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Evaluation of flood management plan on Cilemer river basin, Indonesia

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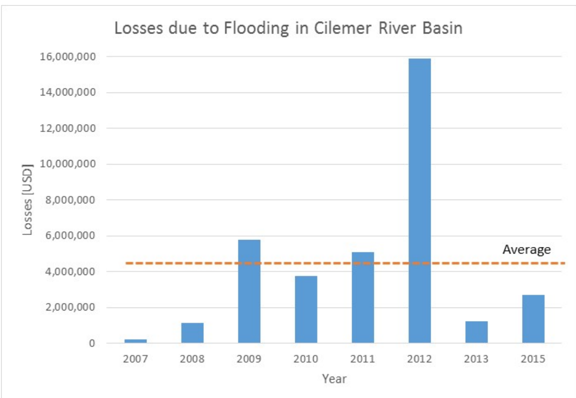
Abstract: As one of the significant rice barn in Indonesia, Banten Province faces serious problems related to flood disaster which occurs in several paddy fields on the rainfall season, especially on January until March. One of the critical area which is oftenly flooded is Cilemer River Basin around Cilemer River. This river flows through 94.3 km with 56.957 Ha area of its river basin. The disaster causes an average loss of approximately USD 4.33 million every year, and an additional losses of morale due to the disruption of the community activities in the flood area. A flood management was proposed in a previous study by the local government, based on a 1D model. The total cost is approximately USD 16.196 Million, mainly to construct levees and to normalize the river. Unfortunately, this river basin is maintained by the province under a limited budget. Therefore, stake holders had studied and issued a flood management plan to divide the construction in three stages. the middlestream, downstream, and upstream of this river basin. In this study, the plan was evaluated in order to find a more effective solution, with a lower cost. The evaluation was conducted using a coupled 1D-2D model. The model is used to simulate the flood based on 2, 5, 10, and 25 years of return periods. The flood discharge was calculated based on five rainfall stations, Mandalawangi, Pasir Wangi, Pagelaran, Sanghiang Damar, dan Kadubera stations. The model was used to obtain the inundation maps for each return period, following each stage of the flood management plan. The results show that the completion of the second stage has successfully reduced the flooding, up to a 25 years return period.

Key words: Cilemer, flood management, adaptive structural engineering, 2D Modelling

1. INTRODUCTION

Banten Province is one of the rice barn in Indonesia. Unfortunately, the rice paddy field in several areas are facing problem from flood in the rainy season. The flood causes an annual loss of approximately USD 4.35 million per year shown on Figure 1. This value was estimated based on Economic Commission for Latin America and the Caribbean (ECLAC) method for the period of 2007 to 2015.



No	Year	Losses (USD)
1	2007	191,731
2	2008	1,134,423
3	2009	5,764,231
4	2010	3,734,115
5	2011	5,093,738
6	2012	15,903,731
7	2013	1,227,692
8	2015	2,686,154

Figure 1. Losses due to Floodng in Cilemer River Basin

The flooding requires an immediate action in order to minimize the loss. The local government conducted a study and proposed a flood management plan. The study was conducted using a 1D model for simulating the inundation in Cilemer River Basin. The proposed plan costs about to USD 16.196 Million, mainly to construct levees and to normalize the river.

The Cilemer River and River Basin is maintained by the Province that faces limited budgetting. Hence, the proposed solution was divided into three stages as ilustrated in Figure 2. Each of the stage varies in cost. The cost for the first, second and third stages are USD 6.72 Million, USD 5.49 Million, and USD 3.97 Million, respectively. The first stage is in the middle of the stream with a length of approximately 6.757 km, the second stage in the downstream, approximately 5.634 km long, and the last one is in the upstream, 8.356 km long.

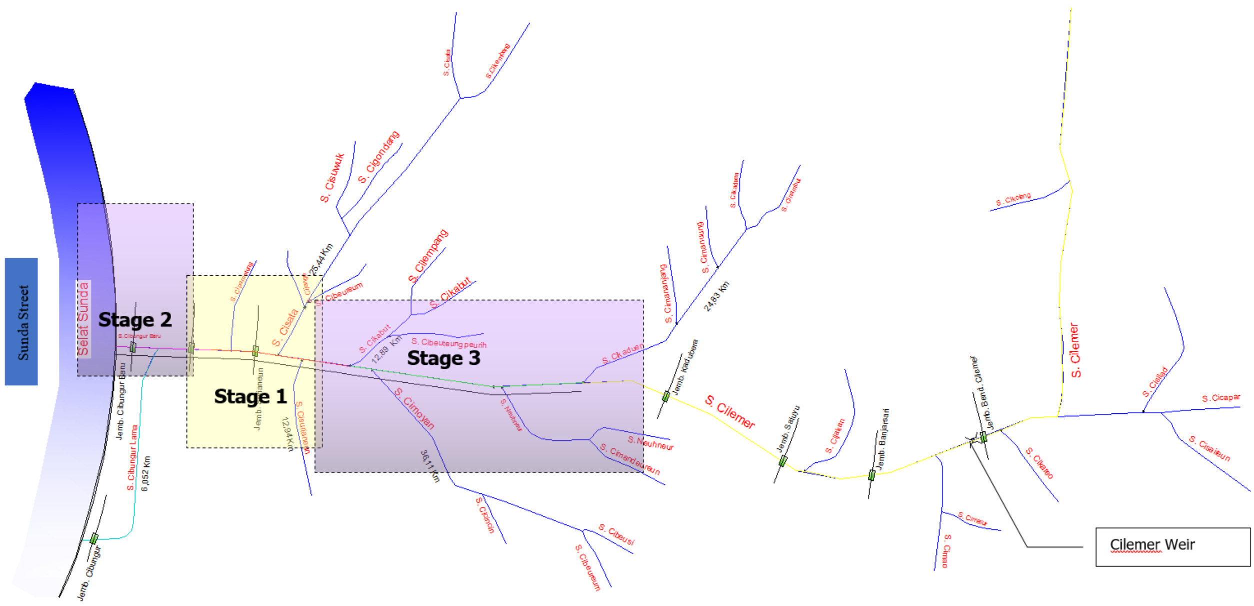


Figure 2. Schematic of Cilemer River

This proposed plan may face social problems. It requires a large sum of land acquisitions that may cause resistance from the locals. Thus, the local government requires an evaluation of the proposed plan to find a more effective way to solve the flooding.

The local government conducted their study using a one dimensional hydrodynamic model. The 1D approach is commonly used for flood simulation. However, the accuracy of this approach may not be sufficient in some cases (Lin et al., 2006). The interaction between the river and the overland flow cannot be properly simulated using a 1D model. In this case, a 2D approach is more accurate, as it is shown in previous studies for modeling the flood in in upper Citarum River Basin (Suryadi, 2008; Indrawati, 2011). A 2D model was successfully used to simulate a high-magnitude outburs flood in Kverkfjoll, Iceland (Carrivick, 2005). Flooding in urban area was also studied using a 2D based Shallow Water Equation (Mignot et al., 2005). However, a full 2D model may be time consuming and temperamental in term of stability. Therefore, a coupled 1D-2D model was proposed. The method combines the effectiveness of a 1D approach in the river, while taking the full advantage of a 2D approach for the overland flow. This method was used and tested for large and complex river system with good results (Lin et al., 2006; Patro et al., 2009; Giles and Moore, 2010).

The Cilemer River Basin is large and therefore, a coupled 1D-2D model is more appropriate for simulating the flood. In this study, the method was used to evaluate the proposed flood management plan in order to obtain a better solution for the flooding in Cilemer River Basin.

2. METHODOLOGY

This study employs a coupled 1D-2D model. The 1D model was used to simulate the flow in the river. On the other hand, the 2D model was used to simulate the overland flow. Both models are coupled using MIKEFLOOD (MIKEFLOOD, 2010).

The 1D model is based on the well known Saint Venant Equations, as follows:

Continuity Eq. $$\frac{\partial Q}{\partial x}+\frac{\partial A}{\partial t}=q \tag{1}$$

Momentum Eq. $$\frac{\partial Q}{\partial t}+\frac{\partial\left(\alpha\frac{Q^2}{A}\right)}{\partial x}+gA\frac{\partial h}{\partial x}+\frac{gQ|Q|}{C^2AR}=0 \tag{2}$$

where Q is discharge (m^3/s), A is the flow area (m^2), q is the lateral flow (m^2/s), h is the height above datum (m), C is the Chezy coefficient (√m/s), R is the hydraulic or resistance radius (m) and α is the momentum distribution coefficient which is dimensionless.

The 2D model is based on the following equations:

Continuity Eq. $$\frac{\partial \varsigma}{\partial t}+\frac{\partial p}{\partial x}+\frac{\partial q}{\partial y}=\frac{\partial d}{\partial t} \tag{3}$$

Momentum Eq. for X- Direction $$\frac{\partial p}{\partial t}+\frac{\partial\left(\frac{p^2}{h}\right)}{\partial x}+\frac{\partial\left(\frac{pq}{h}\right)}{\partial y}+gh\frac{\partial \varsigma}{\partial x}+\frac{gp\sqrt{p^2+q^2}}{C^2h^2}-\frac{1}{\rho w}\left[\frac{\partial(h\tau_{xx})}{\partial y}+\frac{\partial(h\tau_{xy})}{\partial x}\right]+\Omega_q-fVV_x+\frac{h}{\rho w}\frac{\partial(p_\alpha)}{\partial x}=0 \tag{4}$$

Momentum Eq. for Y- Direction $$\frac{\partial p}{\partial t}+\frac{\partial\left(\frac{p^2}{h}\right)}{\partial y}+\frac{\partial\left(\frac{pq}{h}\right)}{\partial x}+gh\frac{\partial \varsigma}{\partial y}+\frac{gp\sqrt{p^2+q^2}}{C^2h^2}-\frac{1}{\rho w}\left[\frac{\partial(h\tau_{yy})}{\partial y}+\frac{\partial(h\tau_{xy})}{\partial x}\right]+\Omega_p-fVV_y+\frac{h}{\rho w}\frac{\partial(p_\alpha)}{\partial y}=0 \tag{5}$$

where ζ is the surface elevation (m), d is time varying water depth (m), h is water depth (m), p is the flux density in x-direction (m^2/s), q is flux density in y-direction (m^2/s), C is Chezy resistance coefficient (√m/s), g is the gravity acceleration (m/s^2), V, V_x, V_y are the wind speed and the components in the x and y direction (m/s), f is the wind friction factor (dimensionless), Ω is the Coriolis parameter (/s), $p\alpha$ is the atmospheric presure (kg/ms^2), ρw is the water density (kg/m^3), x and y are the space coordinates (m), t is time (s), and τ_{xx}, τ_{xy}, τ_{yy} are the components of effective shear stress (m^2/s^2).

The boundary condition on the upstream is the flood discharge and hydrograph, and the downstream is the tidal level. The model was simulated by changing the upstream boundary condition for several return periods. The flood discharge was estimated using Syntetics Hydrograph Nakayashu. The method is commonly used in the Ministry of Public Works, Indonesia, since 1976. The peak discharge is given as:

$$Q_p=\frac{AR_a}{3.6(0.3T_p+T_{0.3})} \tag{6}$$

where Q_p is peak discharge (m^3/s), R_a the unit rainfall (mm), T_p is time between rainfall start to peak (mm), $T_{0.3}$ the declining time until 30% of peak discharge and A the river basin area to the river outlet.

The rainfall data was obtained from 5 measurement stations. They area Mandalawangi, Pasir Wangi, Pagelaran, Sanghiang Damar, dan Kadubera stations. The regional rainfall was obtained using the Polygon Thiessen method. This rainfall was further analyzed to estimate the return period rainfall, for calculating the flood discharge.

3. CILIMER RIVER BASIN

The delineation of Cilimer River Basin was conducted based on the Digital Elevation Model (DEM), provided by the Geospatial Information Agency (BIG). This river basin has 569.57 km^2 area with the main river is Cilemer river of approximately 94.30 km long.

Administratively, Cilemer River Basin is dominated by counties in Pandeglang District (74.99%) and Lebak District (24.75%), while the rest is located in Serang district (0.26%). Topographically, 77.38% of the total area is flat, which is typical for a lowland area. Rocks and soil in Cilemer River Basin are mostly derived from Brecciated Lava unit (Qhv) (27.04%) and Alluvium (Qa) (23.65%). This condition leads to a high probability of erosion on the upstream and sedimentation on the downstream of river basin.

The River Basin can be divided into 7 (seven) sub river basins listed on Table 1 and shown on Figure 3. There are five rainfall stations that influence Cilemer River Basin, Mandalawangi, Pasir Wangi, Pagelaran, Sanghiang Damar, dan Kadubera stations, as shown on Figure 3.

Table 1 Sub River Basin in Cilemer

	Cilemer Hulu	Cikadeun	Cimoyan	Cikobut	Cisurianeun	Cisata	Cilemer Hilir
River Length (km)	69.0	24.0	36.1	12.8	12.9	25.4	8.5
River Basin Area (km^2)	243.24	79.89	105.88	26.03	21.00	62.89	27.78

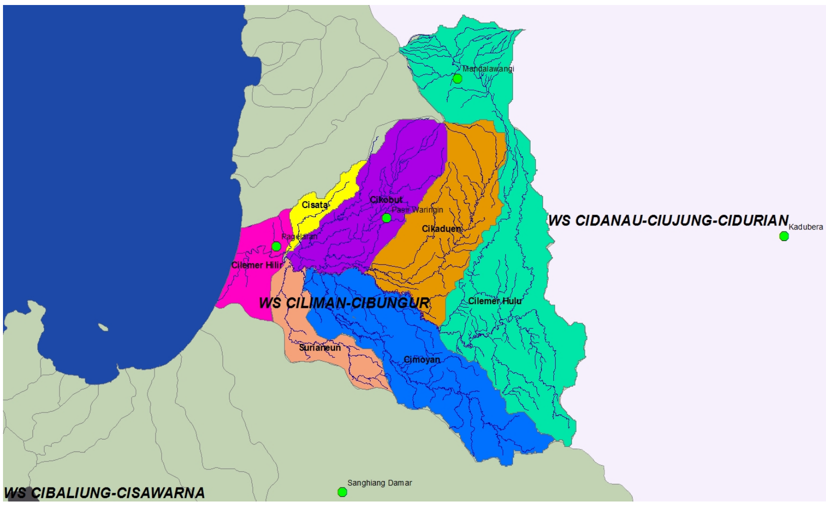
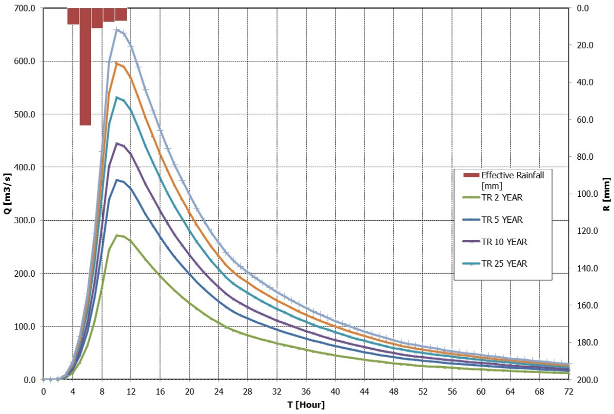


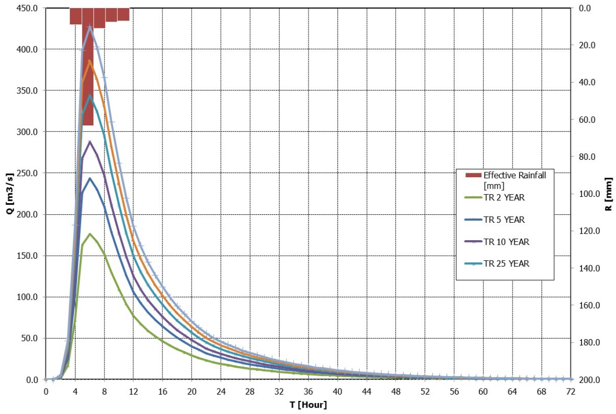
Figure 3. Cilemer River Basin

4. HYDROLOGICAL MODELING

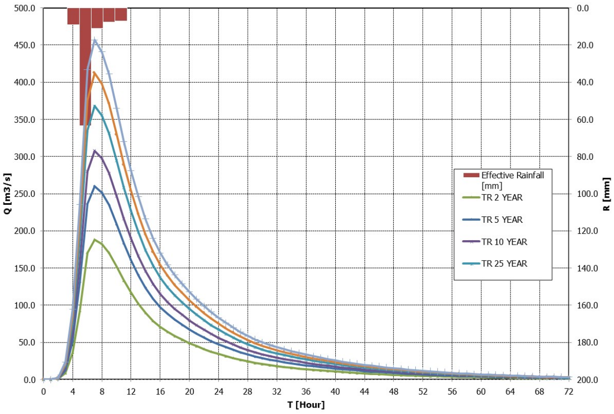
Based on Nakayashu SUH, flood discharge was estimated per sub river basin, for 2, 5, 10, and 25 years of return periods. The results show that the flood discharge varies from 170 m^3/s in Cisurianeun sub river basin until 670 m^3/s in Cilemer Hulu sub river basin as shown on Figure 4 below.



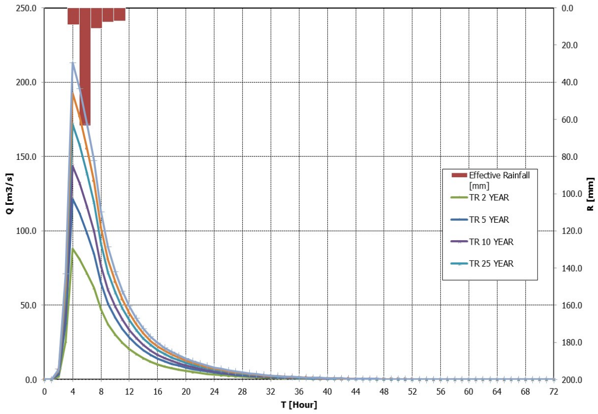
(a) Cilemer Hulu Sub River Basin



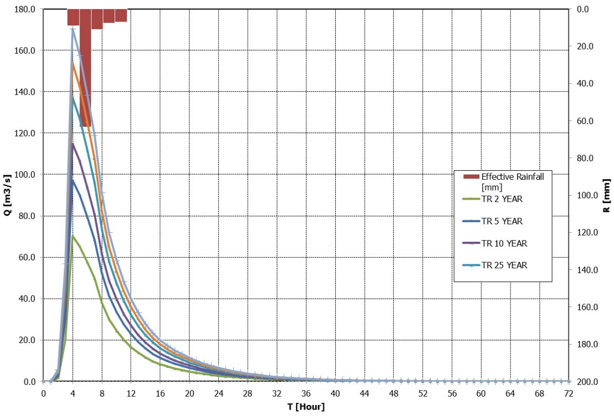
(b) Cikaduen Sub River Basin



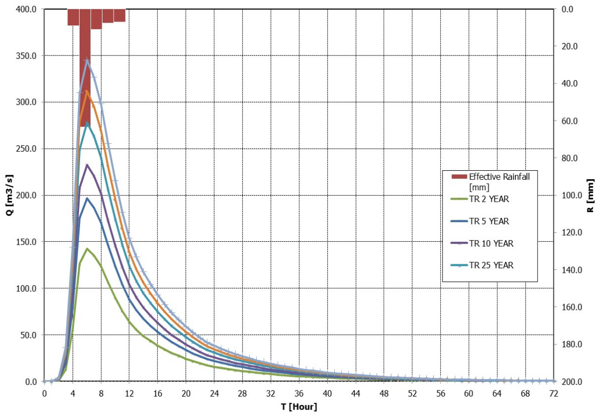
(c) Cimoyan Sub River Basin



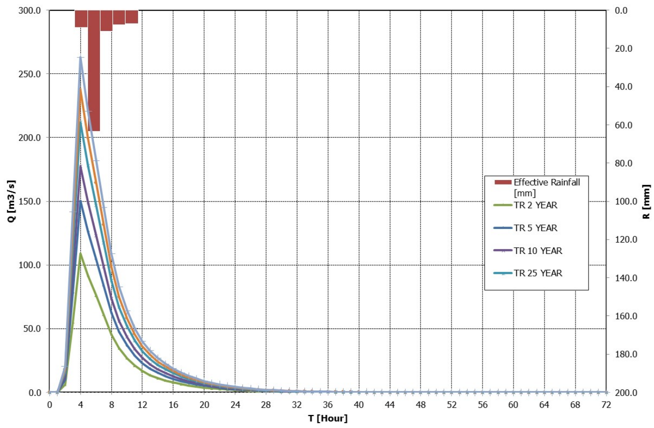
(d) Cikobut Sub River Basin



(e) Cisurianeun Sub River Basin



(f) Cisata Sub River Basin



(g) Cilemer Sub Hilir River Basin

Figure 4. Discharge in Several Sub River Basin

5. FLOOD MANAGEMENT PLANNING

At present, the average width of Cilemer river varies from 32 to 40 meters. Public Works and Public Housing Regional Office of Banten Province plans to increase the river capacity gradually. The construction is divided into 3 stages, with a total of 7 (seven) segments, which are listed below.

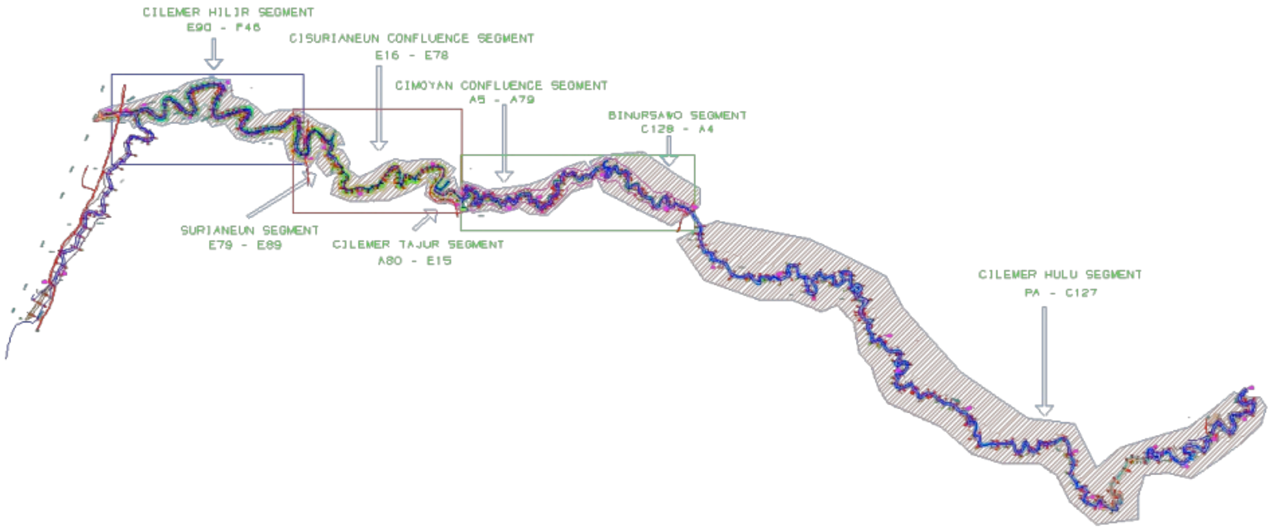


Figure 5. Segmentation of Flood Management in Clemer River

Table 2 River Improvement Planning

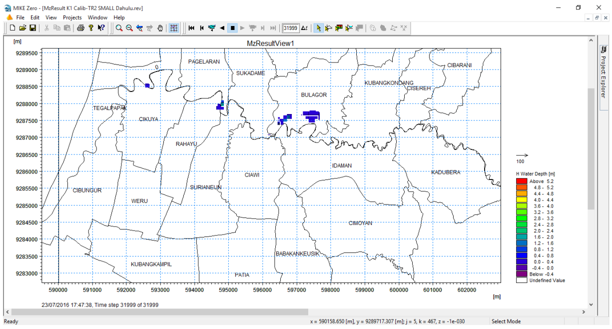
Stages	Segementation	Width (m)	Height (m)	Length (km)
-	Cilemer Hulu Segment PA-C127	18.00	3.00	24.973
Stage 3	Binursawo Segment C128-A4	30.00	4.00	26.535
	Cimoyan Tributaries Segment A5-A79	34.00	4.00	4.485
Stage 1	Cilemer-Tajur Segment A80-E15	46.00	4.00	1.317
	Cisurianeun Tributaries Segment E16-E78	52.00	4.00	2.615
	Surianeun Segment E79-E89	64.00	4.00	1.163
Stage 2	Cilemer Hilir Segment E90-F46	70.00	4.00	7.895

6. FLOOD MODELING

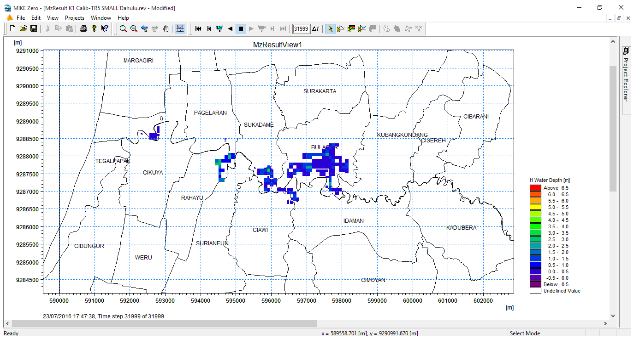
The model is used to simulate the effectiveness of the solution at each stage to decrease the flooding in Cilemer River Basin. There are three scenarios, existing, first stage, and a combination of first and second stages.

The model input are the topography data, river network and cross sections, the flood discharge, and the tidal level. The river network and cross section were used in the 1D river model. The topography data are uses in the 2D overland flow model, with a 50 m x 50 m grid size. A maximum tide level (HWL) of +0.82 m is used as the boundary condition at the downstream. The upstream boundary condition is the estimated flood discharge, as given in the previous section.

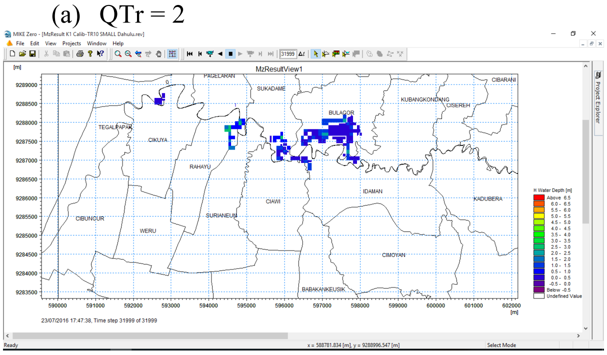
The inundation maps of the existing condition for the flood discharge with return periods of 2, 5, 10, and 25 years is shown in Figure 6.



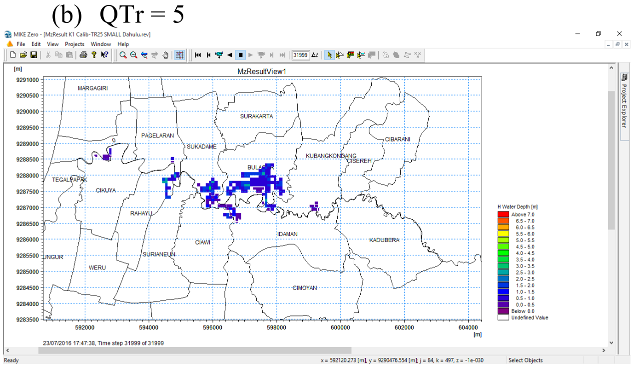
(a) QTr = 2



(b) QTr = 5



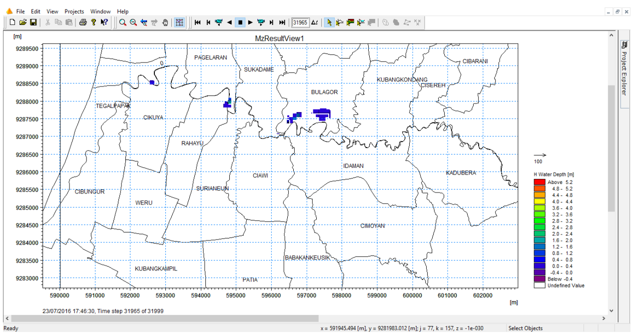
(c) QTr = 10



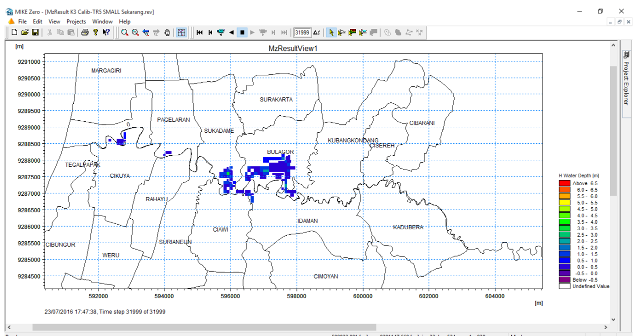
(d) QTr = 25

Figure 6. Inundation Map, Existing

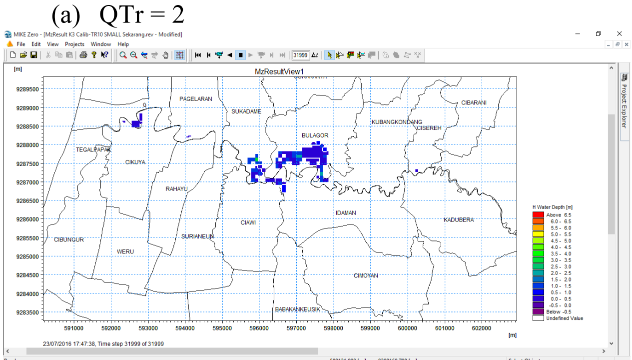
Based on the simulation results for the existing condition, inundated area for a 2 year return period is located in Bulagor, Pagelaran, Rahayu, Cikuya dan Tegalpapak Villages, with a total area of approximately 95.75 Ha and an average depth of approximately 0.43 m. The inundated area and depth gets higher with the return period. Sukadame, Idaman, Ciawi, and Surianeun Villages, are inundated with a total area of approximately 574.75 Ha and an average depth of approximately 0.75 m, for a 5 year returns period. The area and depth for 10 and 25 years return periods are 600.50 Ha, 0.75 m, and 668.00 Ha 0.98 m, respectively.



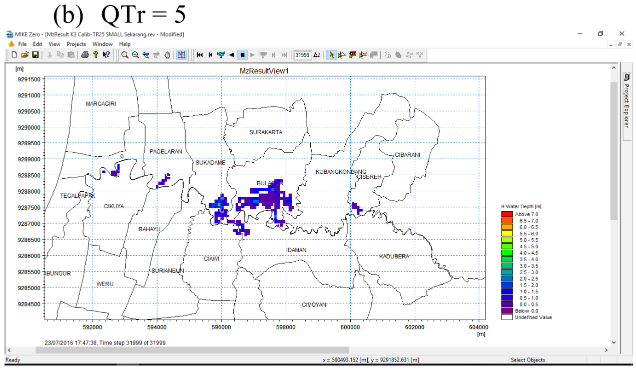
(a) QTr = 2



(b) QTr = 5



(c) QTr = 10



(d) QTr = 25

Figure 7. Inundation Map, Stage 1

The model shows the decreasing of the flood inundation following the completion of stage 1 as shown in Figure 7. The inundated area for a 2 years return period is located in Bulagor, Pagelaran, Rahayu, Cikuya dan Tegalpapak Villages with a total area of approximately 197 Ha and an average depth of approximately 0.35 m. The inundated area for the 5, 10, and 25 years return periods are 350.25 Ha, 435.25 Ha, and 628.75 Ha, respectively. The inundation depth for the same return periods are 0.63 m, 0.64 m, and 0.76 m, respectively.

There are no inundation following the completion of stage 2. Therefore, it should be highlighted here that there is no need for constructing stage 3.

7. CONCLUSION

In this study, a coupled 1D-2D model was used to evaluate the flood management plan in Cilemer River Basin. The study indicates that the flooding in Cilemer River Basin, up to a 25 years return period, can be reduced to none after completing the second stage of the proposed flood management plan. Therefore, there is no need to spend an extra USD 3.97 Million to complete the third stage.

This study has not considered the inundation due to local drainage system. It is possible that the local inflow and flooding may contribute to the overall flooding in Cilemer River Basin, especially because of the flat contour. In addition, a sediment transport related study in this river should be conducted. They should be studied further to support the flood management plan in Cilemer River Basin.

ACKNOWLEDGEMENTS

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