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Effectiveness Study of Twin Tunnel Nanjung in Flood Management of Citarum River

Sindy Witari[1, a)] and Rakhmat Yusuf[2,b)]

[1]*Civil Engineering Study Program, Faculty of Technology and Vocational Education, Indonesia University of Education*

[a)]email: sindywitari22956@upi.edu
[b)]rakhmatyusuf@upi.edu

Abstrack. Indonesia has a high risk of natural disasters such as flooding, which particularly affects the West Java region. Floods often occur due to high flow rates that exceed the capacity of water bodies, triggered by rainfall and population growth. Based on the data collected, floods hit Dayeuhkolot, Bojongsoang and Baleendah Subdistricts with water levels between 40 - 200 cm which resulted in 919 households with 3,577 people displaced. Flood control can basically be done in various ways, but it needs to consider the whole system and find the most optimal one. To reduce flooding around the Upper Citarum, the Nanjung Twin Tunnels were built. Therefore, researchers are interested in further reviewing the performance and effectiveness of the Nanjung Twin Tunnel for the handling of the Upper Citarum. This research uses descriptive method with HEC-RAS v6.5 software modeling approach with 2D method. From the modeling results, it was found that after the installation of Twin Tunnel Nanjung, the flood inundation area was reduced by 64% from 13.44 km2 to 4.8 km2 and the depth was reduced by 2-3 m on average at 5 points in Dayeuhkolot area.

Keywords: Flood, Twin Tunnel Nanjung, Performance, Effectiveness

INTRODUCTION

Indonesia is one of the countries that has many areas with a high risk of natural disasters, including floods, earthquakes, volcanic eruptions and tsunamis. One disaster that causes high damage in Indonesia is flooding. Most areas in Indonesia are affected by floods, one of which is West Java. West Java Province is one of the provinces with a high number of flood events, amounting to 251 flood events, and the largest number of flood events is in Bandung Regency. The high incidence of flooding in Bandung Regency is influenced by land morphological conditions in the form of basins, and anthropogenic factors including changes in forest land use to agricultural land. [1]

Several major cities in West Java are prone to flooding, including Bandung City, Bandung Regency, West Bandung Regency, Sumedang, and Purwakarta. These cities are prone to flooding because of the Citarum River, especially in Bandung Regency. Several major flooding points occur in the Bandung Regency area with the potential impact of alert status such as Pacet, Arjasari, Ciparay, Majalaya, Solokan Jeruk, Baleendah, Bojongsoang, Rancaekek, Cileunyi, Cimenyan, Dayeuhkolot, Margahayu, Katapang, Pameungpeuk, Banjaran, Pangalengan, and Kertasari.

Based on its morphology, the area is called the Bandung Basin. The condition of the basin has a high potential for flooding, where water gathers and causes flooding in the lowest part of the basin. Major floods caused by the overflow of the Citarum River that occurred in the Bandung Basin were recorded in 1986, 1998, 2005, and 2010 [2].

Flooding in the Citarum River is caused by several problems, namely deforestation of the upstream area of the Citarum watershed, land subsidence due to excessive water use, sedimentation, and poor behavior of the people around the river in treating the environment, especially in littering the river. [3]. In addition, flooding can also be caused by the amount of flow discharge and the capacity of the water body that exceeds the limit. High rainfall, increasing population growth, and several problems from the river, such as the presence of backwater at several points of the Citrarum River. One of the backwater points in the Citarum River is at Curug Jompong, where the heavy rainfall is held back by large rocks at Curug Jompong, causing the river flow to be held back and unable to flow appropriately downstream.

Flood control can be done in various ways, but it needs to be looked at to find the most optimal system. To address this, the government, through the Citarum River Basin Center (BBWS), built the Nanjung Twin Tunnels in the upper reaches of the Citarum River. The construction of the Nanjung Twin Tunnels is a structural approach-based solution that aims to increase the river's flow capacity to reduce flood risks in the South Bandung area, which is expected to reduce flooding around Bandung Regency, especially in the Dayeuhkolot area. The tunnel consists of two channels with a length of 230 meters and a diameter of 8 meters that cut the Citarum River through the Curug Jompong area—using HEC-RAS modeling to simulate water flow and predict its impact on river hydrology. Therefore, researchers are interested in further examining how effective the Nanjung Twin Tunnel is in reducing flood inundation and how the flood depth changes after installing the Nanjung Twin Tunnel for handling in the upstream Citarum region [6].

METHODOLOGY

Research on the performance of the Nanjung tunnel to reduce the flood discharge of the Citarum watershed uses a descriptive method with a software modeling approach using HEC-RAS v6.5. Descriptive research is research that uses a technique to describe a research result. As the name implies, descriptive research aims to describe, explain, and validate the phenomenon under study. [4]

In hydraulic analysis, two-dimensional (2D) based modeling is preferred to capture more complex surface flow dynamics than one-dimensional (1D) models. [5] 2D models are more effective in the following ways:

- Depicting water flow more realistically, especially in areas with complex topography and irregular drainage systems.
- Analyzing the interaction of river flow and floodplain areas, which cannot be accurately modeled in 1D models.
- Account for the effects of backwater and diffuse flow, which often occur in areas with sharp topographic changes, such as the Citarum River.

The 2D model in HEC-RAS was used to predict the distribution of flood inundation after the construction of the Nanjung Twin Tunnels, allowing for a more accurate simulation than the 1D model that only considers flow along one principal axis. By using a grid resolution of 30x30 meters based on the following considerations:

- Computational efficiency: Grids smaller than 30x30m can improve accuracy but require significantly longer processing times, while larger grids can lead to the loss of essential details in flood flow distribution [6].
- Compatibility with elevation data resolution: The available Digital Elevation Model (DEM) data for the Citarum River region has a resolution of about 30m, so selecting a grid of similar size ensures that topographic changes remain well represented in the model.

RESULTS AND DISCUSSION

In a river, the amount of flow discharge is difficult to measure; usually, the number that becomes the benchmark for monitoring is the water level. High water value is then used to estimate the amount of discharge in the river or watershed. The amount of river water discharge is influenced by surface runoff subsurface flow and groundwater. [6].

The automatic method uses an automatic water gauge installed at a river water gauge post, known as AWLR (Automatic Water Level Recaşder). This tool measures the water level continuously and the measurement results are in the form of hydrographs. [7].

AWLR is a replacement tool for conventional water level measurement systems where data recording is still done manually, so the measurement system and data storage are not precise and accurate. [8].

The data used for the calculation of discharge plans is AWLR (Automatic Water Level Recorder) data from the Water Duga Post:

1. Cisangkuy-Kamasan River (7°2'45.88“-107°34'40.46”)
2. Citarum-Dayeuhkolot River (6°59'5.15“-107°36'59.09”)
3. Ciwidey-Sadu River (7°2'23.65“-107°29'47.40”) 3.

To determine the return period of a particular year's discharge, rain frequency analysis is a statistical analysis of interpretation (Statistical inference) discharge. [9]. In the calculation of the discharge plan using the Gumbel distribution method as follows:

$$X_T = \bar{X} + \frac{Y_T - Y_n}{S_n} S$$

X_T = Value of planned discharge with measured data Year (mm)
$\bar{X}$ = Average discharge value (mm)
S = Standard deviation
$= \sqrt{\frac{\sum(x_i - \bar{x})^2}{n-1}}$
Y_T = The variate reduction value of the variable that is Expected to occur at a return period of T years, can be calculated by the formula:
$= -\ln[-\ln\frac{T-1}{T}]$; for T ≥ 20, then Y = ln T
Y_n = The average value of variate reduction depends on the amount of data (n).

For Unsteady Flow data used, namely on December 23, precisely at the peak discharge state, the interval data used is 10 minutes. To find data every 10 minutes, the Interpolate Missing Values tool is used. It can be seen that the results of data interpolation are as follows :

TABLE 1. 10-minute interval interpolated discharge data

Time	Kamasan	Sadu	Dayeuhkolot
00.00.00	65.25	81.14	855.43
00.10.00	65.632	80.941	855.409
00.20.00	66.015	80.742	855.388
00.30.00	66.397	80.543	855.367
00.40.00	66.78	80.344	855.346
00.50.00	67.162	80.145	855.325
01.00.00	67.545	79.946	855.304
01.10.00	67.927	79.747	855.283
01.20.00	68.309	79.548	855.262
01.30.00	68.692	79.349	855.241
01.40.00	69.074	79.15	855.22
01.50.00	69.457	78.951	855.199
02.00.00	69.839	78.752	855.178
02.10.00	70.222	78.553	855.157
02.20.00	70.604	78.354	855.136
02.30.00	70.986	78.155	855.115
02.40.00	71.369	77.956	855.094
02.50.00	71.751	77.757	855.073
03.00.00	72.134	77.558	855.052
03.10.00	72.516	77.359	855.031
03.20.00	72.898	77.16	855.01
03.30.00	73.281	76.961	854.989
03.40.00	73.663	76.762	854.968
03.50.00	74.046	76.563	854.947
04.00.00	74.428	76.364	854.926
04.10.00	74.811	76.165	854.905
04.20.00	75.193	75.966	854.884
04.30.00	75.575	75.767	854.863
04.40.00	75.958	75.568	854.842
04.50.00	76.34	75.369	854.821
05.00.00	76.723	75.17	854.8
05.10.00	77.105	74.971	854.779
05.20.00	77.488	74.772	854.758
05.30.00	77.87	74.573	854.737

Time	**Kamasan**	**Sadu**	**Dayeuhkolot**
05.40.00	78.252	74.374	854.716
05.50.00	78.635	74.175	854.695
06.00.00	79.017	73.976	854.674
06.10.00	79.4	73.777	854.653
06.20.00	79.782	73.578	854.632
06.30.00	80.165	73.379	854.611
06.40.00	80.547	73.18	854.59
06.50.00	80.929	72.981	854.569
07.00.00	81.312	72.782	854.548
07.10.00	81.694	72.583	854.527

Continued table 1

Time	Kamasan	Sadu	Dayeuhkolot
07.20.00	82.077	72.384	854.506
07.30.00	82.459	72.185	854.485
07.40.00	82.842	71.986	854.464
07.50.00	83.224	71.787	854.443
08.00.00	83.606	71.588	854.422
08.10.00	83.989	71.39	854.401
08.20.00	84.371	71.191	854.38
08.30.00	84.754	70.992	854.359
08.40.00	85.136	70.793	854.338
08.50.00	85.518	70.594	854.317
09.00.00	85.901	70.395	854.295
09.10.00	86.283	70.196	854.274
09.20.00	86.666	69.997	854.253
09.30.00	87.048	69.798	854.232
09.40.00	87.431	69.599	854.211
09.50.00	87.813	69.4	854.19
10.00.00	88.195	69.201	854.169
10.10.00	88.578	69.002	854.148
10.20.00	88.96	68.803	854.127
10.30.00	89.343	68.604	854.106
10.40.00	89.725	68.405	854.085
10.50.00	90.108	68.206	854.064
11.00.00	90.49	68.007	854.043
11.10.00	90.872	67.808	854.022
11.20.00	91.255	67.609	854.001
11.30.00	91.637	67.41	853.98
11.40.00	92.02	67.211	853.959
11.50.00	92.402	67.012	853.938
12.00.00	92.785	66.813	853.917
12.10.00	93.167	66.614	853.896
12.20.00	93.549	66.415	853.875
12.30.00	93.932	66.216	853.854
12.40.00	94.314	66.017	853.833
12.50.00	94.697	65.818	853.812
13.00.00	95.079	65.619	853.791
13.10.00	95.462	65.42	853.77
13.20.00	95.844	65.221	853.749
13.30.00	96.226	65.022	853.728
13.40.00	96.609	64.823	853.707
13.50.00	96.991	64.624	853.686
14.00.00	97.374	64.425	853.665
14.10.00	97.756	64.226	853.644
14.20.00	98.138	64.027	853.623
14.30.00	98.521	63.828	853.602
14.40.00	98.903	63.629	853.581

Time	Kamasan	Sadu	Dayeuhkolot
14.50.00	99.286	63.43	853.56
15.00.00	99.668	63.231	853.539
15.10.00	100.051	63.032	853.518
15.20.00	100.433	62.833	853.497
15.30.00	100.816	62.634	853.476
15.40.00	101.198	62.435	853.455
15.50.00	101.58	62.236	853.434
16.00.00	101.963	62.037	853.413
16.10.00	102.345	61.838	853.392
16.20.00	102.728	61.639	853.371
16.30.00	103.11	61.44	853.35

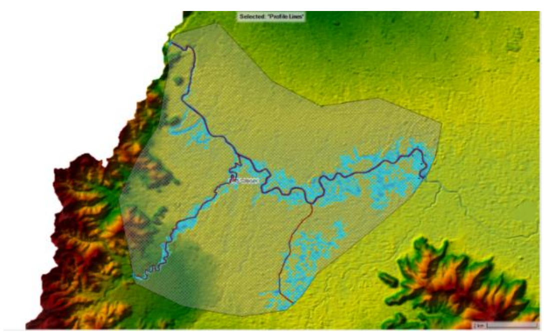
In this research, 2D modeling and simulation are used so that the overflow results represent the inundation according to the conditions in the field, and the computational boundaries and river flow are described with Break Lines so that the flow rate is not limited to the cross-section alone but as wide as the inundation area described.

This study modeled 18.9 km of the Citarum River, 16.8 km of the Cisangkuy River, and 16.4 km of the Ciwidey River along the research observation.

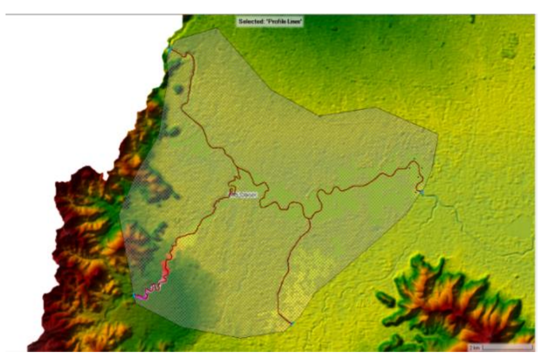
Cell size in the 2D Flow Area of Citarum Watershed is 30 x 30 m with a total of 122638 cells with an average size of 759 m2. The Manning's roughness used is 0.045. A break line along the river channel was used for detailed river geometry, which was associated with a Digital Elevation Model (DEM) map. For the elevation reading on the river channel to be more precise and represent the geometry of the river, Cells are made with a minimum size of 5 x 5 m and a maximum of 10 x 10 m.

Boundary conditions were placed upstream of the Citarum River, Cisangkuy River, and Ciwidey River as inflow and downstream of the Citarum River as outflow. Unsteady Flow Data was used to fill in the boundary condition data. For the upstream boundary condition, 100-year plan discharge data / Q100 from the previous discharge calculation was used, and for the downstream condition, Normal Depth was used.

Initial modeling used a simulation time of 16 hours using interpolated discharge data with a computation interval of 0.3 seconds and an hourly printing time interval.



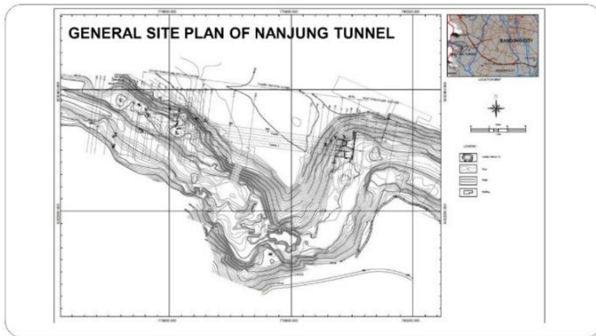
PICTURE 1. Results Depth (Depth) running Q100 existing conditions



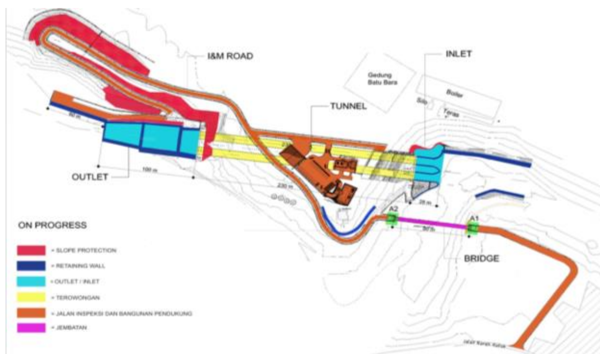
PICTURE 2. Results of Water Surface Elevation (Water Surface Elevation) running Q100 existing conditions

Based on the results of running Q100, the inundation area is 13444225.3527 m2 or 13.44 km2, and the maximum water surface elevation in the Dayeuhkolot area is 662.5 meters above sea level. If seen on the Dayeuhkolot TMA graph on AWLR PJT II monitoring, the situation is included in the AWAS situation.

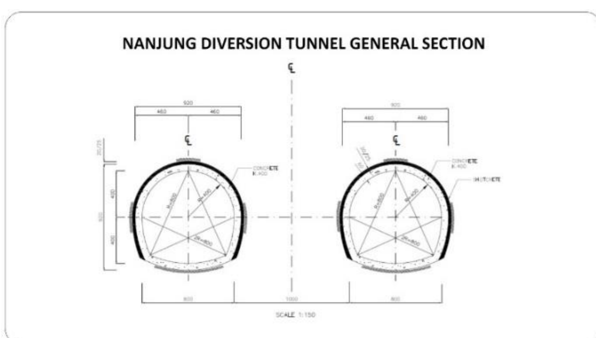
Modeling of Twin Tunnel Nanjung in this study, the engineering used to overcome inundation is a 230 m long straight parallel twin tunnel with a diameter of 8 m with concrete material installed at the inlet elevation at 647.20 masl and outlet at 646.74 masl. The following is the design tunnel scheme from BBWS Citarum.



PICTURE 3. Twin Tunnel Nanjung Scheme



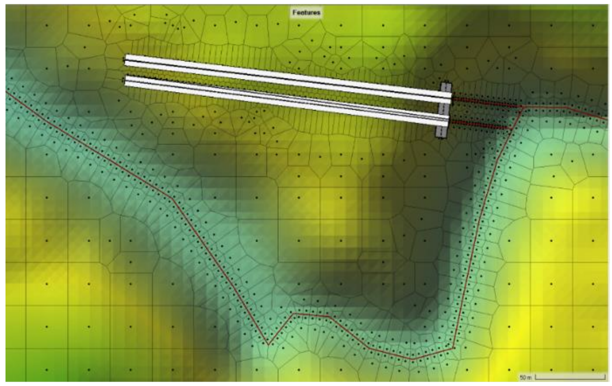
PICTURE 4. Twin Tunnel Nanjung Scheme



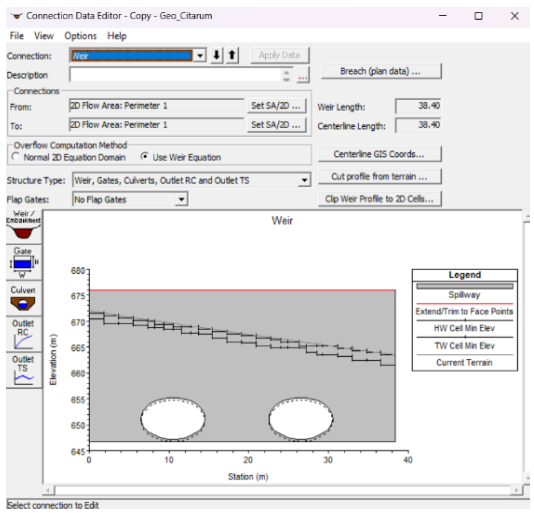
PICTURE 5. Front View of Tunnel

The modeling in HEC-RAS is represented by the 2D method so that the overflow results represent the inundation according to the conditions in the field, and the computational boundaries are drawn with Break Lines according to the location of the twin tunnel construction. Brake lines were used along the river channel associated with the Digital Elevation Model (DEM) map for detailed geometry. To make the elevation reading on the river channel more precise and to represent the river geometry, Cells with a minimum size of 2 x 2 m and a maximum of 5 x 5 m were made. The

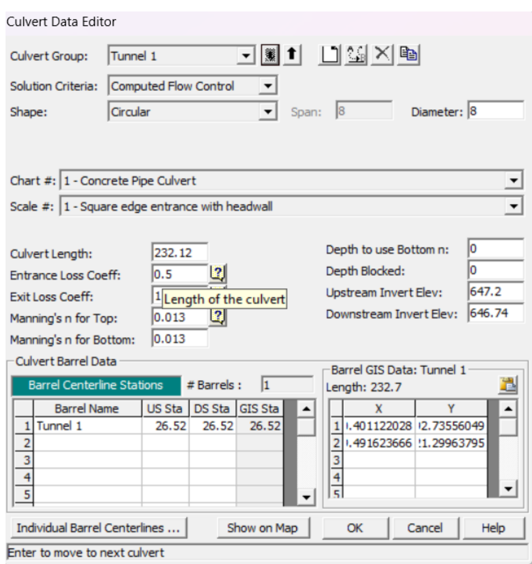
Tunnel is connected to the SA/2D Area Connection structure with a simple weir type to integrate the Tunnel with the inundation area.



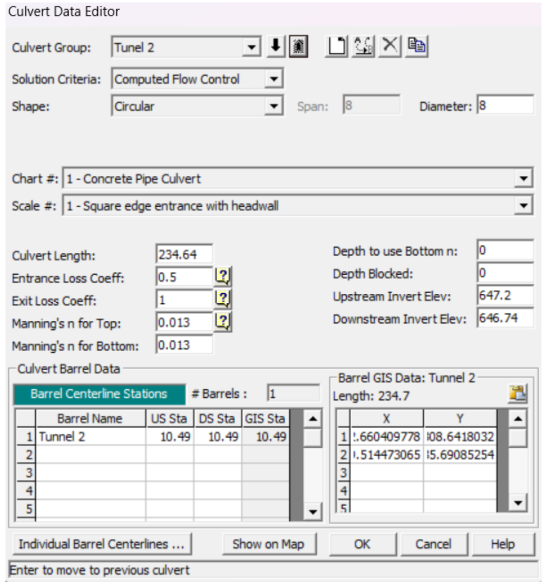
PICTURE 6. Weir and tunnel structures



PICTURE 7. Connection data SA/2D Area Connection

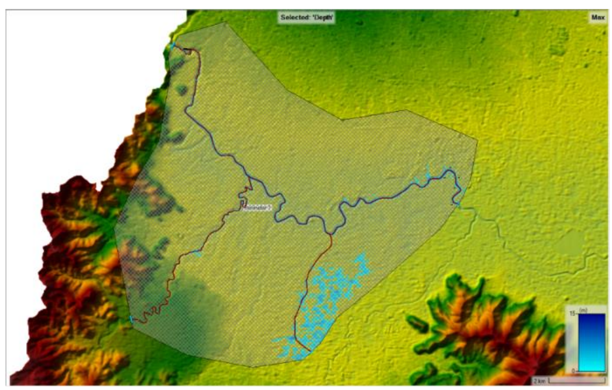


PICTURE 8. Data of culvert one specification of BBWS Citarum

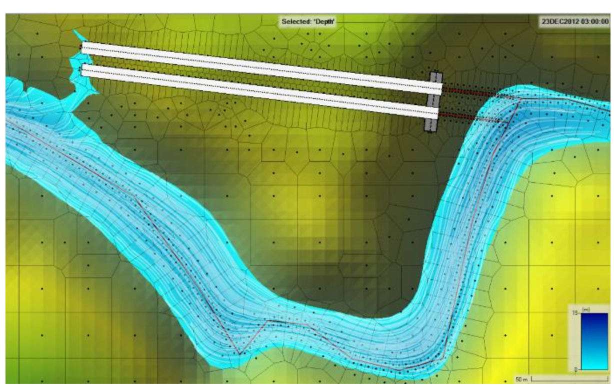


PICTURE 9. Data of culvert two specifications of BBWS Citarum

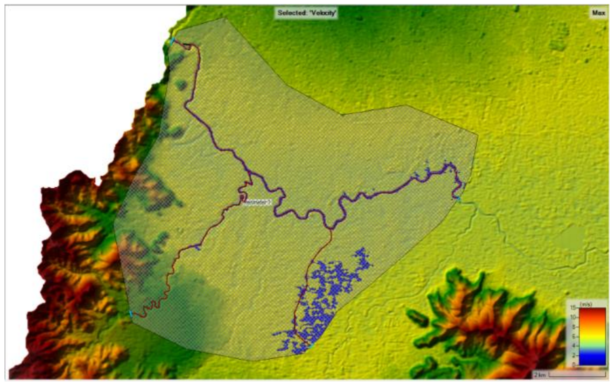
In modeling with tunnels, use the same simulation as the initial modeling. A simulation time of 16 hours was used, and the discharge data was interpolated with a computation interval of 0.3 seconds and an hourly printing time interval.



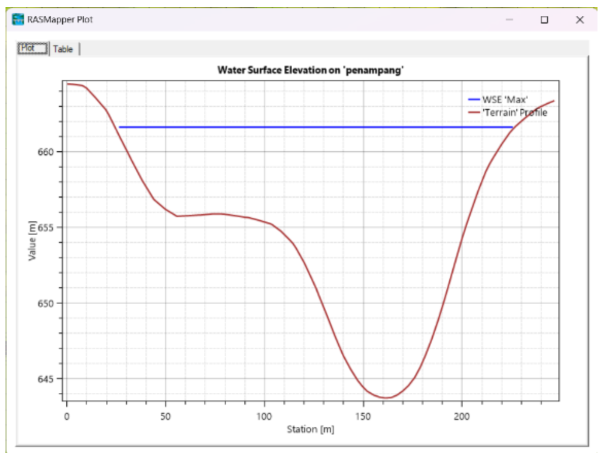
PICTURE 10. Depth results of running Q100 with Tunnel



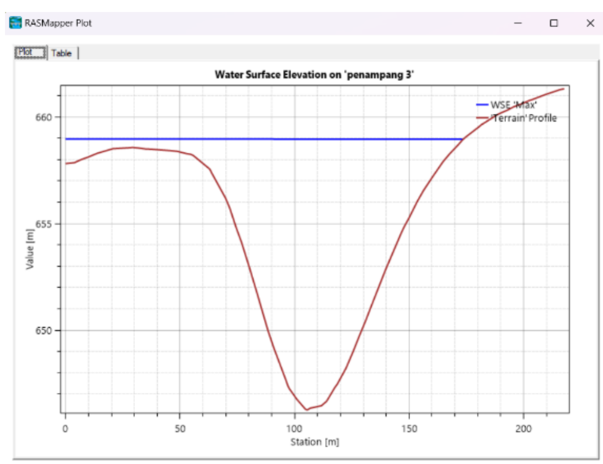
PICTURE 11. Results of Particle Tracing



PICTURE 12. Results of Water Surface Elevation of running Q100 with Tunnel

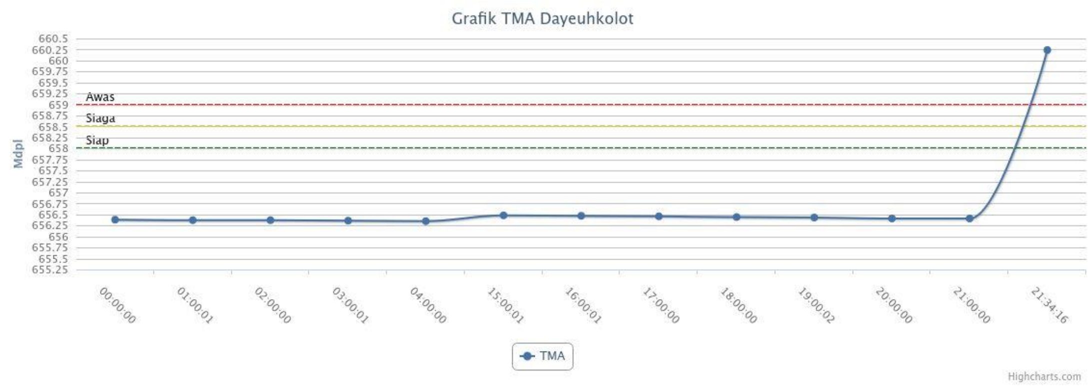


PICTURE 13. Water Surface Elevation before the Tunnel



PICTURE 14. Water Surface Elevation after the Tunnel

Based on the results of running Q100 using the Tunnel, the inundation area is reduced to 4780081.18958 m2 or 4.8 km2, and the maximum water surface elevation in the Dayeuhkolot area is 658.76 meters above sea level. When viewed on the Dayeuhkolot TMA graph on AWLR PJT II monitoring, the situation is included in the SIAGA situation.



PICTURE 15. TMA graph of Dayeuhkolot AWLR PJT II

For the percentage of tunnel performance from the condition before and after installation.

TABLE 2. Percentage of tunnel performance to inundation area

Inundation Area			
Before the Tunnel Installation	**After the Tunnel Installation**	**Difference**	**Reduction of Area**
Km2	Km2	Km2	%
13.44	4.8	8.64	64.28571429

TABLE 3. Percentage of tunnel performance against inundation depth

Coordinates		**Depth**		
X	**Y**	**Before the Tunnel Installation**	**After the Tunnel Installation**	**Difference**
788775.70	9228222.59	661.61	658.76	2.85
788242.96	9227928.17	661.59	658.68	2.91
789466.25	9227542.13	662.25	658.97	3.28

Continued table 3

Coordinates		**Depth**		
X	**Y**	**Before the Tunnel Installation**	**After the Tunnel Installation**	**Difference**
787600.43	9227778.62	661.53	658.27	3.26
787070.13	9227308.28	661.46	658.09	3.37

From the table above, it can be seen that there was a reduction in inundation by 64%, and the depth was reduced by an average of 2-3 m, which was reviewed at several points in the Dayeuhkolot area for the early warning system also changed from AWAS to SIAGA. This is because, after the installation of the Twin Tunnel Nanjung, the water flow is no longer held in the Curug Jompong section. From the modeling comparison results, it can be seen that the installation of Twin Tunnel Nanjung can prevent the overflow of the upstream Citarum River. However, flooding still occurs at several points due to the inadequate cross-section of the Citarum River in the Dayeuhkolot area to accommodate the discharge.

CONCLUSIONS

From the results of HEC-RAS v6.5 modeling using a 100-year return period discharge (Q100), it is found that before the Twin Tunnel Nanjung, the inundation area was 13.44 km2 and the maximum water surface elevation in the Dayeuhkolot area was 662.25 m above sea level in the Upper Citarum River. From the results of HEC-RAS v6.5 modeling using a 100-year return period discharge (Q100), it is found that after the Nanjung Twin Tunnel, the inundation area is 4.8 km2 and the maximum water surface elevation in the Dayeuhkolot area is 658.76 m above sea level in the Upper Citarum River. The effect of Twin Tunnel Nanjung's performance in Citarum River flood management efforts is a 64% reduction in inundation and a reduction in depth with an average of 2-3 m reviewed at 5 points in the Dayeuhkolot area, for the early warning system also changed from AWAS to SIAGA. Installing the Nanjung Twin Tunnel can prevent the overflow of the upstream Citarum River. However, flooding still occurs at several points due to the inadequate cross-section of the Citarum River in the Dayeuhkolot area to accommodate the discharge.

It ignores the existing hydraulic buildings along the river for river modeling but considers the incoming flows from the tributaries. In using the HEC-RAS program, it is better to use the latest version and a device with high specifications so that the simulation can take place quickly, accurately, and well. In calculating unsteady flow, use the most minor computation interval to make the modeling results more accurate. To obtain better modeling results and better represent the Tunnel in the original, a gate can be added upstream of the Tunnel, and a swale pool downstream of the Tunnel can be adjusted to the design tunnel scheme of BBWS Citarum.

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