity (**I**) in the study area is 2.65x10^{-5} mm/s. From the result of land cover analysis, there are seven types of land cover in the study area: roof, green open space, green belt, pedestrian track, paving, road, and parking area.

The results are the runoff discharge of 5-years rainfall on Catchment Area 1 is 0.94 m^3/s while in the Catchment Area 2 is 0.37 m^3/s. Compared to the existing drainage capacity, the runoff discharge of 5-years rainfall in both catchment areas could be well accommodated by both drainage existing. So, this leads to the conclusion that the main problem of the local flooding in the street during the rain is not because the existing drainage is not having enough capacity to accommodate the stormwater runoff, instead the design of the drainage system is very poor; therefore, it will stagnate in somewhere before reach the channels.

3.2. Design recommendation

At the local and site scales, it has been defined as a storm water management approach that mimics natural hydrologic processes [11]. Traditionally, the country relies on a network of concrete canals and rivers to quickly channel water into the reservoirs and the sea to prevent flooding. These rivers and canals are designed to quickly and efficiently convey storm water runoff to the sea or to the nearest waterbody [12]. When new developments are planned, appropriate management interventions, including infrastructure and development controls are required to manage storm water and prevent flooding of properties [13]. Based on study there are two important design solutions to effectively reduce stormwater runoff and create a more sustainable environment on the streetscape:

3.2.1. A multifunctional green belt

Storm water runoff on the streetscape is very difficult to reach the drainage due to inadequate design and maintenance of conventional drainage. On the roads that have a green belt as in the study area, it can be utilized as a bioretention swale before it enters the existing drainage. This will help shorten the flow of water and reduce the runoff significantly. In essence, the aims of bio-swale approaches are two folds: to reduce the amount of impervious surface in order to reduce storm water runoff, to utilize the landscape and soils to move naturally, store and filter storm water runoff before it leaves the development site [14]. Bio-swale is one of the types of green infrastructure that suitable for green belt. Figure 5 is a sample of the bio-swale system that can accommodate the storm water runoff. Use of local plant species is very recommended to enhance the biodiversity and easier maintenance. Plants such as Cymbopogon citratus, Pennisetum alopecuroides, Sanchezia nobilis, Ipomea pes-caprae, and Widelia biflora are proven to help reduce water pollutants in the runoff [15].
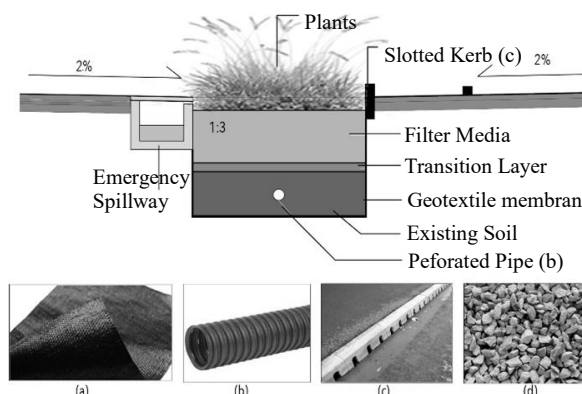

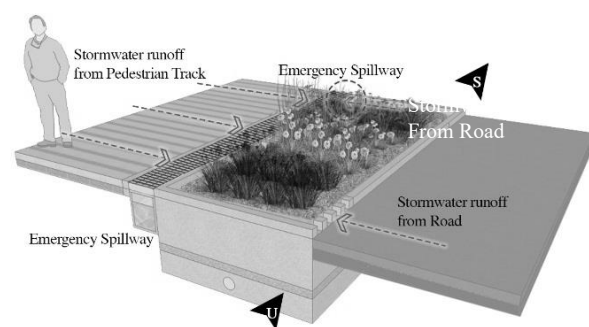**Figure 5.** Cross section of bioswale (adapted from PUB 2011).

Figure 6. The design flow of water in the bioswale.

3.2.2. Capacity of bio-swale

To create more efficient and sustainable infrastructure, the capacity of bio-swale should properly accommodate storm water runoff within the study area. At first, the design of flow direction must be clear and efficient to convey the water to the bio-swale, as well as the boundary of the catchment area. Figure 6 shows the design of flow direction in the streetscape. Once catchment area is determined, the size of bio-swale could be designed by calculating the capacity with Manning Equation (3) and Rational Method (7). The results are the runoff discharge within the catchment area is 0.07 m^3/s and the capacity of bio-swale is 0.5 m^3/s (Figure 7). Thus, the bio-swale has more than enough capacity to accommodate up to 5-years storm.
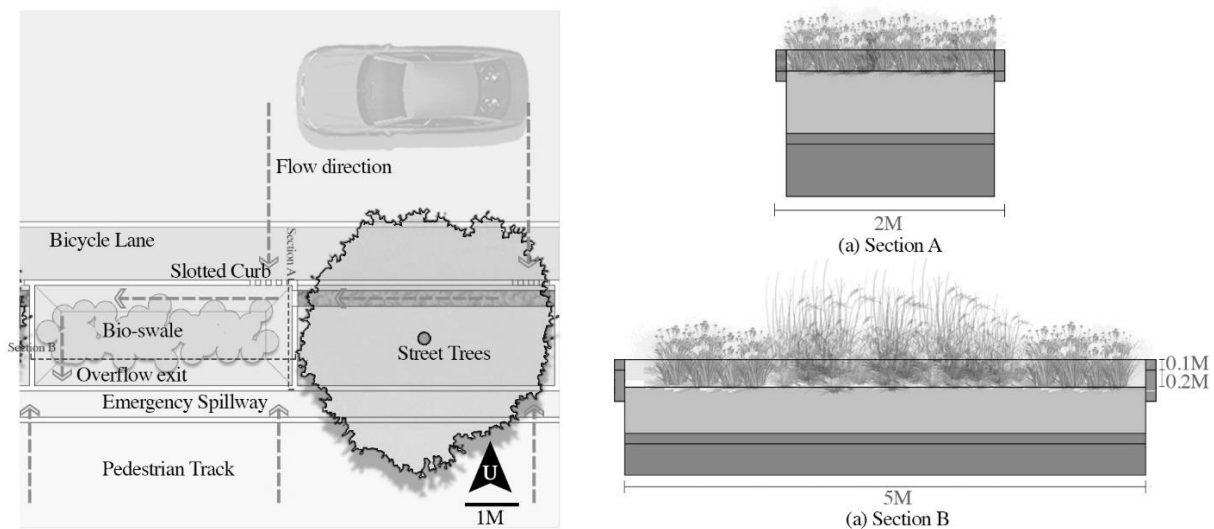
Figure 7. Design solution for utilizing green belt as bio-swale to reduce storm water runoff in the streetscape; Plan (left) and Section (right).

4. Conclusion

The existing drainage has enough capacity to accommodate storm water runoff up to 5-years rainfall, yet the runoff in the streetscape still occurs. Therefore, this leads to conclusion that the existing drainage system needs to be reevaluated to decrease storm water runoff significantly. The design solutions are to utilize green belt as bio-swale and calculate proper capacity towards the site's runoff condition. It will help to reduce storm water runoff up to 100%. The local plants will absorb the pollutant and will contribute to increase the quality of water within the area.

This paper is trying to enhance the hydrological analysis in the landscape design process with storm water management approach. So, hopefully the design product will effectively work and contribute to environmental sustainability. It will be much related to city planners, engineers, and landscape designer to design our environment in more sustainable ways.

References

[1]   Head L 1969 Key issues in environmental change Cultural Landscapes and Environmental Change (New York: Oxford University Press Inc.) p 44
[2]   Dan M B 2014 Planning and designing sustainable and resilient landscapes Green Walls (New York: Springer) p 180
[3]   UACDC 2010 Low impact development A Design Manual for Urban Areas (Fayetteville: University of Arkansas Press) p 92
[4]   Donald W and Adams M 1937 Design for flooding Architecture, Landscape, and Urban Design for Resilience to Flooding and Climate Change (New Jersey: John Wiley & Sons.Inc) p 92
[5]   Russ T H 2002 Site Planning and Design Handbook (New York: McGraw-Hill) p 211
[6]   RTRW Kota Bogor 2011-2031
[7]   Harris W C, Dines T N 1998 Time Saver Standards for Landscape Architecture(USA: McGraw-Hill.Inc) p 330-27
[8]   Al M G 1978 A Simple Version of Gumbel's Method for Flood Estimation Hydrological Sciences Bulletin Taylor and Francis Group p 374-380 http://dx.doi.org/10.1080/02626667809491810
[9]   Sulung G 2012 Probabilitas Kejadian Hujan Maksimum untuk Perencanaan Saluran Air pada Tambang Terbuka Studi Kasus: PT Adaro Indonesia Online Publication (Bandung: Program Studi Meteorologi Institut Teknologi Bandung)

[10] Gribbin J E 2014 Introduction to Hydraulics and Hydrology with Applications for Stormwater Management (Delamr: Cengage Learning) p 219

[11] Rousse D and Ossa I 2013 Green infrastructure A Landscape Approach (Chicago: American Planning Association) p 1

[12] PUB 2011 ABC Waters Design Guidelines (Singapore: Public Utilities Board)

[13] Melbourne Water 2013 Stormwater strategy A Melbourne Water Strategy for Managing Rural and Urban Runoff (Australia: State Government of Victoria)

[14] Nigel D and Clayden A 2006 Rain gardens Sustainable Water Management for the Garden and Designed Landscape (Portland: Timber Press.Inc)

[15] Hunt W F 2015 Plant Selection for Bioretention Systems and Stormwater Treatment Practices SpringerBriefs in Water Science and Technology DOI 10.1007/978-981-287-245-6_2