Using HEC-RAS for analysis of flood characteristic in Ciliwung River, Indonesia

Moh Sholichin\textsuperscript{1,2}, T B Prayogo\textsuperscript{1} and M Bisri\textsuperscript{1}
\textsuperscript{1}Water Resources Engineering, Brawijaya University, Indonesia
E-mail: mochsholichin@ub.ac.id

Abstract. Jakarta is a large city with a population of around 10 million who still suffer flooding during the rainy season. A program that is being implemented to reduce flooding that occurs every year is called “Total Solution for Ciliwung”. One of the programs is to build 3 (three) diversion channels on the Ciliwung River located in Kalibata, Kebon Baru, and Kampung Melayu respectively. This paper only discusses the problem of flooding in Jakarta in the aspect of hydraulics. This research was conducted with the aim of analyzing the character of floods in the Ciliwung River based on variations in the choice of diversion channel locations. Analysis of flood characteristics using the HEC-RAS 4.1 Program. The results of the analysis provide conclusions, that variation 7 (seven) provides the most optimal reduction in flooding. The main result is, the water level profile in point 260, the water flow is sub-critical which the water level at +18.50 m or decreases by 0.5 m from the existing condition at +19.00 m. While the inundation area become of 2,414 km\textsuperscript{2} is reduced by 0.60 km\textsuperscript{2} or by 20% from the existing condition 3,018 km\textsuperscript{2}.

1. Introduction
Jakarta, the capital city of Indonesia, suffers from regular floods that cause significant environmental and economic damage. The city is prone to flooding, not only because of precipitation, but also as a result of soil subsidence, increasing sea level, and natural \cite{1}. Over the past two decades, Jakarta was hit by major floods in 1996, 2002, 2007, and 2013. The 2007 flood was regarded as a national disaster, which caused a total loss of US$ 565 million. The residential sector suffered most with 74% of total losses \cite{2}. The ability to conduct flood damage assessments is the main key in developing a mitigation policy to reduce flood damage that is expected to occur \cite{3}. Therefore, accurate flood damage assessment is very important as part of efficient flood risk management \cite{4}.

One of the causes of flooding that occurred in central Jakarta was the overflow of water from the Ciliwung River because the capacity of the river was unable to pass the flowrate from upstream to downstream. The narrowing of the capacity of the Ciliwung river is due to sedimentation and the construction of settlements on uncontrolled riverbanks. While the increase in flow rate occurs because of changes in land use that increase the runoff coefficient.

The Central Office of the Ciliwung Cisadane River Region has a program for handling floods in Jakarta which is named Total Solution for Ciliwung. There are 9 activities planned in Total Solution and one of them is the Ciliwung River Basin which is planned in the Kebon Baru and Kalibata areas. The planned spatial location has been regulated in Governor Regulation No. 44 of 2010. The aim of the plan is to shorten the distance to the estuary, which means short cutting flow time from upstream to downstream.

The morphology of the Ciliwung river which is meandering with a high meandering level with a
low slope of the riverbed is very potential to cause flooding. This study focuses on discussing the hydrological aspects of the Ciliwung river flow. The aim of the study was to know the characteristics of flooding in the Ciliwung River by observing changes in the water level due to some alternative patterns of placement of the diversion channel.

2. Materials and method

2.1. Study area
This research was conducted on the Ciliwung river which is the largest river that passes through the city of Jakarta (figure 1). Detail location that was discussion in this study is limited to 3 (three) locations of divers channel in middle of Ciliwung River section (figure 2).

![Figure 1. Location of study Ciliwung River in Jakarta City.](image1)

![Figure 2. Detail location of study case in middle section of Ciliwung River.](image2)

2.2. Method of study

2.2.1. HEC-RAS. HEC-RAS is a hydraulic model designed by the US Corporation Engineers Hydraulic Engineering Centre to model river flow [5]. It is a well-established and well-tested model globally and sometimes used as benchmarked against the performance of other hydrodynamic model simulation software [5]. HEC-RAS allows users to estimate water surface profile along a river in a steady and unsteady flow river hydraulic calculation including sediment transport modelling. Energy and momentum equation (equations (1) and (2)) are used to derive 1D Saint Venant equation in solving steady and unsteady state flow water surface profile simulation within HEC-RAS using implicit finite different method [6,7].

This study uses a two-dimensional numerical model simulation using the HEC-RAS 4.1.0 auxiliary program. The scope of activities in this study are as follows:
- Secondary data collection in the form of:
  - Water level data recorder from the AWLR (Automatic Water Level Recorder) recorder.
  - Geometry data, the longitudinal and cross section data of the Ciliwung River.
  - Contour data for the land around the Ciliwung River as study area.
- Analysis of design discharge

The design discharge analysis uses a more or equal to the maximum flood return period in the Hydrological data series from 2004-2013 year. the Log Pearson Type III used to analysis distribution discharge [8].
\[ \log X_T = \log \bar{X} + (G \cdot S) \]  

Where \( X_T \): Design Discharge with a \( (T) \) year return, \( \log \bar{X} \): Average value, \( S \): Standard deviation, \( G \): Factor properties of Type III Logson distribution which price depends on the asymmetry value \( (C_s) \) and return period \( (T) \).

- Calibration.
  Calibration uses the RMSE method (Root Mean Square Error). Calibration is done by adjusting the river water level at the end of the simulation compared to the actual conditions of the survey recorded in AWLR (point 174). HEC-RAS is in accordance with the actual conditions Adjustment is done by changing the value of the Manning coefficient \( (n) \) to the allowable Manning coefficient value [9]. Mannings coefficient \( n \) varied with a flow parameter that was the product of the velocity \( V \) and flow depth \( D \). For application to all shapes of channel \( D \) could be replaced with the hydraulic mean depth \( R \) [9, table 1]

### Table 1. Manning Coefficient (n).

| Channel Type                                      | Minimum | Maximum |
|--------------------------------------------------|---------|---------|
| Large channel (upper width at flood level> 100 feet (30 m). N value is smaller than small channel with details: |         |         |
| a. Irregular cross section without large stones or thickets | 0.025   | 0.060   |
| b. Irregular and rough cross section              | 0.035   | 0.100   |

Source: Chow, 1992 [9]

- Determination of Inlet and outlet for diversion channels
  Determination of inlet and outlet diversion channels based on the existing analysis of the Ciliwung River. Determination of inlet and outlet diversion channels is determined based on the theory of flow behavior by considering such are: Reduction in flow length, value of a river bend and slope of the river bed.

- Analysis of profile water level
  This analysis is carried out to determine the profile water level that occur from modeling the position variation variation. Simulation uses the HEC-RAS 4.1.0 program. Simulation is done by varying the position of the diversion channel location. There are 7 variations in the position of the location of diversion channel to be carried out, namely:
  - Variation 1: in Kalibata.
  - Variation 2: in Kebon Baru.
  - Variation 3: in Kampung Melayu
  - Variation 4: in Kalibata and Kebon Baru.
  - Variation 5: in Kalibata and Kampung Melayu
  - Variation 6: in Kebon Baru and Kampung Melayu.
  - Variation 7: in Kalibata, Kebon Baru, and Kampung Melayu.

  The profile of the water level will change depending on water and whether the ratio of normal depth to the depth of flow \( (y_n/y) \) and comparison of depth of criticism with flow depth \( (y_c/y) \) is greater than one (Triatmodjo Bambang, 2013). The base slope can be negative, zero and positive. Negative slope is called back slope \( (I_o < 0) \) which is given symbol A (adverse slope). Negative slope occurs when the channel base elevation increases in the direction of flow. The base slope of the channel is zero if the channel base is horizontal \( (I_o = 0) \) and given the symbol H (horizontal). While the positive slope is called a directional slope which is differentiated into a mild given a symbol M, criticism (critical) is given the symbol C, and steep (steep) is given the symbol S.

- M curve (mild)
  The M curve occurs when \( I_o < I_c \) and \( y_n > y_c \). The M curve is divided into 3 profiles, namely \( M_1 \), \( M_2 \), and \( M_3 \).
  - \( M_1 \) water level profile if \( y > y_n > y_c \).
  - \( M_2 \) water level profile if \( y_n > y > y_c \).
  - \( M_3 \) water level profile if \( y > y_c \).
M3 water level profile if \( y_n > y_c > y \).

- C Curve (critical)
  
  C curve occurs when \( I_0 = I_c \) and \( y_n = y_c \). Because the normal and critical depth lines coincide, there are only two profiles, profiles C1 and C3.

- S Curve (steep)
  
  The S curve occurs when \( I_0 > I_c \) and \( y_n < y_c \). There are 3 types of S curves, namely profiles of S1, S2, and S3.

2.2.2. Analysis of flood inundation area. The data carried out to carry out the simulation is the flood water elevation that occurs from the simulation results of water level profile simulation. Simulations for inundation analysis were carried out 7 times according to the number of variations in the position of the diversion channel such as in the analysis of water level profiles.

3. Results and discussion

3.1. Result of hydrological data

Based on the annual hydrological data series, calculations are carried out by using the HEC-RAS 4.1.0 auxiliary program to obtain water level and water level profile. From table 2, it can be seen that the water level in Point 174 (AWLR point) in 2013 of +15.04 m represents the largest water level compared to other years of occurrence. This is because the flood discharge that occurred in 2013 was the biggest event discharge.

| Years | Water Level (m) | Years | Water Level (m) |
|-------|----------------|-------|----------------|
| 2007  | 13.44          | 2012  | 13.56          |
| 2008  | 15.37          | 2013  | 13.52          |
| 2009  | 13.22          | 2014  | 13.01          |
| 2010  | 13.83          | 2015  | 13.6           |
| 2011  | 12.79          | 2016  | 15.41          |

The smallest RMSE value is searched as in table 3. The smallest calibration value based on RMSE is 0.0721 at \( n = 0.0456 \). This means the calculation of hydraulics using HEC-RAS 4.1.0 will approach the most appropriate with the manning coefficient (n) = 0.0456. So that the next hydraulic calculation with the HEC-RAS 4.1.0 auxiliary program will use the value \( n = 0.0456 \).

| n     | RMSE | n     | RMSE |
|-------|------|-------|------|
| 0.0400| 0.2378| 0.0457| 0.0732|
| 0.0450| 0.0800| 0.0458| 0.0740|
| 0.0451| 0.0758| 0.0459| 0.0733|
| 0.0452| 0.0758| 0.0460| 0.0742|
| 0.0453| 0.0763| 0.0500| 0.1742|
| 0.0454| 0.0745| 0.0550| 0.3462|
| 0.0455| 0.0748| 0.0600| 0.5126|

3.2. Analysis of ciliwung river based on \( Q_{50} \) conditions

Based on running with HEC-RAS 4.1.0 it was found that flooding occurred in almost all cross sections such as in Point 260 (Elevation WL. +19.02 m), 239, 205, 161, 140, 90 and 70. Whereas only a small proportion were not experiencing flooding (safe) as in point 174 and point 1 (see table 4). The overall face profile has a sub-critical flow with various curves. Figure 3 shows the elevation extending the riverbed from upstream to downstream, and the water level elevation in each section, the elevation of the left embankment and the right embankment.
### Table 4. Analysis of existing water level profiles of the Ciliwung river with $Q_{50}$.

| Section number (Point) | Flow Type Based on Froude Number | Flow Type Based on Water Level Profile Curve Shape | Flood Analysis | note |
|------------------------|---------------------------------|-----------------------------------------------|----------------|-----|
|                        |                                 | Flow Type                                    | Water Level (m) | Lowest Elevation | Embankment |
| 260                    | Subcritical                     | A2                                           | 19.02          | 16.00            | Flood      |
| 239                    | Subcritical                     | M2                                           | 18.33          | 16.00            | Flood      |
| 205                    | Subcritical                     | S1                                           | 17.61          | 14.00            | Flood      |
| 174                    | Subcritical                     | A2                                           | 16.61          | 18.32            | No flood   |
| 161                    | Subcritical                     | A2                                           | 16.61          | 14.00            | Flood      |
| 140                    | Subcritical                     | A2                                           | 14.95          | 12.00            | Flood      |
| 90                     | Subcritical                     | A2                                           | 13.77          | 9.09             | Flood      |
| 70                     | Subcritical                     | A2                                           | 13.50          | 9.00             | Flood      |
| 1                      | Subcritical                     | S1                                           | 9.33           | 10.00            | No flood   |

3.3. Determination of inlet and outlet of diversion channel location

Based on consideration of tree things:
- can reduce the river length to the maximum value
- maximum river turn angle value
- the smallest sloping riverbed

Then the inlet and outlet points in each row are obtained as shown in table 5.

### Table 5. Point of inlet and outlet of diversion channel.

| Location            | Inlet Point | Outlet Point | Angle (°) | Turn Length (m) | Diversion channel (m) | Long reduction (m) |
|---------------------|-------------|--------------|-----------|-----------------|-----------------------|-------------------|
| Kalibata            | P239        | P205         | 170       | 1600            | 308                   | 1291              |
| Kebon Baru          | P161        | P140         | 164       | 1000            | 264                   | 736               |
| Kampung Melayu      | P90         | P70          | 154       | 926             | 187                   | 738               |

3.4. Diversion channel design

The form of diversion channel is made of trapezoidal type channels. Detail of it can be seen in the table 6 below:
Table 6. Size of the cross section of the Ciliwung River channel.

| Location  | Position | Point | Distance between Channel Width (B) | Depth of water Level (h) | High of free board (W) | Elevation of river bed (m) | Elevation of top embankment (m) |
|-----------|----------|-------|-----------------------------------|-------------------------|------------------------|-----------------------------|---------------------------------|
| Kalibata  | Inlet    | P239  | 308.68                            | 18.00                   | 8.04                   | 0.80                        | 10.29                           |
|           | Outlet   | P205  |                                    | 23.00                   | 9.07                   | 0.80                        | 8.54                            |
| Kebon     | Inlet    | P161  | 264.00                            | 31.00                   | 8.30                   | 0.80                        | 8.31                            |
| Baru      | Outlet   | P140  |                                    | 22.00                   | 10.18                  | 0.80                        | 4.77                            |
| Kampung   | Inlet    | P90   | 187.61                            | 21.00                   | 8.82                   | 0.80                        | 4.95                            |
| Melayu    | Outlet   | P70   |                                    | 31.00                   | 8.82                   | 0.80                        | 5.59                            |

3.5. Analysis of water level profiles

Simulation results in each variation of the position such as:

- Variation 1
  Floods occurred on point 260, 161, 140, 90, and 70, while in point 239, 205, 174 and 1 did not flooding. The water level on point 260 + 18.65 m, has decreased by 0.37 m from the existing condition +19.02 m. The shape of the profile of the water surface due to variations in position 1 is a sub-critical flow on point 260, and the shape of the flow profile does not change compared to the existing condition.

  Based on table 7, we can discuss at points 239, 205 and 174 there is no flooding, even though the flow conditions are subcritical, up to points 260, 161, 140, 90 and 70 the flow is also subcritical but floods occur. This can occur because at that point the type of flow is A2 type [10].

Table 7. Water Profile in Position Variation 1

| Section number (point) | Flow Type Based on Froude number | Curve Shape | Flow Type | Flood Analysis | Water Level (m) | Elevation of Embankment | note |
|------------------------|----------------------------------|-------------|-----------|----------------|------------------|-------------------------|------|
| 260                    | Subcritical                      | A2          | Subcritical | Flood          | 18.65            | 16.00                   |      |
| 239                    | Subcritical                      | M2          | Subcritical | No Flood       | 17.59            | 19.13                   |      |
| 205                    | Subcritical                      | S1          | Subcritical | No Flood       | 17.60            | 18.41                   |      |
| 174                    | Subcritical                      | A2          | Subcritical | No Flood       | 16.61            | 18.32                   |      |
| 161                    | Subcritical                      | A2          | Subcritical | Flood          | 16.61            | 14.00                   |      |
| 140                    | Subcritical                      | A2          | Subcritical | Flood          | 14.95            | 12.00                   |      |
| 90                     | Subcritical                      | A2          | Subcritical | Flood          | 13.77            | 9.09                    |      |
| 70                     | Subcritical                      | A2          | Subcritical | Flood          | 13.50            | 9.00                    |      |
| 1                      | Subcritical                      | S1          | Subcritical | No Flood       | 9.33             | 10.00                   |      |

- Variation 2
  Floods occurred on point 260, 239, 205, 90, and 70, while in point 174, 161, 140 and 1 did not flood. Water level on point 260 + 18.93m, decreased by 0.09 m from existing conditions +19.02 m. The shape of the water level profile due to variations in position 2 is a sub-critical flow on point 260.

- Variation 3
  Floods occurred on point 260, 239, 205, 161 and 140, while in point 174, 90, 70 and 1 did not flooding. Water level on point 260 + 19.02 m, does not decrease in water level from existing conditions. The shape of the profile of the water surface due to variations in position 3 is a sub-critical flow on point 260, and the shape of the flow profile changes to point 70 to S1.

- Variation 4
  Floods occurred on point 260, 90, and 70, while in point 239, 205, 174, 161, 140 and 1 did not flooding. Water level on point 260 + 18.54m, has decreased by 0.48 m from the existing condition
+19.02 m. The shape of the profile of the water surface due to variations in position 4 is a sub-critical flow on point 260, and the shape of the flow profile changes to point 140 to S1.

- Variation 5
  Floods occurred on point 260, 161 and 140, while point 239, 205, 174, 90, 70 and 1 did not flood. The water level on the point 260 +18.65 m, has decreased by 0.37 m from the existing condition +19.02 m. The shape of the water profile due to variations in position 5 is a sub-critical flow on point 260, and the shape of the flow profile changes to point 70 to S1.

- Variation 6
  Floods occurred on point 260, 239, and point 205, while point 174, 161, 140, 90, 70 and 1 did not flood. The water level on the point 260 +18.93 m, has decreased by 0.09 m from the existing condition +19.02 m. The shape of the water level profile due to variations in position 6 is a sub-critical flow on point 260, and the shape of the flow profile occurs on point 140 and point 70 becomes S1.

- Variation 7
  Flooding occurred in point 260, while point 239, 205, 174, 161, 140, 90, 70 and 1 did not flood. The water level on the point 260 +18.54 m, has decreased by 0.48 m from the existing condition +19.02 m. The shape of the water level profile due to variations in position 7 is sub-critical flow on point 260, and the shape of the flow profile occurs on point 140 and 70 into S1.

The longitudinal section of the Ciliwung River from point 260 to point 1 in each variation of the position of the line can be seen in figure 4.

Figure 4. Resume of longitudinal cross section of river water elevation in several conditions variations 1 to 7 respectively. (a) variation – 1 and (b) variation – 7.

3.6. Analysis of the area of inundation in the Ciliwung River Basin

From the results of analysis, the inundation area in each variation of the position position is as follows:

- Variation in position 1 results in a large inundation area of 2.7920 km² or a reduction in the area of 0.2265 km² (7.50%) from existing conditions.
- Variation in position 2 results in the inundation area of 2.8483 km² or a reduction in area of 0.1702 km² (5.64%) from existing conditions.
- Variation in position 3 results in a large inundation area of 2.7973 km² or a reduction in area of 0.2212 km² (7.33%) from existing conditions.
- Variation in position 4 resulted in the inundation area of 2.6228 km² or a reduction in area of 0.3957 m² (13.11%) from existing conditions.
- Variation in position 5 results in the area of inundation on an area of 2.5800 km² or a reduction in area of 0.4386 km² (14.53%) from existing conditions.
- Variation in position 6 results in inundation area of 2.6417 km² or a reduction in area of 0.3768 km² (12.48%) from existing conditions.
- Variation in position 7 resulted in the inundation area of 2.4143 km² or a reduction in the area of 0.6042 km² (20.02%) from the existing condition.

4. Conclusion

Based on the results of the study of Analysis of Water Face Profiles and Inundation Areas in the Field
due to Position Variations in the Ciliwung River Canal can be summarized as follows:

- Based on the results of the calculation of water level profiles on existing conditions with a 50-year ($Q_{50}$) flood rate design return obtained the general water profile profile is a form of subcritical flow with the water level passing through the lowest cliff elevation in most sections. At upstream flow (Patok 260) water level elevation +19.02 m passes the lowest cliff elevation +16.00 m with a subcritical water level profile. While the inundation area caused by Ciliwung River runoff under existing conditions with $Q_{50}$ is 3.0185 km$^2$.

- Based on the results of the study, the inundation area of all alternative variations in the position of the inundation experienced a reduction in inundation area compared to the existing inundation area. The inundation area at variation of position 1 is 2.7920 km$^2$ decreases 7.50%, variation of position 2 is 2.8483 km$^2$ decreases 5.64%, variation of position 3 is 2.7973 km$^2$ decreases 7.33%, variation of position 4 is 6228 km$^2$ reduced by 13.11%, variation in position 5 by 2.5800 km$^2$ reduced by 14.53%, variation in position 6 by 2.6417 km$^2$ reduced by 12.48%, and variations in position 7 of 2.4143 km$^2$ reduced by 20.02%.

- Based on the decrease in water level, the variation of position 7 has the largest decrease in water level, which is reduced by 0.48 m (el. Water level +18.54 m from existing +19.02 m). Based on the inundation area with a variation of position 7, the inundation area is 2.4143 km$^2$ reduced by 0.6042 km$^2$ (20.02%) from the existing condition of 3.0185 km$^2$.

References

[1] Firman T, Surbakti I M, Idroes I C and Simarmata H A 2011 Potential climate-change related vulnerabilities in Jakarta: challenges and current status Habitat Int 35 372-8

[2] BAPPENAS 2007 Laporan Perkiraan Kerusakan dan Kerugian Pasca Bencana Banjir Awal Februari 2007 di Wilayah Jabodetabek (Jakarta, Bogor, Depok, Tangerang, and Bekasi). Badan Perencanaan Pembangunan Nasional (BAPPENAS) Indonesia, Jakarta

[3] Green C 2003 Handbook of Water Economics: Principles and Practice (Chichester: Wiley)

[4] Middelmann-Fernandes M H 2010 Flood damage estimation beyond stage-damage functions: an Australian example J Flood Risk Manag 3 88-96

[5] HEC RAS User manual, 2008, River Analysis System, Hydraulic Reference Manual (California: U.S. Army Corps of Engineering)

[6] Brunner G W 2016 Hec-Ras: River Analysis System User's Manual Version 5.0 available at: http://www.hec.usace.army.mil/software/hec-ras/downloads.aspx

[7] Zellou B and Rahali H 2016 Assessment of reduced-complexity landscape evolution model suitability to adequately simulate flood events in Complex flow conditions Natural Hazards 86 1-29

[8] Montarcih L 2010 Practical Hydrology 1st Edi. (CV. Lubuk Agung, Bandung)

[9] Chow V T, 1959, *Hidrolika Saluran Terbuka*, (terjemahan) Open-Channel 1 Hydraulics 1997 edt. (Jakarta, India: Penerbit Erlangga)

[10] Raju K. R., 1981, *Flow Throught Open Channels* (New Delhi: McGraw-Hill Limited)