SUSTAINABLE DRAINAGE SYSTEM OF POPULATED SITEBA AREA, CITY OF PADANG, INDONESIA

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ABSTRACT

High rainfall over a long period of time and the inability of the drainage network in the city of Padang to hold the overflow of the Batang Kuranji River, and dispose of rainwater within the area, are the main cause of flooding in the city of Padang. Based on flood event data in the city of Padang in 2016 and 2017, floods have occurred at least once a year, with varying depths of inundation between 0.5m and 1.0m. The worst flood recorded to date occurred on September 26th, 2018, with a depth of 1.5m. This flood caused damage to residential areas, agricultural land, irrigation channels and caused landslides on several hills in the city of Padang.

A sustainable drainage system is recommended to solve the flood problems of such area. Sustainable drainage systems encourage water infiltration; reduce runoff magnitude, thus helping preserve water resources and river flow for the dry season. In addition to reducing the peak of the flood, this drainage system also maintains the existence of wetlands in a wider scope as a flood retention area, protects and improves water quality and increases evapotranspiration and climate regulation in urban areas. Reduction of flood peaks could be done by building infiltration wells, allowing inundation for certain depth and duration in several low risk areas such as sports fields and parking lots. In addition to manage internal flooding, the drainage system also needs to be integrated with the flood prevention system.

Flood control simulations are carried out by utilizing the HEC-RAS mathematical model. The mathematical models integrate the internal drainage system and the external drainage system which is influenced by the Batang Kuranji River. The simulation begins with an evaluation of the capacity of the existing internal drainage channel network for the flood discharge and rainfall that have occurred and calibrated with flood water level data at the location. The simulation models were run for a 25-year return flood by increasing drainage channel capacity; increasing the infiltration rate with infiltration wells; allowing certain depth and duration of inundation in low risk areas.

Keywords : Flood, Urban Area, Sustainable Drainage System, Indonesia.

1. INTRODUCTION

From several natural disasters that occurred in the city of Padang, flooding is one that occurs frequently. The floods of March 21st, 2016 resulted in damage to agricultural land, irrigation channels and caused the occurrence of landslides on several hills in the city of Padang, in this incident the flood depth reached 0.8m ~ 1.0m (republika.co.id). The following year, March 31st, 2017, As a result of this disaster, several aftershocks such as fallen trees, billboards collapse and more landslides in the the city of Padang (news.detik.com). 285 residents were forced to evacuate in this

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time the flood depth reached 0.5m ~ 1.0m. Still in the same year, September 9th, 2017 the flood repeated again with a depth of up to 0.5m (republika.co.id). The worst flood recorded to date occurred on September 26th, 2018, with a depth of 1.5m (news.okezone.com).

Based on West Sumatra BPBD data, the Nanggalo Subdistrict area includes, Lapai, Siteba, Maransi, Gunung Pangilun including flooded areas every time there is a flood in Padang City. Of the several flood-prone areas in the city of Padang, the Siteba area is an area of concern. This is quite dense area and results in greater losses compared to other areas in the event of a flood. The Siteba area is a part of the Batang Kuranji watershed, located in the lowlands of Padang City with relatively uneven land at elevations between 13 to 7 meters above sea level. Most of the land in Siteba is used residential area with relatively small drainage channel dimensions and high surface runoff experiences flooding during the rainy season.

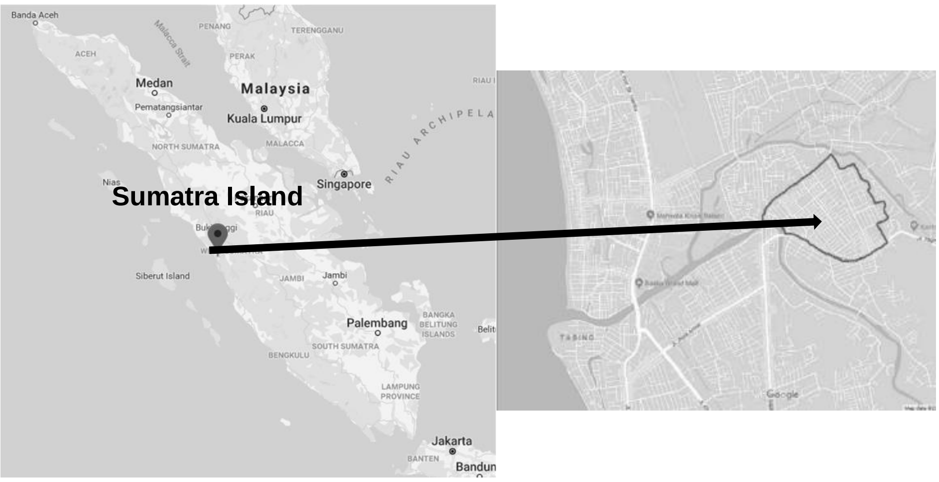

Figure 1. Study area (Siteba area, Nanggalo District, city of Padang, Indonesia)

In some other countries around the world floods have been prevented in the right way according to their natural conditions. In Curitiba, Brazil floods are prevented using the artificial lake method. Areas that are usually flooded are made into city parks and become artificial lakes for temporary excess water storage. This method is quite effective because the costs incurred are estimated to be five times lower as compared to the construction of flood channels. The Kingdom of Malaysia has build the "Stormwater Management and Road Tunnel" project (SMART) to overcome the problem of flooding in Kuala Lumpur. The scope of the SMART project includes bypass tunnels, temporary water collection ponds and the twin box culvert outlet structure. In its planning, this SMART project was calculated to hold 3 MCM of water capacity. The city of Rotterdam, Netherlands has several areas with elevations lower than the depth of the average sea level, but flooding in this area can be prevented by the construction of dikes and dams with an automatic opening and closing system when seawater starts tide which is known as polder system. For some points in the city of Rotterdam which have a lower elevation, a hydraulic pump is used to remove excess water into the sea. In Indonesia itself there have been villages that have succeeded in overcoming the problem of flooding. Drainage systems are needed in developed urban areas because of the interaction between human activity and the natural water cycle. This interaction has two main forms: the abstraction of water from the natural cycle to provide a water supply for human life, and the covering of land with impermeable surfaces that divert rainwater away from the local natural system of drainage. These two types of interaction give rise to two types of water problems that require drainage. Urban drainage systems handle these two types of water with the aim of minimizing the problems caused to human life and the environment. Urban drainage has a number of major roles in maintaining public health and safety. There are further potential problems in large river basins in which the downstream discharges of one settlement may become the upstream abstraction of another. In the UK, some 30% of water supplies are so affected. Also, of particular importance in tropical countries, standing water after rainfall can be largely avoided by effective drainage. This reduces the mosquito habitat and hence the spread of malaria and other diseases. In developing countries, separation of storm drainage channels and sewer drainage is rarely done. (Butler and Davies, 2011)

2. SUSTAINABLE DRAINAGE SYSTEM

A sustainable drainage system is a drainage system that is able to regulate the volume and flow rate of runoff, thereby reducing the destructive power of water and the risk of flooding (Graham, 2012). The sustainable drainage system boosts the water infiltration to help preserve water resources and river flow in the dry season. In addition to reducing the peak of the flood, this drainage system also maintains the existence of wetlands in a wider scope as a flood retention area, protects and improves water quality and increases evapotranspiration and climate regulation in urban areas.The sustainable drainage system is a drainage system which in addition aims to reduce the problems caused by the surface runoff, it also aims to reduce water pollution (aquatic) problems, convert water resources and increase water use value, especially in urban areas (Parkinson, 2005).

The implementation of a sustainable drainage system can be done with surface drainage and subsurface drainage. Surface drainage is a flow above the ground with an open channel flow, allowing runoff or inundation to occur above the ground. Whereas subsurface drainage is carried out with drainage under the surface of the ground, this method is usually done for areas that do not allow the presence of inundation. Seeing the state of the study area which is a developed residential area, the improvement of the drainage system in the Siteba area is more suitable if it is done by means of surface drainage combined with water infiltration into the subsurface.

The principle of an integrated drainage system is to reduce the flood peak by storing as much water as possible. Reduction of flood peaks could be done by building infiltration wells, allowing inundation for certain depth and duration in several low risk areas such as sports fields and parking lots. Sunjoto, 1994, propose formula of designing the infiltration well, by considering the hydraulic conductiviy, depth and radius of well. Application of infiltration well in the catchment, can reduce surface runoff depending on the density and dimension of the well. (Kusumastuti, 2014) The results suggest that using infiltration well with diameters between 0.8 m ~ 1.4 m which are applied each in every 4000 m^2 of land area will reduce flood peaks from 6.9% ~ 12.6%. While the application of infiltration well with density of 500 m2 will reduce flood peaks from 55.21 to 99.8 %.

Mardiah et al. (2018) analysed the probability of using Infiltration wells to conserve surface runoff at the Bandung Institute of Technology (ITB) Campus, by making infiltration wells in accordance with the roof area. For 10 meter depth and 1 m diameter of infiltration wells, with a service area of 500 m2, the number of infiltration wells needed is 3 wells. If the totals of infiltration wells are designed according to roof area per building, with the total roof area 99,733 m^2 , ITB is supposed to have 770 wells. (Mardiah, 2018)

3. METHODS

The location of this study is in the Siteba area, Nanggalo District, city of Padang, Indonesia. Most of the land in this area is used for residential areas with at an average land level of between 7.0~13.0 meters above sea level. The Siteba area is a part of the urban area of the city of Padang, which is full of settlements. The drainage system is a very important infrastructure to support environmental health. At present, even though there is a rainwater drainage system that serves the area, at some point there is an inundation. This study tries to understand the concept of environmentally sound drainage, in addition of trying to increase drainage channel capacity, also introducing infiltration wells for recharging ground water.

The main cause of flooding is the increase in peak discharge due to high runoff and less infiltration. The impact can be in the form of infrastructure damage, economic losses, which in turn has a further impact on environmental health and social life. To avoid the adverse effects of flooding, a number of ways are pursued to increase the value of infiltration in the research area. In this study, it will be discussed in more depth about the effect of increasing infiltration through and reducing the height of flood peaks as a flood prevention solution.

3.1. Hydrological Analysis

The rainfall design was calculated using frequency analysis based on Simpang Alai rainfall station data from 1975 to 2013 with a 25-year return period. Time of concentration is calculated using Kirpich method (Eq. 1), giving the number 1.06 hour. IDF curve calculation using the Mononobe (Eq. 2) method gives the equation: $y = 1538.9\ x^{-0.667}$ where x . The results of drawing IDF curves can be seen in Figure. 2.

$$tc = \left(\frac{0{,}87\ L^2}{1000\ S}\right)^{0{,}385} \quad \text{(Eq. 1)}$$

Where :tc = concentration time (hour); L = channel length from upstream to the outlet (km); S = channel average bed slope

$$I = \frac{R_{24}}{24}\ \left(\frac{24}{tc}\right)^{2/3} \quad \text{(Eq. 2)}$$

Where:I = rainfall intensity on the duration of T hour (mm/hour); R_{24} = maximum daily rainfall (mm); tc = Concentration time (hour)

The results of the design intensity of the 25-year return period calculation obtained 100.66 mm/hour. The value of flow runoff coefficient (C) is calculated based on the average of several types of land use in the study area: housing, green space, markets and asphalt roads. After obtaining the basis, flow loads are then calculated for each block in the study area.

3.2. Infiltration Analysis

The infiltration wells are planned to have an inner diameter of 0.8 m and a depth (H) of 2 m, with storage volume of 1 m3 (Figure 3). The depth of the well is determined by the ground water level. The bottom of the well must be 2~3 m from the ground water level so that there is room for the natural purification process, At full condition, the time needed to infiltrate all water into the soil (T) can be simplified by equation (Eq.

3). With the soil permeability coefficient (k) of 0.02 m/h infiltration wells are expected to be empty after 100 hours (4 days and 4 hours).

$$T = \frac{H}{k} \quad \text{(Eq. 3)}$$

Where :T = time needed to infiltrate all water into the soil (hour); H = infiltration wells depth (m); k = soil permeability coefficient (m/h)

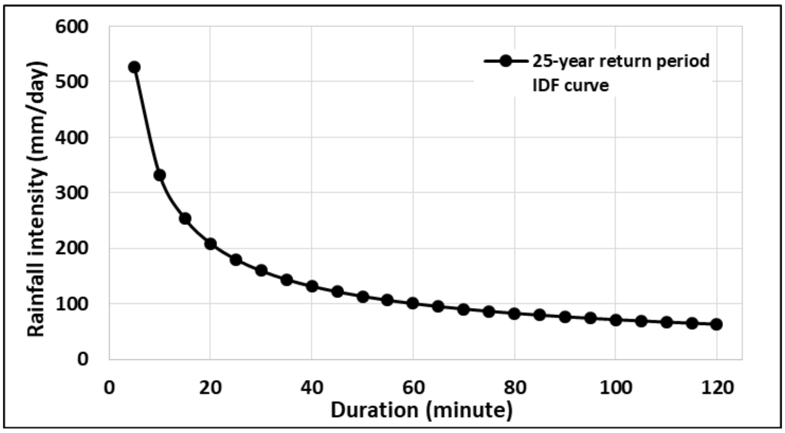

Figure 2. IDF (Intensity-Duration-Frequency) Curve for 25-year rainfall return period

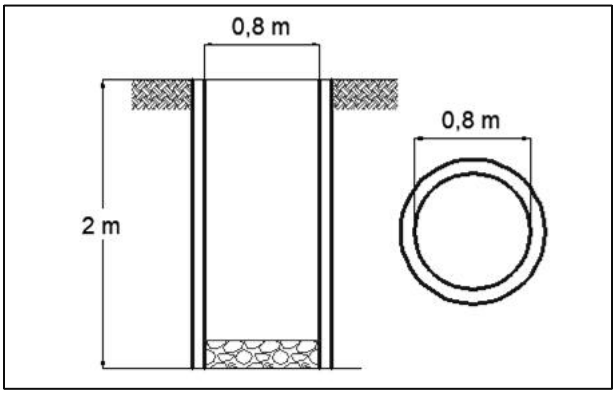

Figure 3. Planned dimensions of infiltration wells

The runoff discharge is calculated by considering the rainfall intensity, time of concentration and the service area of each canal. In case of drainage system equiped with infiltration well, part of the runoff flows to the well until its fully filled. Figure 4 shows the hydrograph of runoff discharge that occurs in the Asrama Kodim 25 cross section, before and after equipped with infitration wells. The results of the analysis show that the presence of infiltration wells can reduce inflow to the main channel 10%~40% during the duration of filling infiltration wells. The amount of runoff reduction also depends on the number of the available infiltration wells.

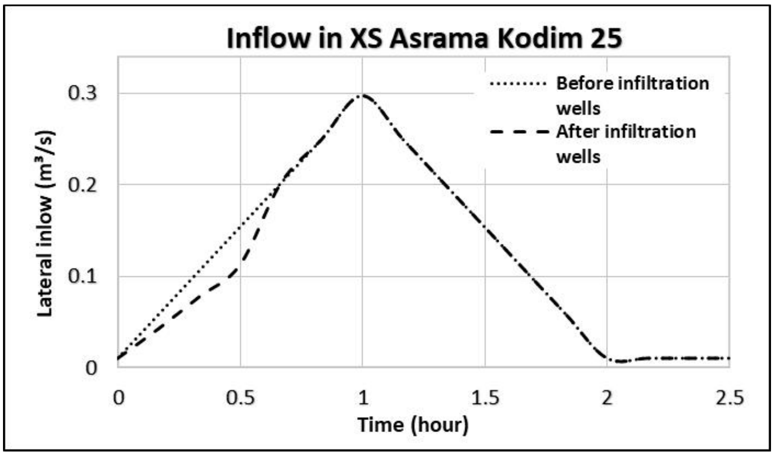

Figure 4. Differences in direct runoff that occur before and after the infiltration well

In this study, 956 infiltration wells are planned; the amount of recharge ground water volume that can be injected in the study area is 960 m^3. With the presence of inundation infiltration wells can be reduced, but not entirely lost because of that the drainage channel normalization is still needed to overcome the inundation that occurs.

3.3. Hydraulic Simulation

Unsteady flow simulations of the drainage system are carried out by utilizing the HEC-RAS mathematical model. The models integrate the internal drainage system and the external drainage system which is influenced by the Batang Kuranji River. The simulation begins with an evaluation of the capacity of the existing internal drainage channel network for the flood discharge and rainfall that have occurred and calibrated with flood water level data at the location when the flood data occurred. The layout of drainage system can be seen in Figure 5. The simulation models are run with a 25-year return flood with four alternatives of model. The first model simulated the flood flow of existing condition, the second model simulated the flood flow of the drainage system with increasing drainage canal capacity, the third model simulated the flow of the existing drainage system equipped with infiltration well, and the fourth model simulated the flow of normalized canal equipped with infiltration wells.

Figure 5. Drainage canal layout

4. RESULTS AND DISCUSSION

After analyzing the existing conditions, several points were noted that are unable to accommodate the flows. The analysis was then continued with the use of infiltration wells as a solution to overcome inundation. Infiltration wells were calculated only in housings that had an opened yard. Among the 3145 housings in the study area, there are 956 housings that had open yard for constructing infiltration wells. Figure 6 and Figure 7 show the inundation area for the first model and the third model.

After planning the application of infiltration wells in the study area, some areas sill remained lilely to be still an inundated. Table 1 shows the channel dimensions before and after normalization. Channel normalization is only done on the channel reaches that need to be normalized. Figure 8 and Figure 9 shows the inundation area for the second model and the fourth model. It can be seen that the application of infiltration wells is not enough to solve the problem of innundation, canals normalization is needed.

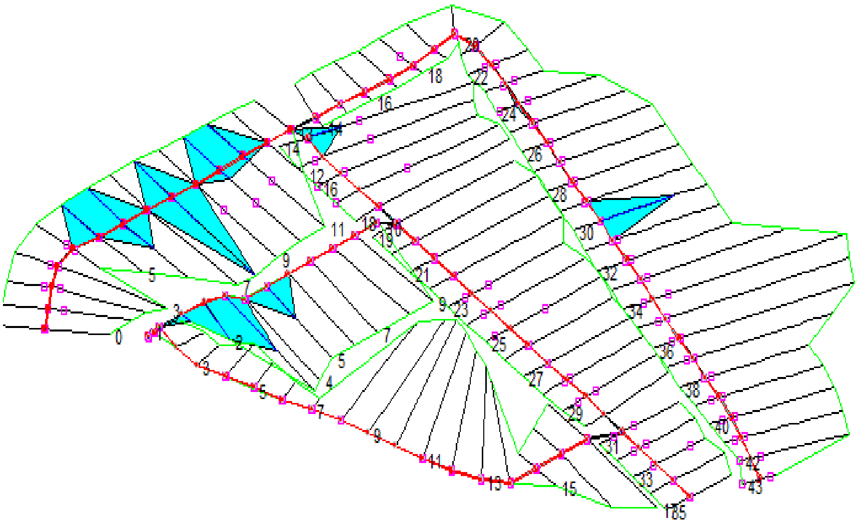

Figure 6. Inundation area that occurs on existing condition without infiltration wells

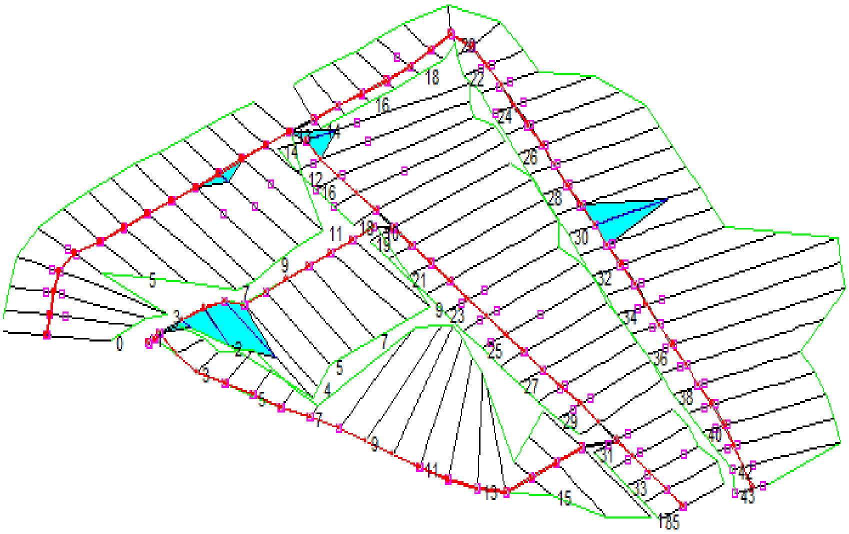

Figure 7. Inundation area that occurs on existing condition with infiltration wells

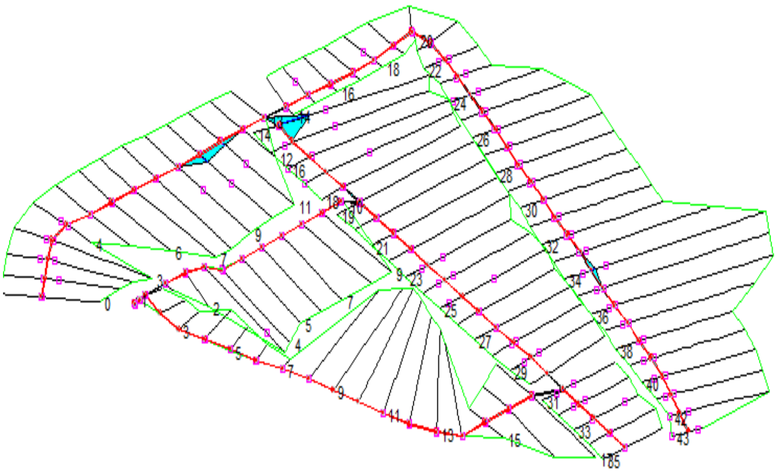

Figure 8. Inundation area that occurs after drainage channels normalization without infiltration wells

Table 1. Channel dimensions

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<tr><th>Before normalization</th><th colspan="2">After normalization</th></tr>
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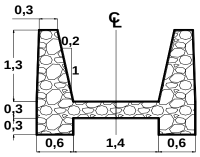
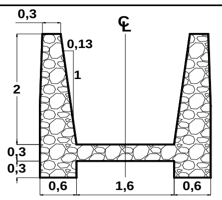
<td>
Reach: Kurao Pagang
S = 0,001 ; n = 0,017</td>
<td>
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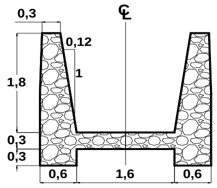
<td>
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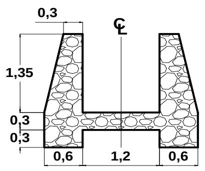
<td>
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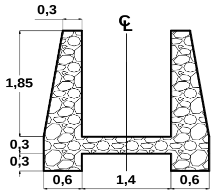
<td>
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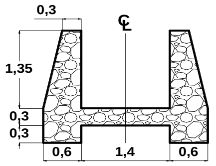
<td>
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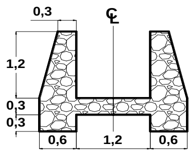
<td>
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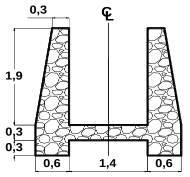
<td colspan="2">
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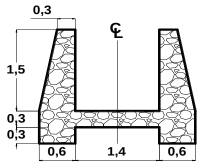
<td>
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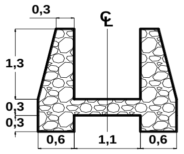
<td>
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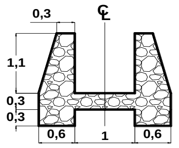
<td>
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S = 0,002 ; n = 0,017</td>
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The problem of flood in the area always considers the depth and duration of inundation. Analysis is continued to evaluate the flow rate and the water stage in some channel locations. The Kurao Hilir 13 river station was chosen to be a flow reference. Figure 10 shows the differences of water stages in several conditions and Figure 11 shows the differences of flow rates in several conditions.

The normalization of drainage canals will shorten the time of drainage, shorten the duration of inundation. This solution is normally favourable for people in the urban areas. Comparing the water level and the land level in that area, the depth and duration of inundation of existing system are 1.0 m and 5 hours consecutively. The normalization will reduce duration of inundation by 2 hours. But, in term of sustainable drainage system, retaining runoff water to allow the storm water to infiltrate to recharge the ground water is sugested.

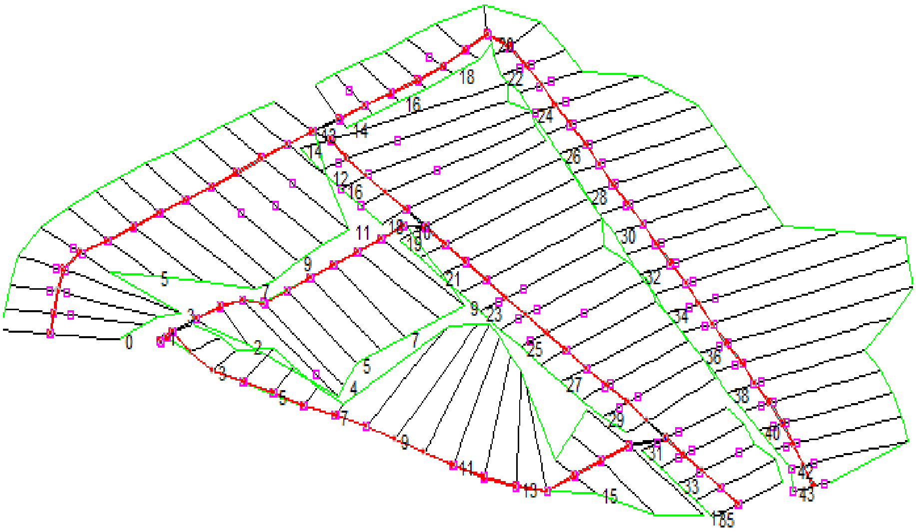

Figure 9. Inundation area that occurs after drainage channels normalization with infiltration wells

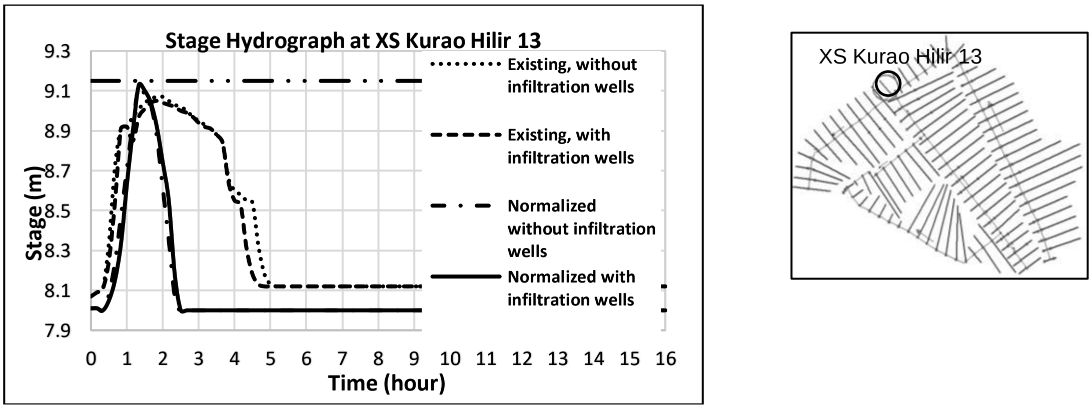

Figure 10. Differences of water stages in several conditions

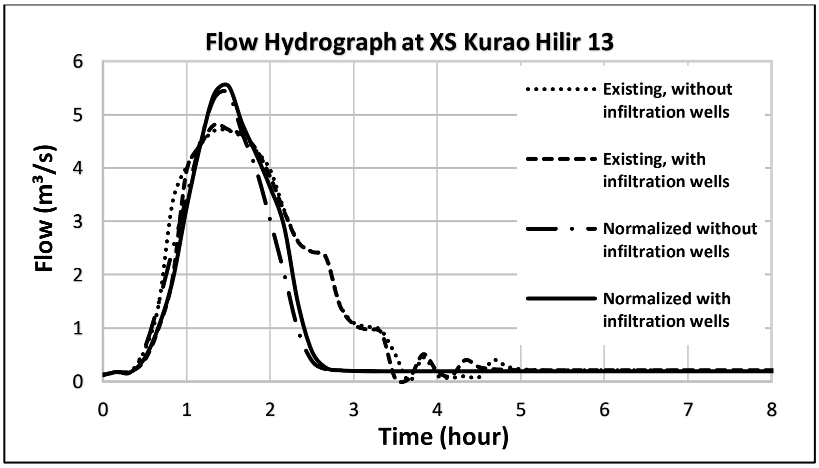

Figure 11. Differences of flow rates in several conditions

5. CONCLUSIONS

Urban areas with densely populated areas, such as city of Padang, require a drainage system that is not only capable of removing storm water, but also able to maintain the presence of fresh groundwater, to prevent saline water intrusion. The study area is planned to overcome an annual rainfall load of 25 years with a rainfall intensity of 100.66 mm/h with 1 hour duration of time concentration.

For groundwater recharge purposes, infiltration wells are needed. Its infiltration capability depends on the permeability of the soil and the volume of water entering the storage. The recommended number of infiltration wells depends on the extent of the recharge area covered by settlements. From 3145 housings in the study area, 956 housings that still have opened yard are planned for constructing infiltration wells. Infiltration wells are planned with dimensions of diameter 0.8 m and depth 2 m. During the filling of infiltration wells (approximately 1 hour) up to 40% of the runoff discharge will enter the infiltration wells, this volume of water is represented as a reduction in the volume of runoff water in the lateral inflow hydrograph.

Flow velocity through open channels is much greater than the speed of infiltration in infiltration wells, therefore to help reduce the duration of inundation, channel normalization is still needed. Widening the channels up to 0.2 m and deepening 0.5~0.7 m is enough to resolve the inundations. The 956 infitration wells may contribute ground water recharge of 960 m^3.

The results of this study are expected to be used as sugestion for the dissemination of the importance of environmentally sound drainage channels in the Siteba urban area.

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