

The difference of drainage channel dimensions at Kopelma Darussalam on the land with and without the use of Bio Pores

Alfiansyah Yulianur, Amir Fauzi and Zaitun Humaira

Civil Engineering Department, Faculty of Engineering, Syiah Kuala University,
Darussalam 23111, Banda Aceh, Indonesia

E-mail: fian_7anur@yahoo.com

Abstract. The changes of land use and diminishing of open field that persistently occur are projected to cause rates acceleration of runoff, which decreases the opportunity for rainwater to infiltrate. It has an impact on the surface runoff into the channels, which eventually may lead to overflow and inundate the surrounding area. Some efforts are required to increase the infiltration of rainfall. Thus, bio pore could be one of the most effective methods to be implemented. The objective of this study is to evaluate the effect of bio pore towards the reduction of runoff discharge into the drainage channel and to determine whether that reduction could lead to effectively lessen the channels' dimension. This study is commenced at Kopelma Darussalam in the southern part where there were several spots that submerged by inundation flood during the rainy season, namely *Sektor Timur* area. Rational modification formula is used to calculate the surface runoff discharge on the land without the use of bio pore. Meanwhile, runoff discharge on the land with the use of bio pores is calculated by the use of water balance formula. The number of bio pores that have planned in *Sektor Timur* area is 3350 bio pores with the diameter of each is Ø10 cm and 80 cm in depth. The result indicates that those bio pores can reduce the runoff discharge on average of 27% and its' reduction lead to the decrease of drainage channel dimension for the average of 26.9%.

1. Introduction

The major development of the cities in Indonesia today's lead to the intensification demand of land for infrastructure and residential area. Consequently, open land areas that functioned to absorb water during the rainy season are predicted to be diminished shortly. The area of Kopelma (Kota Pelajar dan Mahasiswa) Darussalam is particularly the region of Syiah Kuala University that located in Banda Aceh, is one of the locations that experiencing that case. The increasing numbers of faculties, departments as well as other academic buildings result in a land-use change from the open area to covered area. These are directly impacting the environment. As the rainy season comes, the water infiltration reduces that increases surface runoff discharge. Consequently, the drainage channel dimensions predicted will no longer enough to intercept the surface runoff and causing a flood to the surrounding areas. To avoid that, bio pore is one of the solutions to boost the infiltration of rainfall.

Base on those issues, this study is determined to find out the effect of bio pore toward the reduction of surface runoff discharge that goes into drainage channels. The study was designed in southern part of Kopelma Darussalam where there were several spots that experiencing inundation during the rainy season, for instance the area of *Sektor Timur*.

To achieve the objectives of this study, the methods used comprise of collected secondary data and analyze the data. The secondary data involved map of study area, data of precipitation, topographic



map, a map of land cover and use as well as data of infiltration rate on the area with and without the use of bio pore that obtained from the earlier studies by Yulia [1].

2. Literature Review

2.1. Bio pore

Biopore can intensify the ability of soil to pervade water [2]. It seeped through the wall of bio pores' surface then penetrated into the soil around the hole. Thus, it will boost water storage and prevent the surface runoff. Image of bio pore is shown in figure 1.

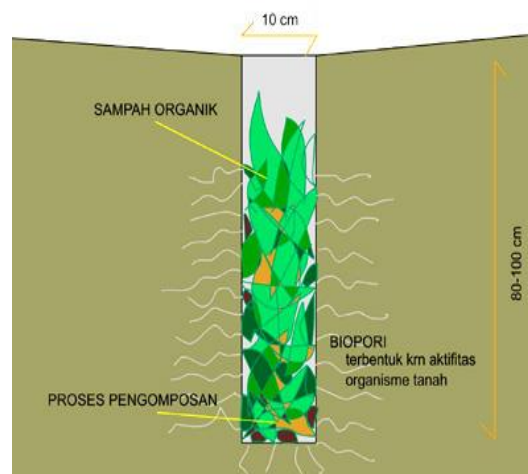


Figure 1. Bio pore

2.2. Urban Drainage

Land use change that continuously happened as an impact of the development of urban area could lead to the increment of surface runoff discharged and flood peak discharge [3]. The amount of surface runoff mostly determined by the pattern of land use that reflected by flow coefficient in the rational equation. The more rainfalls that flow to the drainage channel, the smaller water absorb to the soil. Consequently, it will cause flooding in the rainy season and the drought in the dry season.

2.3. Designed Rainfall

In hydrology, there were several probability distribution functions as listed below [4]:

- Normal and log normal distribution
- Gumbel distribution
- Log Pearson Type III distribution

There are two calibration tests that could be done to prove whether the selected distribution is appropriate with the data. Those calibration tests are Chi-quadrat test and Smirnov-Kolmogorov [5].

2.4. Time concentration

Time concentration of a watershed is the time required by the rainwater that falls to flow from the furthest point to the site of the watershed's output (control points). The formula of concentration time as given below as it is stated in [3]:

$$t_c = t_0 + t_d \quad (1)$$

2.5. Storage coefficient

According to [6], the effect of storage coefficient for the maximum flood is calculated by the equation of storage coefficient (C_s) as the following:

$$C_s = \frac{2t_c}{2t_c + t_d} \quad (2)$$

2.6. Runoff Coefficient

According to [3], if watershed consists of varies land cover use with different surface flow coefficient, C is used as the watershed coefficient as calculated by the equation below:

$$C_{DAS} = \frac{\sum_{i=1}^n C_i A_i}{\sum_{i=1}^n A_i} \quad (3)$$

2.7. Rainfall Intensity

The intensity of rainfall is a measurement of the amount of rain that falls over time. Rainfall intensity is calculated by Mononobe formula as given below [3]:

$$I = \frac{R_{24}}{24} \left(\frac{24}{t} \right)^{2/3} \quad (4)$$

2.8. Designed flood discharge

2.8.1. Rational modification method.

According to [3] the method for estimating flow rate peak that commonly used is Rational Method USSCS (1973). However, the application is limited to watersheds area less than 300 ha. Accordingly, rational modification formula as the following equation is mostly used in designing urban drainage, [6]:

$$Q = 0.2778 \cdot C \cdot C_s \cdot I \cdot A \quad (5)$$

2.8.2 *Water balance.* According to [7], in hydrology, the relationship between input (I), Output (Q) and storage (S) is represented by the following equation:

$$\frac{dS}{dt} = I - Q \quad (6)$$

2.9. Efficient cross-section channel

According to [8], efficient cross-section channel is a cross-section that has the smallest wet circumference with the maximum efficiency.

A discharge of cross-section channel for any random flow can be defined by the following equation:

$$Q_s = V \times A_s \quad (7)$$

3. Methodology

3.1. Study location

Location for this study is in Kopelma Darussalam, particularly in the southern part with a total area 1,040 km². The planned drainage network is obeying the slope of the existing channel condition planned by [9].

3.2. Data collection

3.2.1. Precipitation data

Precipitation data used was the annual maximum daily rainfall of 56 years record since 1958 to 2013. These records obtained from BMKG station in Blang Bintang, Aceh Besar, Indonesia.

3.2.2. Topographic map.

The topographic map used was collected by Planning Bureau of Unsyiah. This data is used to get the information pertaining drainage networking as well as the flow direction in the region of Kopelma Darussalam.

The topographic condition of Kopelma Darussalam is relatively flat. Thus, it needs more attention regarding the preservation of drainage system as efforts toward flood-detention.

3.2.3. Map of land cover and use.

Land use in an urban area is one of the parameters that caused surface runoff. Land cover and use map are used to determined flow coefficient (C). The map was collected by the office of regional planning and development in Banda Aceh.

3.2.4. Infiltration data.

Infiltration data used obtained by earlier studies [10]. This data shows in table 1 below:

Table 1. Infiltration data of the land with and without the use of biopore in sand and silt

f_c	Sand	Silt
f_c soil (mm/minute)	0,07	0,025
f_c grass (mm/minute)	0,09	0,033
f_c thatch (mm/minute)	0,1	0,042
f_c biopori (mm/minute)	8	1

3.3. Designed flood discharged

3.3.1. Determination of designed rainfall.

Rainfall distribution type determined by calculating the distributions such as normal and log normal distribution, Gumbel distribution, and log-Pearson type III distribution. The selection of rainfall distribution is evaluated by Smirnov-Kolmogorov test.

3.3.2. The calculation of designed rainfall.

Rainfall estimation is determined based on the selected distribution type. The designed rainfall based on return period of two years. This return period is specified for tertiary channel type that designed for watershed less than 5 ha.

3.3.3. The calculation of storage coefficient.

Storage coefficient is estimated after concentration time that is determined by equation 1. Then, storage coefficient is calculated by the equation 2.

3.3.4. Runoff coefficient.

Runoff coefficient in a specific area related to its land cover and use is calculated by equation 3.

3.3.5. Rainfall intensity estimation.

Rainfall intensity estimated by Mononobe Formula as given in the equation 4.

3.3.6. Bio pore.

The bio pore is planned to be $\varnothing 10$ cm in diameter and 80 cm in depth. These bio pores were dug on the land by an interval of 1 m to each other. Those determinations based on the reference, where the ideal diameter for bio pore is $\varnothing 10$ cm and the depth of bio pore is depended on the water table. The depth should not exceed the water table. Based on site observation, the suitable depth of bio pore to be planned in Kopelma Darussalam is 80 cm.

3.3.7. The estimation of designed flood discharge.

The estimation of designed flood discharge is calculated in two conditions. First, flood discharge on the land without the use of bio pore by rational modification formula as in Equation 5. Second, the flood discharge on the land with the use of bio pores by water balance formula as given in equation 6.

3.4. The calculation of drainage channel dimension

The calculation of drainage channel dimension is designed with efficient cross-section channel in the shape of rectangular. Designed freeboard for this study is 30% from the water depth in the designed condition. Image of efficient cross-section channel is shown in figure 2.

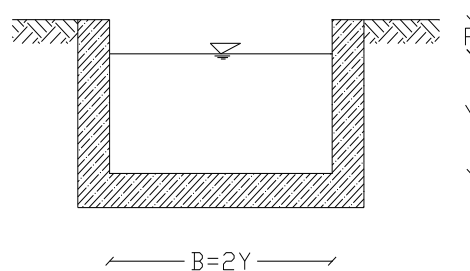


Figure 2. The efficient cross-section in the shape of rectangular.

The planned drainage channel is a tertiary channel and designed in two land conditions, with the use of bio pore and without the use of bio pore.

This study is redesigning the 13 tertiary channels with two outlets. Slope and elevation of the bottom channels for outlets are obeying the condition. Water elevation of Lamnyong river in the flood condition is projected save since it has been adapted to the condition designed by Sea Defense Consultant (SDC).

4. Result and discussion

The result and discussion involved the determination of rainfall distribution, the calculation of designed rainfall, storage coefficient, rainfall intensity, runoff coefficient, the determination of bio pore quantity, and the calculation of designed discharge as well as the calculation of dimension of drainage channel on the land with and without the use of bio pore.

4.1. Rainfall distribution

Statistical parameters used for the calculation are mean average ($\bar{x}$), standard deviation (Sd), an asymmetric coefficient (Cs), and variance coefficient (Cv). The calculation result of statistical parameters resumed on table 2.

Table 2. Statistical Parameters of Rainfall Distribution

Parameter	Result
Rainfall mean avg ($\bar{x}$)	111,998
Standard deviation (Sd)	40,724
asymmetric coefficient (Cs)	0,886
Varance Coefficient (Cv)	0,364
Cv3+3Cv	1,140

According to Table 2, a normal distribution is not fulfilled the rainfall distribution, since $Cs \neq 0$. It also does not match with log-normal distribution due to $Cs \neq 3Cv + Cv^3$. Rainfall distribution is estimated to supremely follow Gumbel distribution or log-Pearson type III distribution. Afterwards, Smirnov-Kolmogorov test is performed and results in $\alpha=0.05$ as well as $N=56$, and $D_0 = 0,18$. From the overall calculation, $D_{\max}=0.0481 < D_0$ is obtained. Meanwhile, Chi-Square testing found that $X^2 = 1.5 < X^2_{cr} = 9,488$. The result of both tests shows that rainfall distribution of BMKG Blang Bintang station is obeying Gumbel Distribution.

4.2. Designed rainfall

Designed rainfall is calculated based on the selected distribution, it was Gumbel distribution. According to the calculation, R_{24} for two return periods is 105.7 mm.

4.3. Storage coefficient

Storage coefficient is determined by equation 2 that the result for storage coefficient is as it shown in table 3.

Table 3. Calculation table of time concentration and storage coefficient

No	Channel	Td(hour)	Tc(hour)	Cs
1	1-2	0,091	0,220	0,829
2	2-3	0,055	0,205	0,883
3	4-5	0,098	0,211	0,812
4	4-6	0,121	0,268	0,816
5	5-7	0,101	0,312	0,861
6	6-7	0,122	0,319	0,840
7	8-9	0,214	0,533	0,833
8	8-10	0,075	0,562	0,938
9	11-12	0,155	0,242	0,758
10	11-13	0,124	0,355	0,851
11	12-14	0,115	0,333	0,853
12	13-14	0,152	0,237	0,757
13	15-16	0,047	0,360	0,939
14	15-18	0,206	0,330	0,762
15	17-18	0,141	0,502	0,876
16	20-36	0,199	0,434	0,813
17	19-21	0,182	0,253	0,735
18	19-36	0,013	0,301	0,978
19	20-21	0,151	0,590	0,886

4.4. Runoff coefficient

Considering watersheds have varies land cover and different flow coefficient, C is determined by the formula that shown in the equation 3.

In this study, the region of Kopelma Darussalam separated into six watersheds. The total area for each watershed is shown in table 4.

Table 4. Watershed total areas

Watershed	Area(m ²)	Area (km ²)
1	123751,165	0,124
2	39087,801	0,039
3	143982,232	0,144
4	113793,028	0,114
5	311870,508	0,312
6	307169,400	0,307
Total	1039654,134	1,040

The calculations of runoff coefficient thoroughly provided in table 5.

Table 5. Runoff coefficient calculation (C)

Watershed	C
1	0,499
2	0,497
3	0,267
4	0,324
5	0,510
6	0,526

4.5. Rainfall intensity

Rainfall intensity is affected by daily rainfall for 24 hours (R_{24}) and concentration time (T_c) in mm/hour. Rainfall intensity is calculated by Mononobe formula as given in Equation 4. Return period used is two years with designed rainfall 105.7 mm. The rainfall intensity that obtained is illustrated in table 6.

Table 6. Rainfall intensity calculation (I)

No	Channel	Intensity (mm/hour)
1	1-2	100.404
2	2-3	105.209
3	4-5	103.351
4	4-6	88.160
5	5-7	79.653
6	6-7	78.420
7	8-9	55.770
8	8-10	53.829
9	11-12	94.303
10	11-13	73.042
11	12-14	76.244
12	13-14	95.815
13	15-16	72.405
14	15-18	76.777
15	17-18	58.047
16	20-36	63.973
17	19-21	91.689
18	19-36	81.642
19	20-21	52.113

4.6. Bio pore

The number of bio pores determined based on the circumstances where it is dug. Bio pore could be placed around the tree, in the yard, close to the fence, and in other possible locations. In this study, bio pores are placed with 1 m distance for each bio pore.

Considering a case where watershed 1 is located in a dense residential area, the bio pores were placed in the yard with varies quantities depend on the yard space. For a house with a total yard ≥ 50 m², eight bio pores were placed. Meanwhile, for a house with <50 m² total area of the yard, four bio pores is placed. Overall, the first watershed has been installed by 966 bio pores in total.

The layout of bio pore allocation in watershed 1 is shown in figure 3. Subsequently, the number of bio pore in each watershed is given in table 7.

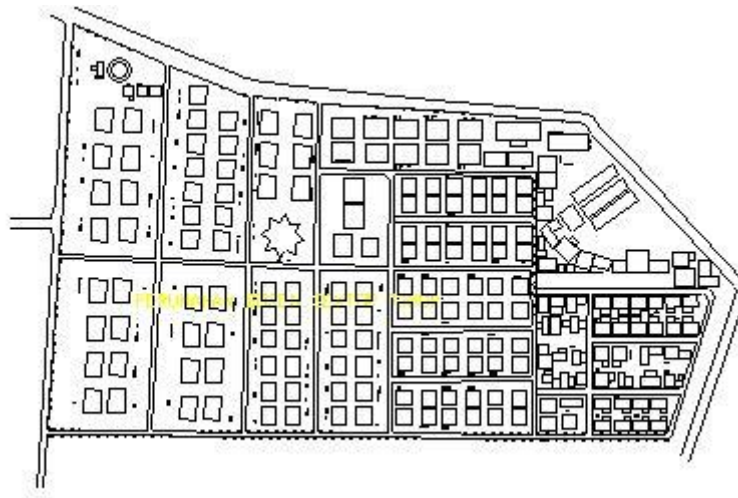


Figure 3. Layout of bio pore in watershed 1

Table 7. Number of bio pore in each watershed

Watershed	Number of bio pore	Bio pore spacious (m ²)
1	966	7,5831
2	188	1,4758
3	354	2,7789
4	388	3,0458
5	898	7,0493
6	556	4,3646
Total	3350	26,2975

4.7. Designed flood discharged

4.7.1. Designed flood discharge on the land without the use of bio pore.

Design Discharge on the land without the use of bio pore is calculated by rational modification as provided in Equation 5. For example, in the channel 2-3 with 0.0026 km² total area, surface runoff coefficient is 0.50, storage coefficient 0.883, and rainfall intensity is 105.4 mm/hour, so that:

$$Q_T = 0,278 \times 0,496519 \times 0,883 \times 105,4 \times 0,026$$

$$Q_T = 0,339 \text{ m}^3/\text{s}$$

Those design discharge also called inflow. The hydrograph of inflow discharge is shown in figure 4.

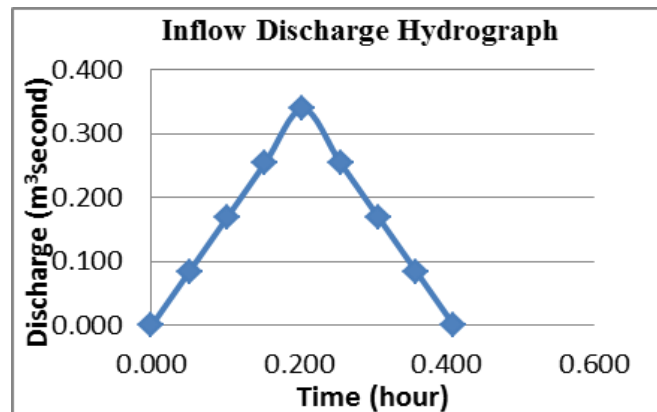


Figure 4. Inflow discharge hydrograph in channel 2-3

Figure 4 shows that time concentration is equal with rainfall duration, which is 0.205 hours.

4.7.2. Designed flood discharge on the land with the use of bio pores.

Design flood discharge on the land with the use of bio pores is calculated by water balance formula as shown in equation 6. For example, channel 2-3 has inflow discharge 0.339 m³/s with total 102 bio pores. The bio pore is 10 cm in diameter and 80 cm in depth. The type of soil in that area is sand with the magnitude of bio pore infiltration is 8mm/minute. Outflow discharge of channel 2-3 is provided in table 8. Furthermore, combination graph of inflow and outflows discharge is illustrated in figure 5.

Table 8. The Calculation of Outflow Discharge in Channel 2-3

No.	T (jam)	Inflow (m³/s)	Vol.I (m³)	Vol.fcibiopori (m³)	ΔS (m³)	Vol.Q (m³)	Q (m³/s)
1	0,00	0,00	0,00	0,00	0,64	0,00	0,00
2	0,05	0,08	7,81	19,69	0,64	0,00	0,00
3	0,10	0,17	23,45	19,69	0,00	3,11	0,03
4	0,15	0,25	39,09	19,69	0,00	19,39	0,17
5	0,20	0,33	54,75	19,69	0,00	35,05	0,20
6	0,25	0,25	54,75	19,69	0,00	35,05	0,17
7	0,30	0,17	39,09	19,69	0,00	19,39	0,03
8	0,35	0,08	23,45	19,69	0,00	3,75	0,00
9	0,41	0,00	7,81	19,69	0,64	0,00	0,00

Table 8 shows that the implementation of bio pore has decreased the designed flood discharge by 40%. It is further illustrated in figure 5.

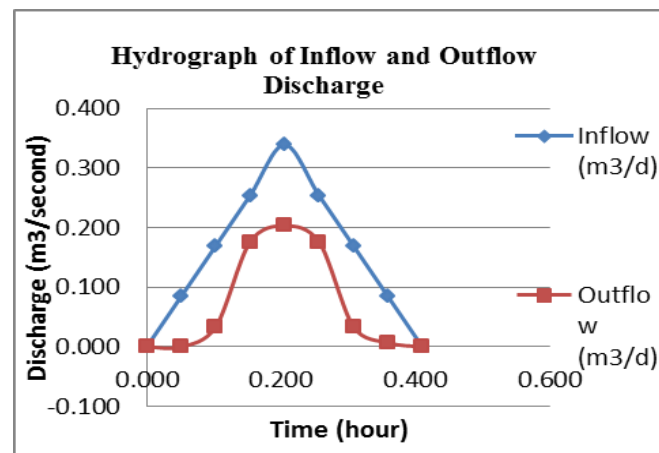


Figure 5. Inflow discharge hydrograph in channel 2-3

4.8. Channel dimension

4.8.1. Channel dimension on the land without the use of bio pores.

Manning coefficient for channel 2-3 is known 0.013, the velocity according to trial and error analysis for this channel is 0.813 m/s with slope 0.0008 (as the condition of existing channel by SDC). Then the calculation for channel dimension is:

$$V = \frac{1}{n} R^{2/3} S^{1/2}$$

$$Y = 2 \left(\frac{n \times v}{\sqrt{S}} \right)^{3/2}$$

$$Y = 2 \left(\frac{0,013 \times 0,813}{\sqrt{0,0008}} \right)^{3/2}$$

$$Y = 0,46 \text{ m}, \quad B = 2Y = 0,91 \text{ m}$$

$$F = 30\% Y = 0,14 \text{ m}$$

Afterwards, Q_s for channel 2-3 is obtained as 0.340 m³/s. It means that $Q_s = 0.340 \text{ m}^3/\text{s} \geq Q_T = 0,339 \text{ m}$ and dimension of drainage channel have met the requirement, where $Q_s \geq Q_T$.

4.8.2. Channel dimension on the land with the use of bio pores.

For channel 2-3, after the decrease of design discharge, the velocity is obtained as 0.716 m/s by trial and error analysis. Thus, the calculation for channel dimension is:

$$V = \frac{1}{n} R^{2/3} S^{1/2}$$

$$Y = 2 \left(\frac{n \times v}{\sqrt{S}} \right)^{3/2}$$

$$Y = 2 \left(\frac{0,013 \times 0,716}{\sqrt{0,0008}} \right)^{3/2}$$

$$Y = 0,38 \text{ m}, \quad B = 2Y = 0,76 \text{ m}$$

$$F = 30\% Y = 0,11 \text{ m}$$

Next, Q_S is calculated and obtained $Q_S = 0.204 \text{ m}^3/\text{s} \approx Q_T = 0,204 \text{ m}^3/\text{s}$. This dimension of drainage channel has met the requirement, where $Q_S \geq Q_T$.

The comparison of drainage channel dimension on the land with and without the use of bio pores have been summarized in table 9, while the comparison of channel discharge on the land with and without the use of bio pores is shown in table 10.

Table 9. The difference dimensions of the land with and without the use of bio pores

No	Channel	Height (Y)			Width (B)		
		Without Biopore (m)	Biopore (m)	Difference (%)	Without biopore (m)	Biopore (m)	Difference (%)
1	2-3	0,46	0,38	17,35	0,92	0,76	17,92
2	4-6	0,51	0,40	20,69	0,92	0,81	12,05
3	5-7	0,76	0,64	15,63	1,52	1,28	15,63
4	6-7	0,40	0,33	17,28	0,80	0,66	17,50
5	8-9	0,41	0,36	12,06	0,82	0,72	12,06
6	8-10	0,89	0,73	17,38	1,78	1,46	17,73
7	11-12	0,64	0,62	2,66	1,27	1,24	2,66
8	12-14	0,74	0,68	7,46	1,48	1,36	7,94
9	15-18	0,37	0,29	20,67	0,74	0,58	21,97
10	17-18	0,40	0,35	13,54	0,80	0,70	12,67
11	19-21	1,19	1,13	5,31	2,38	2,26	4,96
12	19-36	1,02	1,02	0,01	2,04	2,04	0,01
13	20-21	0,92	0,92	0,20	1,85	1,84	0,20

Table 10. The difference of discharge in the channel on the land with and without the use of bio pores

No	Channel	Qs (m3/s)		
		Without Biopore	Biopore	Difference (%)
1	2-3	0,340	0,204	39,958
2	4-6	0,497	0,267	46,190
3	5-7	1,323	0,841	36,448
4	6-7	0,245	0,148	39,774
5	8-9	0,252	0,179	29,019
6	8-10	2,107	1,266	39,898
7	11-12	0,873	0,812	6,949
8	12-14	1,284	1,045	18,647
9	15-18	0,208	0,112	46,070
10	17-18	0,247	0,167	32,160
11	19-21	4,537	3,923	13,529
12	19-36	3,075	3,074	0,027
13	20-21	2,416	2,403	0,535

According to table 9, the comparison of the dimension of drainage channel on the land with the use of bio pores is smaller than channel dimension on the land without the use of bio pores. The average reduction of height and width are 11.5% and 11.7%. Furthermore, table 10 reveals that there is averagely 26.9% reduction of channel capacity.

5. Summary and suggestion

5.1 Summary

- Bio pore can increase the infiltration of rainfall to the soil and decrease surface runoff.
- The reduction of surface runoff discharge proves that bio pore influences over the decrease in surface water discharge.
- The dimension of drainage channel on the land with the use of bio pore is smaller compared to the dimension of drainage channel on the land without the use of bio pore. The average difference for both height (Y) and width (B) is 11.5% and 11.7%. It also reduces the average of channel capacity by 26.9%.

5.2. Suggestion

According to result and summary of this study, there are some recommendations proposed as follows.

- To compare the dimensions of the existing channel with redesign channel, it would be better to use the real existing dimensions accordance with its conditions in the field.
- To decrease more surface runoff, bio pore can be added more densely ($50\text{ cm} < x < 100\text{ cm}$).

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