2D numerical modeling of the Jeneberang River Flood due to the overflow of the Bili-Bili Dam.

Aslam1*, and U Lasminto1

1Department of Civil Engineering, Institut Teknologi Sepuluh Nopember
*Corresponding author’s e-mail: aslam.18031@mhs.its.ac.id

Abstract High rainfall at the end of January 2019 in South Sulawesi, especially in the upstream area of the Jeneberang watershed, caused an increase in the height and volume of water in the Bili-Bili dam reservoir. The elevation of the water level was recorded on January 22, 2019 at 18:00 WITA reaching +101.87 m ASL above the normal water level elevation of +99.50 m ASL. In accordance with the spillway door operating pattern, if the water level exceeds the normal water level elevation limit, the dam floodgates must be opened to prevent dam collapse. To find out the impact caused, it is necessary to numerically model the flow velocity, depth, and inundation area in the downstream area of the Jeneberang river caused by overflow of discharge from the Bili-Bili Dam spillway. The data used are the flow hydrograph data from the outflow of 10-hour dam outflow as an upstream boundary condition and the rating of the rubber dam rating curve downstream of the Jeneberang river as a downstream boundary condition. The 2D research area focuses on 2 sub-districts directly adjacent to the Jeneberang river, namely Pallangga and Somba Opu sub-districts. From the results of flood simulations using the 2D HEC-RAS numerical model, the flow velocity is between 0.57 m/s to 4.84 m/s, the depth is between 1.70 m and 7.38 m, and the inundation area is 1.7 km². These results were then calibrated with the results of observations and measurements in the field of the former high flood inundation in the building and the results of interviews with the affected communities which found that the simulation results correlated well at the seven points of measurement in the field using RMSE which is 0.37.

1. Introduction
The background of this research is the occurrence of high rainfall at the end of January 2019 in South Sulawesi, especially in the upstream area of the Jeneberang watershed causing an increase in the height and volume of dam reservoir water. The elevation of the water level was recorded on January 22, 2019 at 18.00 WITA reaching +101.87 m ASL above the normal water level elevation of +99.50 m ASL (Sisda BBWS Jeneberang Pompengan, 2019). In accordance with the spillway door operating pattern, if the water level exceeds the normal water level elevation limit, the dam floodgates must be opened to prevent dam collapse (BPSDM 2017). The highest flow outflow of the Bili-Bili dam outflow spillway was 1,426 m³/d on January 22, 2019 from 18.00 to 21.00 WITA, causing an increase in the volume of the Jeneberang river downstream which then overflowed and caused floods in several Gowa regency areas bordering directly with the Clear river. The flood disaster is the first event that hits the riverbanks in the Palangga and Somba Opu sub-districts within the last 10 years.

Observing these data, this research needs to be done to analyze the area, flow velocity and flood inundation based on the outflow discharge data of the Bili-Bili dam in the area along the Jeneberang river to be used as an early anticipation of flood hazards, and then determine the affected areas as one of the efforts to mitigate floods in the preparedness stage.

To be able to do an assessment of the element of preparedness, then we need a mathematical calculation that can describe the behavior of flooding in the area around the Jeneberang river. This mathematical calculation can also be said as a flood modeling to see the amount of discharge over time through natural event approaches through hydrodynamic model. The modeling results obtained are then
used as a virtual flood control effort schematically to determine the results before the application in the field; one of the mathematical methods used in flood simulations is a two-dimensional numeric simulation (2D). With 2D simulations approaching the actual situation on the ground, it is expected that the flood disaster can be anticipated earlier.

The purpose of this study is to analyze how much influence the flow outflow of the Bili-Bili dam from January 17 to 27 January 2019 on floods in the downstream watershed that is directly adjacent to the Jeneberang river through 2D numerical modeling using the HEC-RAS application when compared with inundation floodwaters data, area and flow velocity based on field observation data and efforts to support flood disaster mitigation.

2. Literature review
Flooding is an event where the overflow of river water exceeds a riverbed or a pool of water that occurs in areas that are low and cannot be drained, (SNI 2415: 2016). Flooding is a disaster caused by high rainfall, topography of a watershed, inadequate cross section of a river, and changes in land use. High rainfall and watershed topography are natural conditions that cannot be changed so that river capacity has an important role in flowing rainwater to prevent flooding (Wasim 2018). Based on the occurrence process, the possibility of a river channel or channel which is not able to accommodate normal discharge capacity, in extreme conditions suddenly can cause river water to overflow and enter areas that have lower topography.

2.1. Flood Mapping
To reduce the risk of flood events, a proper and integrated flood control system planning is needed. Kodoatie (2013) explains that in planning a flood control system in an area, there needs to be an evaluation and analysis that take into account the area or the extent of the flood inundation. The characteristics of floods in the form of the area / scope of inundation, inundation depth and flow velocity need to be mapped so that it can become a very basic and important foundation in flood control planning. Flood map is also a necessity in planning an area by developers to determine flood insurance and insurance from buildings, houses, offices and so on. In addition, the government also needs flood maps to support infrastructure plan, transportation facilities, and other plans, including flood emergency preparation and response (Al Amin 2018).

Flood mapping is a series of analyses conducted to produce flood maps that at least contain the scope or boundaries of inundation, flood risk zones, and depth of inundation. There are four methods that can be used for flood studies and mapping as explained in the National Research Council (2009), namely: 1) detailed studies, 2) limited detailed studies 3) approach studies, and 4) redline. The detailed study method requires river measurement data and / or rain-runoff models in hydrological analysis, while hydraulic analysis requires flow modeling (steady or unsteady) with detailed river building survey data. The limited detailed study method requires river measurement data for hydrological analysis, whereas for hydraulic analysis a steady flow modeling is required without detailed information about the river structure. The method of study approach is done by determining or estimating inundation boundaries without technical studies, for example by reading topographic maps and field surveys. The fourth method, namely redelineation, is to re-create flood maps based on the historical elevation of floodwaters on a new topographic map (Al Amin 2018).

The most commonly used methods in flood mapping are limited to the approach study and redesign method, such as loading flood map information on the depth and area of flood inundation areas carried out by Siregar (2016), Suleman (2017), Utomo (2019), and Seniarwan (2013). Meanwhile, to produce complete information about the characteristics of flood inundation which include discharge, flow velocity, inundation depth and extent of flood, it is necessary to model and simulate hydrodynamics as has been done by Alif (2018), Al Amin et.al (2018) and Sulaiman (2017).

According to Goel (2005), one method to help flood management is done by numerical simulations. Numerical simulations of flood estimates cannot immediately get good results because inundation depends on the topography and it changes with time (dynamic). This makes flood prediction more
complicated and requires a long process. Flood information with a visual display helps better planning (Suleman 2017).

2.2. Flood Simulation Modeling

At present, mathematical modeling in solving a flood problem can be simulated using 1-dimensional (1D), 2-dimensional (2D) hydraulic modeling or a combination of 1-and 2-dimensional (1D / 2D) modeling. 1D Modeling is a model that has one direction of flow that is the direction of flow along the main channel, whereas 2D Modeling is a model that has two directions of flow, namely the direction of flow along the main channel and the direction of flow in the area around the flow.

The modeling of flood flow propagation is carried out based on the numerical settlement of the St. Venant equation using 1D calculations for along the river flow and 2D calculations if there is inundation at the surface of the land due to overflow from the river. The calculation process that occurs between rivers and land is done by 1D and 2D interconnection approaches.

2D flow calculations will use three equations as follows: 2D continuity equation, 2D momentum equation of the x-axis direction, and 2D momentum equation of the y-axis direction. The 2D continuity equation is as follows:

\[
\frac{\partial \zeta}{\partial t} + \frac{\partial (\mathbf{u}h)}{\partial x} + \frac{\partial (\mathbf{v}h)}{\partial y} = 0
\]  

Information:
\( \mathbf{u} \): velocity of the x-axis direction
\( \mathbf{v} \): velocity of the y-axis direction
\( V \): velocity refer to \( V = \sqrt{\mathbf{v}^2 + \mathbf{u}^2} \)
\( \zeta \): water level above reference
\( h \): depth \( \zeta + d \)
\( d \): water level bottom reference (m)

Flow equation of x-axis 2D flow is as follows:

\[
\frac{\partial \mathbf{u}}{\partial t} + \mathbf{u} \frac{\partial \mathbf{u}}{\partial x} + \mathbf{v} \frac{\partial \mathbf{u}}{\partial y} + g \frac{\partial \zeta}{\partial x} + g \frac{u |\mathbf{v}|}{c^2 h} + a \mathbf{u} |\mathbf{u}| = 0
\]

Information:
\( C \): Chezy coefficient
\( a \): wall roughness coefficient

Flow equation of x-axis 2D flow is as follows:

\[
\frac{\partial \mathbf{v}}{\partial t} + \mathbf{u} \frac{\partial \mathbf{v}}{\partial x} + \mathbf{v} \frac{\partial \mathbf{v}}{\partial y} + g \frac{\partial \zeta}{\partial x} + g \frac{u |\mathbf{v}|}{c^2 h} + a \mathbf{v} |\mathbf{v}| = 0
\]

HEC-RAS can be used to simulate flood inundation of 1D or 2D flow or a combination of 1D and 2D using the Saint Venant or Diffusion Wave equation in both permanent and non-permanent flow (steady and unsteady one-dimensional flow model). Research that uses the application of HEC-RAS 5.0 is Sulaeman (2017), Mamuaya (2018) and Alsorigussa (2018).

2.3. Calibrating Model

Validation is needed so that the accuracy of the results of modeling done can be known. Parameters that can be used to carry out the validation process are the elevation of the surface of the former floodwaters in the field with the results of the analysis on the HEC-RAS program.

Validation is done using the root mean square error (RMSE) method. RMSE is calculated by squaring the error divided by the amount of data, then rooted. If the RMSE value is close to 0, then the model is considered good or can represent the existing conditions in the field.
\[
RMSE = \sqrt{\frac{1}{n} \sum_{i=1}^{n} (H_{obs} - H_{sim})^2}
\] (4)

3. Methods of the research

3.1. Research sites

This research takes a case study in the Jeneberang Sub-watershed in the western part after the Bili-Bili dam, where the outflow discharge of the dam is channeled through the spillway to the Jeneberang river along ± 30 km which then empties into the Makassar Strait (Figure 1).

![Figure 1 Research sites in the Jeneberang Sub-watershed downstream](image)

3.2. Data collection

In this study some secondary data are used, namely the Bili-Bili dam outflow discharge data as input data on the upstream boundary condition and the relationship data between the discharge and river water level (rating curve) of rubber dam (BBWS Pomengan Jeneberang). Measurement of flood inundation height is carried out by measuring the former inundation and interviewing affected communities.

3.3. Hydraulic Model

The hydrodynamic model is used to calculate the elevation of flood water levels. With topographic data input in the form of digital elevation model (DEM) and a base map in the Mapper RAS menu, it can be simulated and modeled on characteristics, flood inundation area, flow velocity, and flood depth using HEC-RAS 5.0. In this study, the outflow spillway hour flow rate data of the Bili-Bili dam during the high rainfall events on January 17 to January 27, 2019 became the upstream boundary conditions and the rating curve of the rubber dam in the downstream area of the Jeneberang river was made as downstream boundary conditions.

The components of the geometry model used in this study are features of river geometry parameters that are connected schematically, with various hydraulic elements in the river which are the physical representation of the river. River geometry data used in this study consist of cross sections, banks, and flow paths. These four-geometry data are configured in the RAS Mapper menu integrated in the HEC-RAS program.

For the flow, this research used unsteady flow. The boundary conditions in unsteady flow can be divided into 2, namely upstream boundary conditions and downstream boundary conditions. The upstream boundary conditions are applied as flow hydrographs with connection to the time (Flow Hydrograph). Meanwhile, the downstream boundary conditions are needed at the downstream end, which is not connected to the reach or other storage area.
3.4. Calibration of Simulation Results
Calibration of simulation results on the HEC-RAS program are conducted using the flood events on the study site that occurred on January 21 to January 23, 2019 through observation. The calibration data are collected based on the interviews with affected residents and the measurement of inundation height in the field from the former flood that is still visible in the walls of people's houses. The research flowchart can be seen in Figure 2

![Research Flowchart]

4. Results and discussion
4.1. DEM Data Processing
DEM data are used as terrain conditions at the study site affected by the overflow of the Jeneberang river processed using the help of a GIS-based program. Based on the DEMNAS map data sheet, it is known that the research location is divided into several map sheets (Figure 3). These map sheets are
then combined into 1 sheet according to the area to be analyzed using the RAS-Mapper program in the HEC-RAS program sub-menu.

![Figure 3 DEM map on research location (source: modelling result)](image)

The DEM data are used to get the catchment area delineation from the research location using a GIS based program. Digital elevation model data used are sourced from the DEMNAS website of the Geospatial Information Agency (http://tides.big.go.id/DEMNAS/) in the Geotiff32bit float format with a resolution of 0.27-arcsecond (8.1 mx 8.1 m) and a scale of 1: 25,000 using the EGM2008 datum with the geographic system coordinate projections, which is converted using the 50S zone’s WGS84 UTM projection.

The hydrograph data on spillway discharge at the Bili-bili dam on January 17 to January 27, 2019 (11 days) are the upstream boundary conditions, whereas the rating curve of the rubber dam data located at downstream of Jeneberang river are the downstream boundary conditions.

![Figure 4 Graphic of Hydrograph on spillway of Bili-Bili dam](image)

![Figure 5 Graphic of rating curve on the rubber dam](image)

(Source: Balai Besar Wilayah Sungai Pompengan Jeneberang)

In Figure 4, it can be seen that there was an increase in the flow of discharge through the outflow of the Bili-Bili dam, starting on January 22, 2019 with the recorded debit from 245 m3/s at 03.00 WITA increasing to 545 m3/s at 05.00 WITA until its peak was 1,426 m3/s at 20:00 WITA. Then it gradually dropped and returned to normal on January 24, 2019 to 246 m3/s at 04.00 WITA. Then in downstream, stage rating curve for water level is depicted on the vertical axis while discharge is the horizontal axis on the cross section (Figure 5).

4.2. Hydraulic Modeling

The results of the DEM map delineation are used as an input for terrain model in the RAS Mapper menu in the HEC-RAS 5.0 program. Following is the imitation of Jeneberang river geometry in HEC-RAS 5.0 including river coverage, cross sections, lateral structures and 2D areas that include inundation areas.
(2D areas). Geometry model of the Jeneberang river on HEC-RAS in Figure 6 shows that the upstream boundary condition is the hydrograph of spillway from the Bili-Bili dam, while the downstream boundary condition is the rating curve of the rubber weir. Along the river there is a lateral structure which is a direct runoff connection from the Jeneberang river. The distance between cross sections (cross section) is ± 100 m with a total of 270 cross sections (Figure 6).

The flow scenario is unsteady flow. The upstream boundary condition data can be seen at figure 4, whereas the downstream boundary conditions can be seen at figure 5.

![Figure 6 Geometry model of Jeneberang river](image)

4.3. Result

After running simulation using HEC-RAS, it can be seen that in the side view of the left and right overbanks profile there is an increase in the river water level through the riverbanks (figure 7 and 8). The slope of the river from the Bili-bili dam at RS 2070 tends to be critical up to RS 9228 and the influence of the narrowing of the river crossing width at RS 9327 to RS 8326 (figure 9) can be a cause of the overflow of Jeneberang river if flowing is 1,426 m3/d suddenly.

The simulation results of the profile of the water surface on this longitudinal surface are then used as the boundary conditions for runoff flow simulations in the 2D model and the determination of the lateral structures as a medium for connecting 1D and 2D areas. The lateral structure is made following the topographic profile of the river flow boundary that directly intersects the 2D area.

The cross-section profiles of the simulation results will be analyzed as a reference in making 2D areas. If the cross section of the river is not able to withstand the flow of the river, the river will run off into the riverbanks and cause flooding. From 270 cross-section profiles, there are 4 cross-section profiles that overflow exceeding the carrying capacity, namely at RS 6625, RS 9327, RS 8126, and RS 17824 (figures 10 to 12).

The 2D flow area on the HEC-RAS is modeled on the area behind the embankment or overbank flow by connecting the river to the 2D area using a lateral structure. In mesh creation in 2D areas, it is implemented in the RAS Mapper sub-menu in the HEC-RAS application. In this model, a 10x10m mesh was used with the segmentation of the stagnation area on the right and left sides of the river in accordance with the side view of banks profile (Figure 7 and 8) of 13 lateral structures and many cells on the mesh 207793 cells on the left side of the river. Whereas, in the right stream there are 6 lateral structures and 80311 cells.
Figure 7 Left over banks profile

Figure 8 Right over banks profile

Figure 9 River reach section 9327 to 8326 (Source: Simulation result)

Figure 10 Water Surface Elevation RS 6625

Figure 11 Water Surface Elevation RS 9327

Figure 12 Water Surface Elevation RS 8126

Figure 13 Water Surface Elevation RS 17824 (Source: Simulation result)
From the results of field observations, 7 measurement points were determined based on the former high inundation within two sub-districts. The 7 measurement points can be seen in figure 15.

![Figure 14 Result simulation of Depth 2D Jeneberang river](image1)
![Figure 15 Result simulation of Velocity 2D Jeneberang river](image2)

The results of the simulation are known that the flood inundation area that occurs is 1.7 km² with the flow velocity at the maximum river discharge conditions between 0.57 to 4.84 m³/s and the depth varies between 1.70 to 7.38 m. The overflow of the Jeneberang river passes through the right bank first and enters the settlement area in Somba Opu sub-district at RS 9027 on January 22, 2019 at 09.54 WITA with a speed of 0.068 m³/d until the peak on January 23, 2019 at 02.17 Eastern Indonesian Time and receds at 22.31 Eastern Indonesian Time. As for the Pallangga sub-district, the river flow overflowed at RS 8126 on January 22, 2019 at 13.08 WITA with a speed of 0.054 m³ until the peak on January 23, 2019 at 05.24 WITA and then slowly receded at 04.37 WITA. To test the reliability of the simulation model, then measurements were taken of flood inundation in the field, measurements were taken at 7 points of flood on the former flood on the walls of people's houses.

From Graphic 1 below, it appears that the simulation results correlate quite well with the results of the field observation using RMSE, which is 0.37. From the RMSE calculation to test the model, an RMSE value of 0.37 is obtained where the data will be considered more accurate if it approaches 0, then based on the test of the RMSE data the HEC-RAS modeling results are considered to be feasible, so the modeling results can be used as information on flood disaster mitigation efforts in the preparedness stage.

The results of the field survey are based on observations of traces or tracks of flooding and interviews with local communities that are highly biased. For better results, it is recommended to use river discharge and also carry out hydrological modeling to obtain truly accurate data.
5. Conclusion
Based on the analysis and discussion above, several conclusions can be drawn, namely:

1. Discharge from the outflow of the Bili-Bili dam on January 17, 2019 to January 27, 2019 can cause the overflow of the Jeneberang river downstream along the riverbank on River Sta (RS) 6625 to 9327, 6928 to 8126 and 17824 to 19225, and affect by narrowing of the river crossing width on the River Station.

2. In the downstream Jeneberang watershed case study, 2-dimensional numerical modeling can be used to analyze the Jeneberang river runoff that has runoff because the cross section of the river is not able to hold the flow of the river flow to the area directly adjacent to the river.

3. Based on data from flood inundation height measurement results in the field, the post-assessment simulation model correlates reasonably well with the results of the HEC-RAS simulation using RMSE, which is 0.37. It is known that the area of flood inundation is 1.7 km² with the speed at maximum river discharge conditions between 0.57 m³/s to 4.84 m³/s and depths between 1.70m to 7.38m.

4. The HEC-RAS 5.0 program can be used for mapping flood inundation, so it is expected to become a standard in planning flood control systems in the preparedness stage as an effort to mitigate disasters in the downstream Jeneberang watershed.

References
[1] Al Amin M B, Ulfah L Haki H and Sarino 2018 Simulasi karakteristik genangan banjir menggunakan HEC-RAS 5 Studi Kasus Subsistem Sekanak di Kota Palembang (Jurnal Penelitian dan Kajian Bidang Teknik Sipil: Cantilever) 7 2
[2] Alif C J and Andawayanti U 2018 Aplikasi HEC-RAS untuk analisa dan penanganan banjir di sungai mujur, tempeh lor, kabupaten lumajang (Universitas Brawijaya)
[3] Alsorigussa P, Pandulu G D and Sulistyani K F 2019 Evaluasi kapasitas sungai haruyan hilir kabupaten hulu sungai tengah provinsi kalimantan selatan dengan menggunakan HEC-RAS 5.0 Sem. Nas. Tek. Ind. Ling. Infra. (Prosiding SENTIKUIN) 2
[4] Brunner and Gary W 2014 Combined 1D and 2D modeling with HEC-RAS Eng. Hyd. Eng. Cen. (US Army Corps: Davis CA)
[5] Brunner and Gary W 2016 HEC-RAS River analysis system 2D modeling user's manual Eng. Hyd. Eng. Cen. (US Army Corps: Davis CA)
[6] Mamuaya F L, Sumarauw J S and Tangkudung H 2018 Analisis kapasitas penampang sungai roong pondano terhadap berbagai kala ulang banjir Jur. Sip. Stat. 72
[7] Marhendi T, Wardana P N Nurhadi S Bramanti I A P 2017 Alternatif pengendalian banjir kali juana berbasis model HEC-RAS Jurn. Ilm. Din. Rek. 13 1 p 37-42
[8] Pusat Pendidikan dan Pelatihan Sumber Daya Air dan Konstruksi (BPSDM) 2017 Mod. Oper. Wad. (Bandung: Jawa Barat) 8
[9] Sisda 2019 Pola operasi pintu spillway balai besar wilayah sungai pompengan jeneberang Bahan Informasi Bendungan Bili-bili Kabupaten Gowa (Makassar: Sulawesi Selatan).
[10] Siregar R I and Indrawan I 2016 Studi komparasi permodelan hidrologi dan permodelan hidrolika dalam memprediksi banjir Konf. Nas. Tek. Sip. (Universitas Atma Jaya: Yogyakarta) 10
[11] Seniarwan, Baskoro D T and Gandasasmita K 2013 Model spasial genangan banjir Studi Kasus Wilayah Sungai Mangottong, Kabupaten Sinjai, Provinsi Sulawesi Selatan (Majalah Ilmiah Globe) 15 1
[12] Sulaeman A, Ery S and Sumiadi S 2017 Analisis genangan banjir akibat luapan bengawan solo untuk mendukung peta risiko bencana banjir di kabupaten bojonegoro Jur. Tek. Peng. 8 2 p 146-57
[13] Utomo et.al 2019 Analisis banjir dan pemetaan kawasan terdampak banjir di kelurahan laweyan, kota surakarta Mat. Tek. Sip. 7 3
[14] Wasim Z E and Wardhana P N 2018 Flood mapping of juwana river with unsteady flow simulation using hec-georas program