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IDENTIFYING URBAN FLOODS BASED ON HEC-RAS, SWMM, AND GOOGLE EARTH ENGINE

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Abstract.
Urban water-related disasters are a commonly occurring event including in Indonesia. According to recent news, a watershed in South Sumatera submerged due to heavy rainfall and other factors. This study focuses on the Musi River, Palembang. It studied the two alternatives of flood mitigation in the Musi River system, namely hydraulics modification and green infrastructure landscape. The research methodology of the paper covers hydrological analysis, hydraulics, and slope stability calculation by using Google Earth Engine, 1-D HEC-RAS and Geo-Studio software, and green infrastructure simulation by employing SWMM analysis. The hydraulics modification appears to be able to lessen the flood in the watershed with a 100% reduction. Meanwhile, green infrastructure installation provides a 12.5% reduction in water volume in the study area. The government could opt after dealing with their infrastructure budgeting and environmental condition.

Keywords: Urban Floods, HEC-RAS, and SWMM

1. INTRODUCTION

News reported that flooding in the Musi River recently contributes terrible impacts to the economy, environment, and other sectors. People suffer in a dire situation with a lack of facilities that could provide the required supplies during the disaster. Heavy rain in the early year of 2020 makes several regions in Indonesia get flooded due to the overloaded capacity of the rivers, including Palembang province.

Today, as the increasing of urban areas, the country faces not only the water quantity but also the water quality [1], [2]. Currently, researchers have been studying urban stormwater management to discover the most low-cost and effective ways to reduce the impacts on society. There have been many alternatives to implement types of green infrastructure in Musi sub-watershed to improve water quality. This paper addresses the green infrastructure options in the study area.

Flood mitigations have been studied worldwide [3], [4]. Meanwhile, the best decision to be applied is according to the geographical and demographical conditions in a specific watershed. It will be different in the mitigation efforts for urban and rural areas. Some say that grey infrastructure, such as enlarging river capacity or constructing a dam, could be the best alternatives to reduce floods [5], [6]. On the other hand, experts argue that

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green infrastructure will be more efficient and offers a considerable impact to minimize flood impacts such as rainwater harvesting [7], [8], and other eco-infrastructures [9], [10]. Furthermore, the effectiveness study of green infrastructure remains limited for developing regions [10], [11]. In this study, the research aims to evaluate existing river hydraulic conditions and green infrastructure alternatives to manage urban stormwater in the Musi river environment.

2. LITERATURE REVIEW

Palembang, especially the Musi sub-watershed, will confront both urban flooding and lack of water quality due to the urbanization and climate impact effect. People will move to urban areas, and the population growth in developing countries will experience the highest growth rates [12], [13]. Unpredictable climate change in the future will make countries experience drought, increased flood risk, and a high level of environmental vulnerability due to a lack of water quality. Pollution from activities in urban areas makes the water bodies suffer from the point and non-point sources of chemical substances, which are harmful to aquatic habitats and potential as a water-borne disease to society [14], [15].

As an adaptation option to improve urban storm-water management, the use of green infrastructure is developed worldwide. Many approaches are known as landscape urban storm-water management such as green infrastructure (GI) [16] Sustainable Urban Drainage Systems (SUDS) [17], Best Management Practices (BMPs) [18], [19], Low Impact Development (LID) [20]–[22], and Water Sensitive Urban Design (WSUD) [23]. As a supporting tool for urban stormwater management, Storm Water Management Model (SWMM) [24] approach is used in this research to simulate the green infrastructures alternatives to tackle the problems proposed in the paper.

3. RESEARCH METHOD

3.1 Study area

This study focuses on the Musi River, located in Musi watershed, Palembang Province, South Sumatera, Indonesia, as provided in Figure 1. It has a 750 km length with a 6.5 average depth. Suburban and rural areas surround as well as along the river. The variety of housings and complicated demographical sectors make flood mitigation in the region more challenging. Musi experiences the most intensity of rainfall in April and the driest one in September. Today, the Musi River is used as a logistic transportation system navigable by large ships, which means added loadings in the river system.

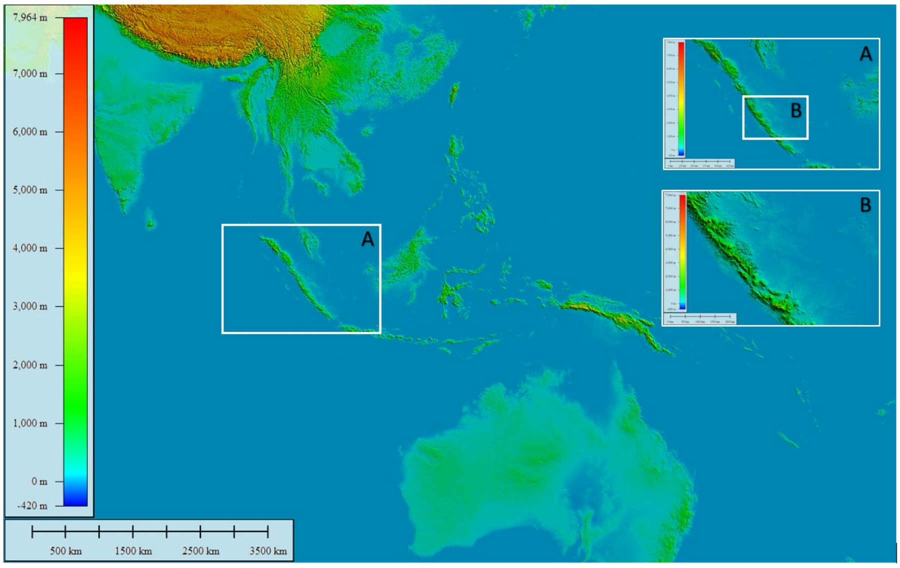


Figure 1. Study area in Indonesia, (A) Sumatera Island, and (B) Palembang Watershed

3.2 Methods

The research is conducted through several procedures: (1) hydrological analysis, (2) hydraulics and stability analysis by using Google Earth Engine, 1-D HEC-RAS, and Geo-Studio modeling approach, (3) runoff analysis by using SWMM.

In the early stage of the research, rainfall analysis is carried out by employing the Thiessen method as weighted regional average rainfall data [25]. In the end process of rainfall analysis, return period flood discharge is calculated by using the Nakayasu method [26], [27].

The maximum discharge due to climate conditions is then compared to the existing hydraulic state of Musi River. If the capacity of the river is less than the volume of discharge occurrence, the capacity needs modification. Here, the research employs a widely-used numerical supporting tool 1-D HEC-RAS program, in other studies [28], [29]. Both existing and new design of the channel is simulated by using HEC-RAS. On top of the water hydraulics, slope stability is observed by using the SLOPE/W feature inside the Geo-Studio [30].

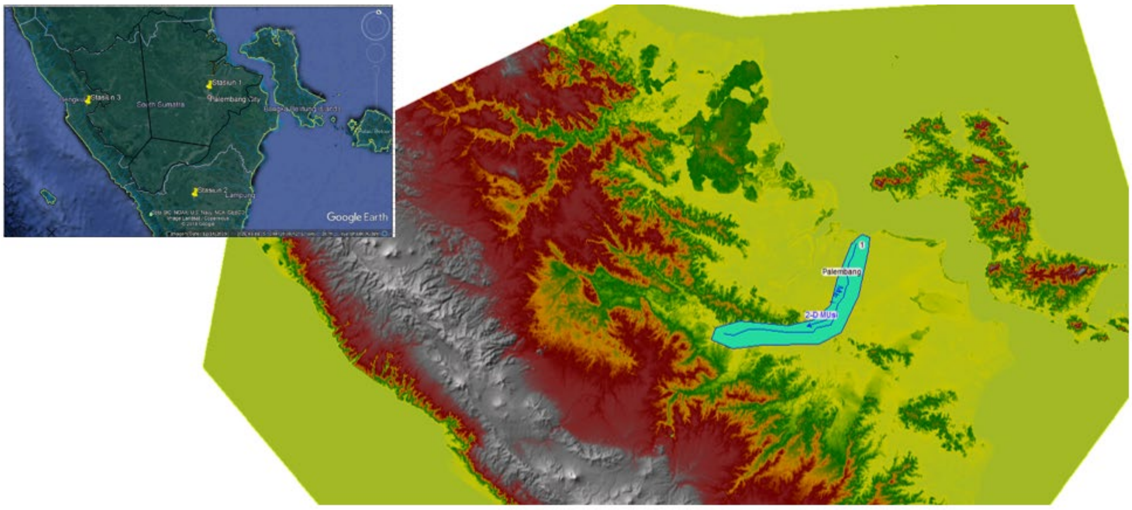


Figure 2. Musi watershed with the investigated three climatology stations

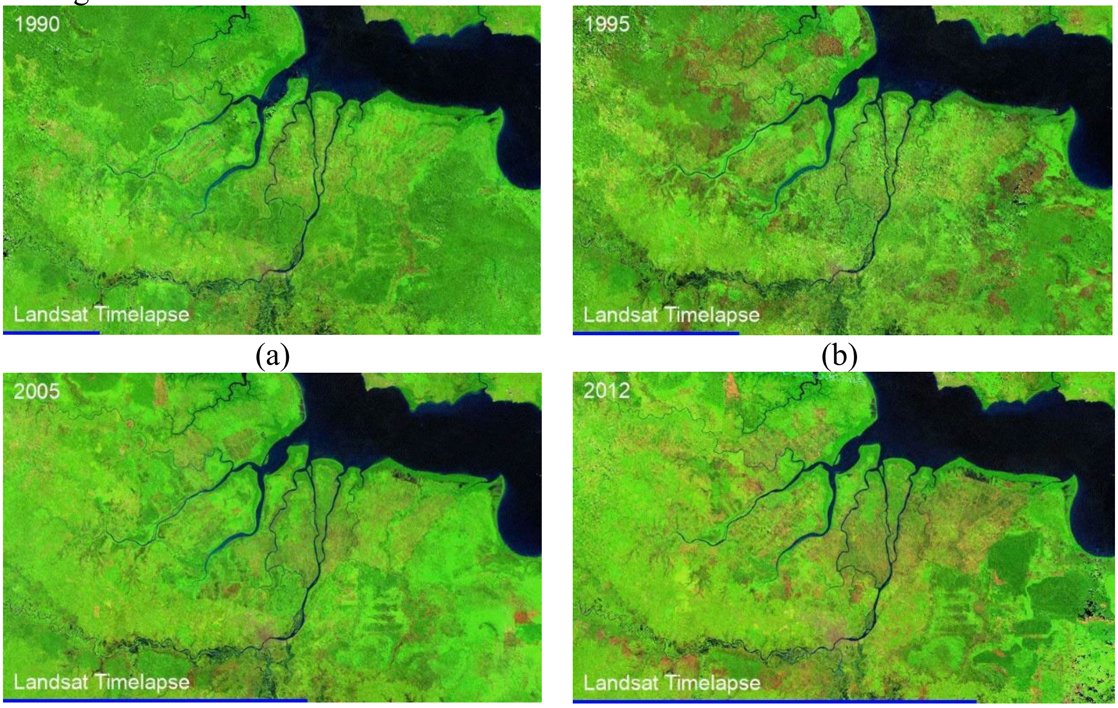
In the following analysis, SWMM is employed to observe the runoff and flooding for urban stormwater management in the study area. Despite its excellent capability to simulate the water quality, water quality modeling is not conducted in this research. The research only focuses on the runoff aspect.

4. Results and Discussion

Rainfall data in three stations of climatology are collected for analysis. The investigation was conducted in the Meteorology station of Sultan Mahmud Baharuddin (Station I), the Climatology station of Kotabumi Lampung Utara (Station II), and the Climatology station of Parahyang (Station III). Figure 2 depicts the location of three stations which are surrounding the watershed. Thiessen polygon method is conducted to analyze the regional rainfall there.

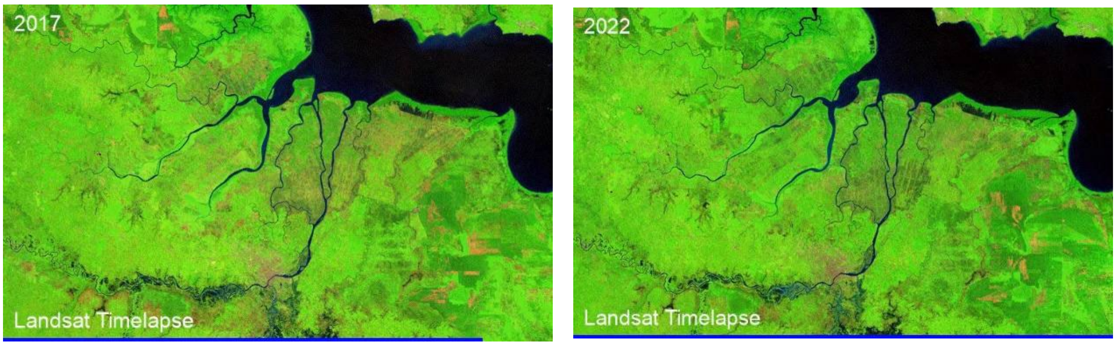
4.1 Land use change

In this research, land use change in the study area was analyzed by Google Earth Engine. Despite the program was run successfully, more development is needed. As a case in this research, the land use change is depicted in a too large area. As a result, the change in a watershed is difficult to investigate in a detailed manner. In future research, detailed land use change should be identified to generate a comprehensive result. Figure 3 below consists of land use changes in the study area based on annual observation. It can be seen that the green colour becomes lighter which indicates the percentage of land cover is deteriorating and can affect the flooding events there. Meanwhile, more causes should be investigated.



(a) (b)

(c) (d)



(e) (f)

Figure 3. Land use change based on annual observation from 1990 to 2022

4.2 Flood and Hydraulic Analysis

After the rain stations are connected and form the Thiessen polygon, then the area of each station in the watershed could be obtained to calculate the average maximum rainfall data of the Musi River watershed. Table 1 describes the maximum rainfall data in the basin for further calculation in the Nakayasu synthetic unit hydrograph (SUH). The SUH method is decided and synchronized with previous researches in Palembang, which used the same Nakayasu SUH [31], [32]. The result of Nakayasu SUH analysis is provided in Table 2.

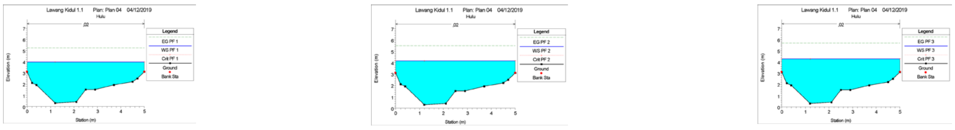
Table 1. Average maximum rainfall (mm)

Year	**Station I**	**Station II**	**Station III**
2009	133	134.1	102.2
2010	133	187.2	133
2011	102.4	95.8	129.9
2012	214.1	103.4	133
2013	126.6	104.8	108
2014	117.3	117	111
2015	105.4	98.5	116.9
2016	101.8	102.5	172.4
2017	84.4	107	113.9
2018	115.2	110.2	97

HEC-RAS Modeling of existing channels is carried out to determine the condition of the channel when the flood discharge occurred so that the severity of flooding in the channel will be visible. The following Figure 4-5 are samples of modeling of HEC-RAS on existing channel segments.

Table 2. Flood design analysis

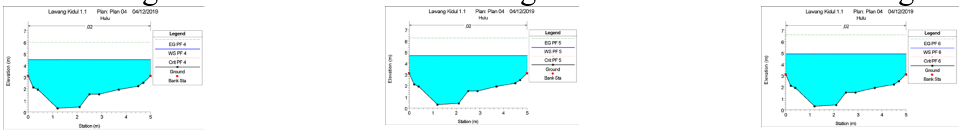
Periodical flood	Maximum discharge (m^3/s)
5-year	68.52
10-year	73.54
25-year	82.19
50-year	89.34
100-year	98.42
500-year	126.79



5-year return period flooding

10-year return period flooding

25-year return period flooding

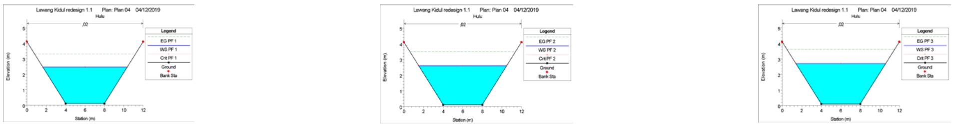


50-year return period flooding

100-year return period flooding

500-year return period flooding

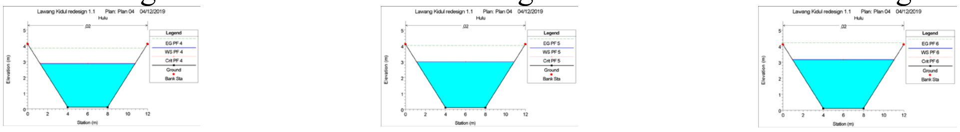
Figure 4. Hydraulics condition in the upper stream part of the observed river



5-year return period flooding

10-year return period flooding

25-year return period flooding



50-year return period flooding

100-year return period flooding

500-year return period flooding

Figure 5. New hydraulics condition in the upper stream part of the observed river

HEC-RAS modeling of the new channel design is carried out to determine the condition of the channel when the flood occurred so that the situation is visible whether the new channel design can accommodate flood discharge until the return period of 500 years or not. The following Figure 6-8 are samples of HEC-RAS modeling on the new channel design.

4.3 Stability analysis

Stability analysis of the existing canals is carried out to determine the level of channel stability in the watershed. From the results of the study, the value of the current channel safety factor that is equal to 2.030. With the effects of the safety factor, the condition of the channel stability is safe enough. On the other hand, the new design of the hydraulic channel produces a higher value of safety factor with 4.943. Figure 6 depicts the result of modeling Geo-studio of the existing channels, while Figure 7 describes the new hydraulic channel safety factor.

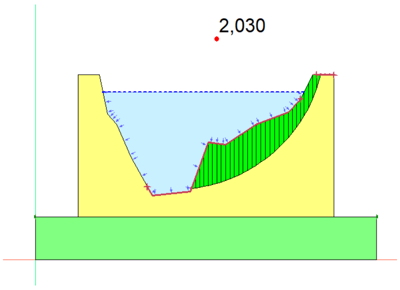


Figure 6. Stability analysis of the current condition

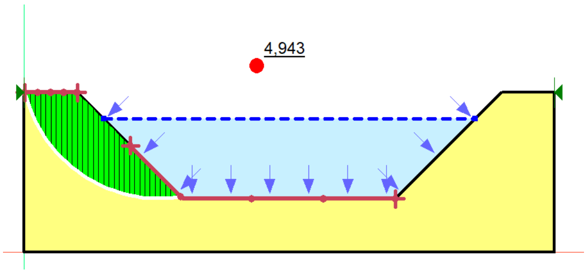


Figure 7. Stability analysis of the new hydraulic condition

4.4 Storm Water Management Model

Low impact development practices in EPA SWMM 5.1 consist of several layers and parameters. Table 3 shows the structure and O&M activities, which are categorized by Chui [33]. The LID practices are conducted in Hong Kong as urban areas near the river activities.

Table 3. Structure of LID practices

LID practice	Structure	O&M activities
Green roof	Layers of: plant, growing media, filter, drainage, root barriers, protection	Management for vegetation, pest, and watering
Bioretention	Layers of: plant, growing media, and storage	Management for vegetation, pest, sedimentation, watering, and mulching
Porous pavement	Layers of: asphalt, filter fabric, filter, and storage	Regenerative vacuum sweeping

Source: Chui [33]

In this study area, urban sub-watershed is chosen to simulate the LID controls to improve the water quality in the area around the Musi River. The time-series flow employs the 2-year discharge rainfall.

Parameters of LID, which are used in the sub-basin, are obtained from previous research [33]. The green roof has berm height 25 mm, vegetation volume fraction 0.1, surface roughness 0.1, and surface slope 1% for the surface layer. While bio-retention's value of 150, 0.1, 0.1, and 1%, respectively. Also, porous pavement only affects the surface roughness 0.012 and the same surface slope value as others. The soil layer could be justified for thickness (mm), porosity, field capacity, wilting point, conductivity,

conductivity slope, and suction head. The value for green roof are variable, 0.5, 0.2, 0.1, 750, 10, and 87.5, consecutively. Bio-retention also has the same value except for conductivity with 250.

Meanwhile, porous pavement does not have this indicator. As the pavement layer, green roof, and bio-retention do not have this indicator. This layer only occupies the permeable pavement with several aspects. They are thickness (mm), void ratio, seepage fate, and clogging factor with the value of variable, 0.15, 0, 500, and 0. For the drainage mat layer, the green roof has 75 mm thickness, void fraction 0.5, and roughness 0.1. Next, both bio-retention and porous/permeable pavement need storage layers with seepage fate 750 mm/hr and 0 clogging factors. Bioretention needs 500 mm thickness, 200 mm higher from the porous pavement while they have void ratio 0.75 and 0.4. Last, the underdrain layer has a 0.5 flow coefficient and flow exponent for bio-retention and permeable pavement. The offset height for bio-retention is 150, a 50 higher than porous pavement.

In this research, we extract sub-watershed of Palembang city near Musi River for SWMM modeling. There are three sub-basin zones for simulation. The areas of the zones are represented in Table 4.

Table 4. Sub-basin areas

Zones color	**Area (km^2)**
Catchment (S3) Yellow	172.5
Catchment (S1) Red	87.5
Catchment (S2) Green	95.5

The area is visualized in the model, as depicted in Figures 8 and 9. Every catchment has junction and conduit to be transferred to the outfall of the Musi River (Out1). This model will simulate runoff from urban areas of Palembang. The LID practices are planned in every catchment. Green roofs plan is put in place in S3 to cover 11.5% of total area, bio-retention in S1 area for 9.8%, and 4% porous pavement in S2. These percentages are estimated according to the available and suitable area of each sub-catchments for green infrastructure implementation. According to the simulation in Figure 10 and 11, the flooding and runoff of the system are decreased by 12.5%. It is predicted that as more green infrastructure types and coverage areas implemented, the lower runoff would be in the sub-watershed.

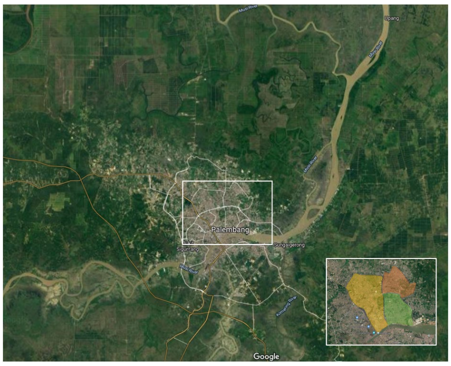


Figure 8. The study area for SWMM simulation

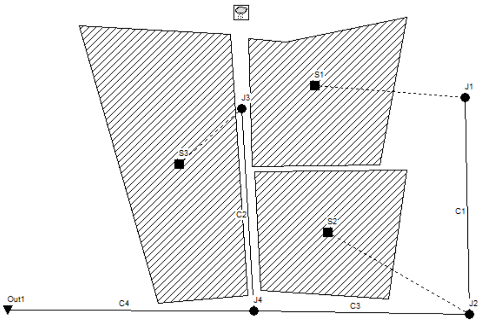


Figure 9. Sub-watershed schematic model

Discussion and Future Work

According to the result, it seems that redesigning the channel will provide a better condition for flood impact in Musi sub-watershed. Meanwhile, it will need a high cost not only in the initial construction but also in operation and maintenance of the infrastructure. Green infrastructures seem to be an excellent landscape alternative for urban runoff management in the study area. Both redesigning channels and implementing green infrastructures could overcome the quantity of runoff and flooding in the sub-watershed. Hence, the next step will depend on the government's capability for budgeting plan of infrastructure in the region. The best alternative then could be opted as an urban stormwater management solution in the study area.

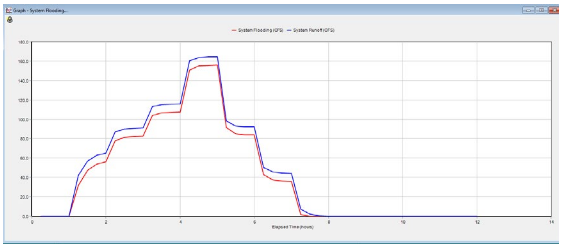


Figure 10. Existing flood condition of the system

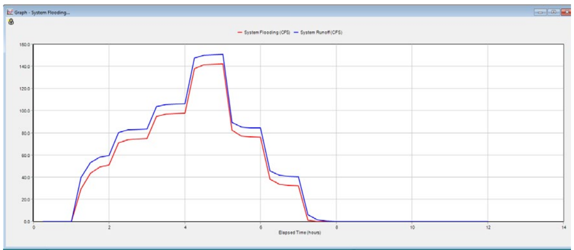


Figure 11. LID impacts in flooding

5. CONCLUSION

Google Earth Engine, HEC-RAS, Geo-Slope, and SWMM could help for the urban stormwater management option in Musi sub-watershed. HEC-RAS and Geo-Slope visualize the channel design to accommodate flood by approximately 100% loss but with high-budget conditions. Meanwhile, SWMM observes that green infrastructures could decrease 12.5% of existing flood in the study area in affordable ways. The study of economic analysis is then needed to deal with the government and environment conditions.

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