Impact of agricultural land-use change to the surface run-off: a case study of Cereng catchment area, Kulon Progo Regency, Special Region of Yogyakarta

L Erdinata¹, A G Pradipta¹*, N Ngadisih¹, C Setyawan¹ and F D Sartika¹
¹Department of Agricultural and Biosystems Engineering, Faculty of Agricultural Technology, Universitas Gadjah Mada, 1 Flora Street, Sleman, 55281 Special Region of Yogyakarta, Indonesia.

*Corresponding author: ansita.pradipta@ugm.ac.id

Abstract. Agricultural land-use changes can cause a reduction in the green open space area, thereby reducing infiltration and increase surface run-off. One of the phenomena in agricultural land-use changes as indicated by the addition of the percentage of irrigation paddy fields in Cereng Catchment Area (CA) by 2.31%, 2.94%, and 4.39%, respectively, in 1995, 2008, and 2018. Besides, the addition of the settlement area and the plantation area's reduction were also phenomena of land-use change. The impact of these changes is associated with curve number (CN) and direct run-off. The analysis conducted on the relationship between effective design rainfall and response to the land-use changes to produce direct run-off volume in 2, 5, 10, 20, and 50 years-return period, respectively, in 1995, 2008, and 2018 using the HEC-HMS model. The result showed that have addition to CN that were 81.85, 85.82, and 86.66, respectively, in 1995, 2008, and 2018. This addition caused an increase in the percentage of direct run-off volume from 1995 to 2018; those values were 24.28%, 16.8%, 13.76%, 11.61%, and 9.53%, respectively, at the 2, 5, 10, 20, and 50-years return period. The increase in the value of direct run-off volume causes a high possibility of a flood.

1. Introduction
Land-use change is the phenomenon of change in the land-use function that decreases other land-use types from different times [1]. The land-use change often causes a reduction of green open space, which can annoy the hydrologic cycle in an area because of the decrease of the infiltration rate. That can increase surface run-off, which causes the possibility of a flood.

Flood is the phenomenon of natural disasters that often happened in the rainy season in Indonesia. Flood identic with a high rainfall volume, so the areas must have green open space with a high water absorption power so that the rainfall in an area can absorb fastly. In the watershed area, that must have green open space in the part of upstream because the upstream function is keeping the hydrologic cycle or being water catchment and conservation area in that watershed [2]. In a watershed, also known downstream area, that is shown about the condition in upstream with the produced of surface run-off volume or flow.

Flood still has often happened in some areas in Indonesia. In March 2019, the flood occurred in some sub-regency in Kulon Progo regency, Special Region of Yogyakarta, there are Wates, Panjatan, Pengasih, and Temon. These areas are included in downstream of Serang Watershed. This flood is due
to the breakdown of the Serang River embankment, caused by the high intensity of rainfall in that area.

Cereng Catchment Area (CA), which has 21.229 km² total area, is the part of the upstream Serang Watershed, so that area becomes a water catchment area and conservation area in Serang Watershed. Based on administration, Cereng CA is located at three sub-regency, there are Girimulyo, Pengasih, and a small area of Kokap. The flood in March 2019 in the downstream of Serang Watershed possibility caused by the condition in upstream of Serang Watershed is not good enough.

The upstream of Serang Watershed affected about Yogyakarta International Airport development. Bambang Tri Budi, the head of the food and agriculture department in Kulon Progo Regency, said that airport development caused the program of new paddy fields area addition in some areas in Serang Watershed upstream from 2017 until 2022. This program’s purpose is anticipated to reduce paddy fields in Kulon Progo regency because of land-use change, which means Yogyakarta International Airport development. One of the new paddy fields area addition programs has been done in Sidomulyo village, Pengasih district, which is part Cereng CA downstream. That is the reason why this research was conducted in Cereng CA.

This research is focused on the hydrologic system in Cereng CA, which has some new paddy fields area addition. The analysis was conducted on the relationship between effective design rainfall and response to the land-use changes to produce direct run-off volume in the return period 2, 5, 10, 20, and 50 years in 1995, 2008, and 2018 using the HEC-HMS model. This research uses rainfall data as input on the hydrologic system in Cereng CA, while direct run-off volume as output. The value of direct run-off volume showed the possibility of a flood.

2. Methodology
Rainfall-runoff transformation is started with rainfall data analysis for specific years, which minimum of 20 data. That rainfall data must be done the homogeneity data test, that in this research use RAPS (Rescaled Adjusted Partial Sums) methods. RAPS method is one of the homogeneity data tests that is conducted to prove the rainfall data are homogeneous or not [3]. The rainfall station is determined before doing a homogeneity data test. To obtain the average rainfall area, it can use polygon Thiessen if the area has a minimum of three reference stations. Rainfall data analysis has been done until got the effective design rainfall distribution. That effective design rainfall distribution has been analyzed with SCS-Unit Hydrograph and SCS-CN (Curve Number) to obtained direct run-off volume (DRO) as run-off value.

2.1 Effective Design Rainfall Distribution
The design rainfall distribution was analyzed from the rainfall characteristic components, such as rainfall intensity (I), rainfall duration (T), rainfall depth (D), rainfall frequency (F), and rainfall area (A). These components produce IDF (Intensity-Duration-Frequency) curve, which uses for peak flow prediction based on rainfall data and generally divided into 2, 5, 10, 25, 50, and 100-years return periods [4].

\[ I = \frac{P_{24}}{24} \left[ \frac{24}{t} \right]^{2} \]  

where:
\[ I \] = rainfall intensity (mm/hours)
\[ t \] = rainfall duration (hours)
\[ P_{24} \] = maximum daily rainfall (during 24 hours) (mm)

In the effective design rainfall distribution, the other components are time concentration and lag time. Time concentration can be defined as the duration for rainfall to flow from the far point to the control point (downstream point), and lag time is the delayed time from effective rainfall [5]. The Australian Rainfall-Runoff method use as an equation to determine the magnitude of time concentration (2).

\[ t_c = 0.76 A^{0.38} \]
Where $A$ is a total watershed area ($\text{km}^2$).

### 2.2 SCS-Unit Hydrograph

Unit Hydrograph (UH) is a diagram that illustrates flow variation or water surface with the time. The main purpose of UH is for analyzed the flood controls [6]. There are two types of UH, which are measured and synthetic UH [7]. UH is affected by watershed physical characteristics and climate as rainfall, etc. That has a condition that is a watershed doesn’t have hydrologic data. So that has synthetic UH, which has analyzed with watershed characteristics and not with river flow, for generally such as total watershed area, river length, and slope [8].

\[
Q_p = C \frac{A}{T_p} 
\]

(4)

\[
T_p = \frac{t_r}{2} + t_p 
\]

(5)

where:

- $Q_p$ = peak flow ($\text{m}^3/\text{s}$)
- $A$ = total area ($\text{km}^2$)
- $T_p$ = time to peak (hours)
- $t_r$ = rainfall duration (hours)
- $t_p$ = lag time (hours), which can be determined with equation (3). If there for synthetic UH, that be determined with equation (6)

\[
t_p = \frac{L^{0.8} \cdot (S+1)^{0.7}}{1500 \cdot Y^{0.8}}
\]

(6)

which $L$ is main river length (mm), $S$ is potensial maximum retention, and $Y$ is river slope (%).

For UH, there are have discharge volume and baseflow volume. The addition of river volume can determine discharge volume, and baseflow volume is usually separated with discharge volume to determine direct run-off, which later uses to illustrate UH. The Baseflow model can be illustrated with an exponential Equation [9].

\[
Q_t = Q_o \cdot k^t
\]

(7)

where:

- $Q_t$ = baseflow in “t” time ($\text{m}^3/\text{s}$)
- $Q_o$ = initial flow ($\text{m}^3/\text{s}$), when $t = 0$
- $k$ = recession constant

### 3.3 SCS-Curve Number

Soil have the rainfall retention potential ($S$), and then divided into three phenomena. There are surface runoff ($Q$), infiltration ($I$), and initial abstraction ($I_a$) [10].

\[
Q = \frac{(P-I_a)^2}{(P-I_a+S)}
\]

(8)

\[
I_a = 0.2 \times S
\]

(9)

\[
S = 25.4 \times \left(\frac{1000}{CN} - 10\right)
\]

(10)

where:

- $Q$ = surface run-off volume (mm or $\text{m}^3$)
- $I_a$ = initial abstraction (mm)
- $P$ = daily rainfall (mm)
- $S$ = retention potential or run-off storage volume (mm)
- $CN$ = curve number
Curve Number (CN) can be defined as the function of physical characteristics from the watershed. These characteristics, such as soil texture, soil moisture, covering crop, and land-use [11]. The range value of CN is 0 until 100. CN is illustrated run-off potential, and then a watershed area has shown the high value of CN so that area has significant run-off potential. The United States Department of Agriculture (USDA) gives several CN that can be used for reference [12].

![Figure 1](image1.png)

**Figure 1.** Cereng CA Boundary Map on Several Watershed

![Figure 2](image2.png)

**Figure 2.** (a) Cereng CA control points (downstream) position; (b) River condition on Cereng CA downstream; (c) Surrounding condition near the downstream river on Cereng CA
3. Results and Discussion
There is some number of analysis in order to determine direct run-off volume (DRO). The analysis started with rainfall analysis until got effective design rainfall distribution. These distributions analyzed with SCS-Unit Hydrograph and SCS-Curve Number to get DRO value, which for this research using the HEC-HMS model. This process is called the rainfall-runoff transformation.

3.1. Effective Design Rainfall Distribution
Rainfall analysis in Cereng CA are using three references station, and there are Kenteng, Borrow Area, and Plaosan station. Rainfall data from their station are available just until 2016, which from Kenteng Station is available from 1985-2016, while Borrow Area and Plaosan Station are available from 2010-2016. So, rainfall analysis in Cereng CA from 1985-2009 uses rainfall data from the Kenteng Station and 2010-2016 using polygon Thiessen methods. These rainfall data are analyzed until got effective design rainfall distribution at last.

In the effective design rainfall distribution, the components are time concentration, rainfall intensity, and rainfall distribution. There analyzed on each 2, 5, 10, 20, and 50-years return period. Time concentration can be determined from Equation (2), and that value is 2.4 hours ≈ 3 hours. The effective design rainfall distribution in this research is correct because the total rainfall distribution value from each return period is the same with the frequency analysis distribution value, which uses Log Pearson III distribution with the Smirnov-Kolmogorov test. The result of effective design rainfall distribution for each return period has shown in Table 1-5.
Table 1. Effective Design Rainfall Distribution for 2 year-return period

| Time (hours) | Rainfall Intensity (mm/hours) | Rainfall Cumulative (mm) | Hourly rainfall (mm) | Rainfall Distribution (mm) | % | Rainfall Distribution for 2 years (mm) |
|--------------|------------------------------|--------------------------|----------------------|---------------------------|---|----------------------------------------|
| t            | \( P \)                      | \( P_{\text{cum}} \)     | \( P_{\text{hours}} \) | \( P_{\text{distribution}} \) |   | \( P_{\text{2-year distribution}} \) |
| 1            | 28.710                       | 28.710                   | 28.710               | 5.235                     | 12.642 | 10.469                                |
| 2            | 18.086                       | 36.173                   | 7.462                | 28.710                    | 69.336 | 57.421                                |
| 3            | 13.803                       | 41.408                   | 5.235                | 7.462                     | 18.022 | 14.925                                |
| Total        | 41.408                       |                          |                      |                           | 100 | 82.815                                |

Table 2. Effective Design Rainfall Distribution for 5 year-return period

| Time (hours) | Rainfall Intensity (mm/hours) | Rainfall Cumulative (mm) | Hourly rainfall (mm) | Rainfall Distribution (mm) | % | Rainfall Distribution for 5 years (mm) |
|--------------|------------------------------|--------------------------|----------------------|---------------------------|---|----------------------------------------|
| \( T \)     | \( P \)                      | \( P_{\text{cum}} \)     | \( P_{\text{hours}} \) | \( P_{\text{distribution}} \) |   | \( P_{\text{5-year distribution}} \) |
| 1            | 41.844                       | 41.844                   | 41.844               | 7.629                     | 12.642 | 15.259                                |
| 2            | 26.360                       | 52.720                   | 10.876               | 41.844                    | 69.336 | 83.688                                |
| 3            | 20.117                       | 60.350                   | 7.629                | 10.876                    | 18.022 | 21.752                                |
| Total        | 60.350                       |                          |                      |                           | 100 | 120.699                               |

Table 3. Effective Design Rainfall Distribution for 10 year-return period

| Time (hours) | Rainfall Intensity (mm/hours) | Rainfall Cumulative (mm) | Hourly rainfall (mm) | Rainfall Distribution (mm) | % | Rainfall Distribution for 10 years (mm) |
|--------------|------------------------------|--------------------------|----------------------|---------------------------|---|----------------------------------------|
| \( t \)     | \( P \)                      | \( P_{\text{cum}} \)     | \( P_{\text{hours}} \) | \( P_{\text{distribution}} \) |   | \( P_{\text{10-year distribution}} \) |
| 1            | 51.453                       | 51.453                   | 51.453               | 9.381                     | 12.642 | 18.763                                |
| 2            | 32.413                       | 64.827                   | 13.374               | 51.453                    | 69.336 | 102.906                               |
| 3            | 24.736                       | 74.208                   | 9.381                | 13.374                    | 18.022 | 26.747                                |
| Total        | 74.208                       |                          |                      |                           | 100 | 148.416                               |

Table 4. Effective Design Rainfall Distribution for 20 year-return period

| Time (hours) | Rainfall Intensity (mm/hours) | Rainfall Cumulative (mm) | Hourly rainfall (mm) | Rainfall Distribution (mm) | % | Rainfall Distribution for 20 years (mm) |
|--------------|------------------------------|--------------------------|----------------------|---------------------------|---|----------------------------------------|
| \( t \)     | \( P \)                      | \( P_{\text{cum}} \)     | \( P_{\text{hours}} \) | \( P_{\text{distribution}} \) |   | \( P_{\text{20-year distribution}} \) |
| 1            | 61.348                       | 61.348                   | 61.348               | 11.185                    | 12.642 | 22.371                                |
| 2            | 38.647                       | 77.294                   | 15.946               | 61.348                    | 69.336 | 122.696                               |
| 3            | 29.493                       | 88.479                   | 11.185               | 15.946                    | 18.022 | 31.891                                |
| Total        | 88.479                       |                          |                      |                           | 100 | 176.958                               |
Table 5. Effective Design Rainfall Distribution for 50 year-return period

| Time (hours) | Rainfall Intensity (mm/hours) | Rainfall Cumulative (mm) | Hourly rainfall (mm) | Rainfall Distribution (mm) | % | Rainfall Distribution for 50 years (mm) |
|--------------|-------------------------------|-------------------------|---------------------|----------------------------|---|---------------------------------------|
| t            | P                             | P cum                   | P hours             | P distribution             |   | P 5th-year distribution               |
| 1            | 75.206                        | 75.206                  | 75.206              | 13.712                     | 12.642 | 27.424                               |
| 2            | 47.377                        | 94.753                  | 19.548              | 75.206                     | 69.336 | 150.412                              |
| 3            | 36.155                        | 108.466                 | 13.712              | 19.548                     | 18.022 | 39.095                               |
| Total        | 108.466                       | 100                     | 216.931             |                            |     |                                       |

3.2. SCS-Curve Number (CN)

Physical characteristics of Cereng CA are identified with the curve number (CN) method. CN is affected by several factors, such as soil texture and land-use type. Soil texture on Cereng CA based on texture laboratory test is included in clay type. This soil type characteristics have very low infiltration rate and high run-off potential, based on The United States Department of Agriculture (USDA) technical release 55. Furthermore, using the land use map (Figure 3), CN table, and soil texture, it can be obtained the amount of CN composite for Cereng CA in 1995, 2008, and 2018, respectively, as shown in Table 6. After got the amount of CN composite, it can be obtained the la and 5 values that can be seen in Table 7.

From table 6, it can be seen that the amount of composite CN for Cereng CA is increased each year. This addition is caused by many aspects, that one of them is affected by the addition of irrigation paddy fields area each year. Paddy fields have a hardpan layer, which that caused the water welled up on the paddy field surface. Therefore, paddy fields tend to increase surface run-off potential [13]. The addition of irrigation paddy fields is not balancing with green open space’s addition too. Besides increasing irrigation paddy fields, the addition of settlement area and the reduction of plantation area in 1995, 2008, and 2018 were also phenomena of land-use change in the Cereng CA.

Table 6. Calculation of composite CN for Cereng CA

| Land-use type            | 1995  | 2008  | 2008  |
|--------------------------|-------|-------|-------|
|                          | Area (%) | Curve Number | Curve Number | Area (%) | Curve Number | Area (%) | Curve Number | Area (%) | Curve Number | Area (%) |
|                          | A | CN | CN x A | A | CN | CN x A | A | CN | CN x A | A | CN | CN x A |
| Irrigation paddy fields  | 2.31 | 84 | 194.04 | 2.9 | 84 | 246.96 | 4.4 | 84 | 368.76 |
| Rain paddy fields        | 0.95 | 84 | 79.80 | 0.8 | 84 | 66.36 | 0.2 | 84 | 12.6   |
| Fields                   | 33.7 | 83 | 2792.95 | 45 | 83 | 3695.9 | 9 | 19 | 1601.0 |
| Settlement               | 11  | 92 | 1014.76 | 39 | 92 | 3603.6 | 4 | 27 | 2448.1 |
| Bush                     | 1.62 | 73 | 118.26 | 4 | 73 | 290.54 | 0.3 | 73 | 24.09 |
| Plantation               | 50.4 | 79 | 3984.76 | 8.6 | 79 | 678.61 | 49 | 79 | 4233.7 |
| Total                    | 100 |  | 8184.57 | 100 |  | 8582.1 | 100 |  | 8688.4 |
| Composite CN ((CN×A)/100)| 81.85 | 85.82 | 86.88 |
### Table 7. Calculation of $I_a$ and $S$

| Year | Curve Number $CN$ | Retention potential $S$ (mm) | Initial abstraction $I_a$ (mm) |
|------|------------------|-------------------------------|-------------------------------|
| 1995 | 81.85            | 56.325                        | 11.265                        |
| 2008 | 85.82            | 41.97                         | 8.394                         |
| 2018 | 86.88            | 38.355                        | 7.671                         |

### 3.3. SCS Unit-Hydrograph

Unit Hydrograph analysis for this research is using the HEC-HMS model. The purpose of this analysis to produce a direct run-off volume (DRO) value. As input for this model is designed rainfall distribution and curve number as Cereng CA physical characteristics. On the other hand, there are $I_a$, $S$, and time lag ($tp$), which are also included in this model's input. The value of $tp$ is 1.8 that determined based on Equation (3).

Furthermore, the input is processing in this model. The results of this process are DRO volume for 2, 5, 10, 20, and 50-year return period for 1995, 2008, and 2018 as shown in Table 8. It can be seen that DRO volume is increasing when the curve number is either (Figure 4). Moreover, other results are produced peak discharge that can be seen in Table 9, and the baseflow volume that is known from this process is assumed stagnant 6.1 MM.

### Table 8. DRO Volume on Cereng CA

| Year | $CN$ | Direct Run-Off Volume (MM) |
|------|------|-----------------------------|
|      |      | 2 year | 5 year | 10 year | 20 year | 50 year |
| 1995 | 81.85| 40.03  | 72.25  | 97.23   | 123.66  | 161.45  |
| 2008 | 85.82| 47.59  | 81.75  | 107.74  | 134.97  | 173.6   |
| 2018 | 86.88| 49.75  | 84.39  | 110.61  | 138.02  | 176.84  |

### Table 9. DRO Volume Addition (%) on Cereng CA

| Return Period | DRO volume addition (%) |
|---------------|-------------------------|
| 1995 to 2008  | 2008 to 2018 | 1995 to 2018 |
| 2 year        | 18.89       | 4.54         | 24.28    |
| 5 year        | 13.15       | 3.23         | 16.8     |
| 10 year       | 10.81       | 2.66         | 13.76    |
| 20 year       | 9.15        | 2.26         | 11.61    |
| 50 year       | 7.53        | 1.87         | 9.53     |

### Table 10. Peak Discharge on Cereng CA

| Year | Peak Discharge (m³/s) |
|------|-----------------------|
|      | 2 year | 5 year | 10 year | 20 year | 50 year |
| 1995 | 128.4  | 237.1  | 321.5   | 410.8   | 538     |
| 2008 | 156.5  | 272.1  | 359.7   | 451.1   | 580.3   |
| 2018 | 164.6  | 281.6  | 369.9   | 461.8   | 591.2   |
4. Conclusion
This research was discussed about the impact of the land-use change on the surface run-off in Cereng CA. One of the land-use change phenomena in Cereng CA was indicated by the addition of irrigation paddy fields area on the downstream of Cereng CA from 1995 until 2018. This phenomenon causes the addition of a composite curve number (CN), in which the value was 81.85, 85.82, and 86.88, respectively, in 1995, 2008, and 2018. This addition causes an increase in direct run-off (DRO) volume as the surface run-off from 1995 to 2018, that value are 24.28%, 16.8%, 13.76%, 11.61%, and 9.53%, respectively, on 2, 5, 10, 20, and 50-year return period. So, the agricultural land-use change can cause the addition of composite CN, which causes an increase in DRO volume on Cereng CA. The high value of DRO volume can cause a high possibility of a flood.

References
[1] Eko T and Rahayu S 2012 Perubahan Penggunaan Lahan dan Kesesuaian terhadap RDTR di Wilayah Sub-Urban Studi Kasus: Kecamatan Mlati J. Pembang. Wil. Kota 8 330–340 (doi: 10.14710/pwk.v8i4.6487).
[2] Anonim 2010 Kajian Model Pengelolaan Daerah Aliran Sungai (DAS) Terpadu Direktorat Kehutanan dan Konserv. Sumberd. Air 5 1–19.
[3] Djafar H, Limantara L M, and Asmaranto R 2014 Berdasarkan Evaluasi Perbandingan Antara Analisa Hidrograf Banjir Dan Banjir Historis J. Tek. Pengair. 5 172–181.
[4] Fasdarsyah 2014 Analisis Curah Hujan Untuk Membuat Kurva Intensity-Duration-Frequency (IDF) Di Kawasan Kota LhokSeumawe Teras 4 22–30 (doi: 10.22219/jmts.v11i1.2824).
[5] Gunawan G 2017 Analisis Data Hidrologi Sungai Air Bengkulu Menggunakan Metode Statistik J. Inersia 9 47–58 (doi: 10.33369/jits.9.1.47-58).
[6] Agus I and Hadihardaja I K 2011 Perbandingan Hidrograf Satuan Teoritis Terhadap Hidrograf Satuan Observasi DAS Ciliwung Hulu J. Tek. Sipil 18 55–70 (doi: 10.5614/jts.2011.18.1.5).
[7] Pradipta A G and Nurhady S 2019 The representative synthetic unit hydrograph in Juana watershed IOP Conf. Ser. Earth Environ. Sci. 355(2019)1 (doi: 10.1088/1755-1315/355/1/012023).
[8] Nugroho S P 2001 Analisis Hidrograf Satuan Sintetik Metode Snyder, Clark dan SCS Dengan Menggunakan Model HEC-1 di DAS Ciliwung Hulu Sains Teknol. Modif. Cuaca 2 57–67.
[9] US Army Corps of Engineers Hydrologic Engineering Center 2000 Hydrologic Modeling System HEC-HMS: Technical Reference Manual. (California: Davis).
[10] Ideawati L F, Limantara L M, and Andawayanti U 2015 Analisis Perubahan Bilangan Kurva
Aliran Permukaan (Runoff Curve Number) Terhadap Debit Banjir Di DAS Lesti J. Tek. Pengair. 6 37–45

[11] Kartikawati T D, Andawayanti U, and Limantara L M 2016 Analisis Perubahan Bilangan Kurva Aliran Permukaan (RunOff Curve Number) Terhadap Debit Limpasan Pada DAS Brantas Hulu Tek. Pengair. 7 150–159.

[12] USDA 1986 Urban Hidrology for Small Watersheds (Technical Release-55) (Washington DC: USDA).

[13] Purnama I S 2004 Infiltrasi Tanah Kecamatan Nguter Kabupaten Sukoharjo, Propinsi Jawa Tengah Majalah Geografi Indonesia 18 013

Acknowledgment
The writers would like to thank the Faculty of Agricultural Technology, Gadjah Mada University, who gives this financial research support via an innovative grant scheme in 2019