International Journal of GEOMATE, June 2019, Vol.16, Issue 58, pp.124 - 131
Geotec., Const. Mat. & Env., DOI: https://doi.org/10.21660/2019.58.icee18
ISSN: 2186-2982 (Print), 2186-2990 (Online), Japan

TWO-DIMENSIONAL SIMULATION OF SULTAN ABU BAKAR DAM RELEASE USING HEC-RAS

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ABSTRACT: Dams are constructed as water storage to compensate for fluctuations in the catchment area and to generate electricity. However, uncontrollable amount of discharges released from the gated spillways of the dam would impact the downstream area. On October 23, 2013, floods occurred in downstream of Sungai Bertam probably due to a huge volume of discharges were released from Sultan Abu Bakar (SAB) dam. Impacts of that flood, three people were confirmed dead and nearly 100 houses destroyed or under water while over 100 vehicles badly damaged. Thus, a study on various maximum discharges released on the behavior of flow along 4 km and 200 m width downstream river was conducted. The objectives in this study were to evaluate flood inundation area and to produce flood hazard map which able to predict risk area of flooding. The computer simulation was done to analyze various maximum discharges released from the gated spillway by using two dimensional HEC-RAS which is constructed by US Army Corp with the aid of a high resolution of Digital Elevation Model (DEM) data. The amount of water release used in the simulation were 10, 25, 30, 50, 100, 230 and 300 m^3/s based on recommendation dam release by Tenaga Nasional Berhad (TNB). The result shows that the safest maximum release was $50 m^3/s$ in order to avoid inundation happen. This study will also help authorities to control the amount of maximum discharge level allowed from the dam. Besides, it can give awareness to local residents of risk area on flood wave travel time.

Keywords: HEC-RAS, 2D Simulation, SAB Dam Release, Sungai Bertam, Flood Inundation

1. INTRODUCTION

Dams are built across rivers and streams as massive barriers to confine and utilize the flow of water. One of the reasons to build dams is to generate hydroelectricity. Dams also control flooding known as detention dams, which are constructed to either stop or slow the amount of water in a river system. Dams help in irrigation, which stops a river’s natural course so that water can be sent to different irrigation channels [1].

However, accidents related to dams such as dam break or uncontrol amount of water discharge due to a high level of energy being stored in the reservoir will give negative impact to the downstream area and have disastrous effects on environment, society and economy [2].

SAB dam is located at Ringlet-upstream of Sungai Bertam. Ringlet creates a man-made lake called Ringlet reservoir on the upstream of the dam. Ringlet reservoir is situated on the Sungai Bertam in the mukim of Ringlet in the Cameron Highlands district [3]. There was a large scale of destruction of the flood that occurred on October 23, 2013, that has caused damaged to the properties, assets and had claimed the lives of four people. Residents of Bertam Valley experienced a tragic event when their village was inundated on October 2013. A huge volume of discharges released from SAB dam had caused an unusual increased of water level in Sungai Bertam.

Adeogun [4] and Bussi [5] found that sedimentation that occurs due to deforestation and natural vegetation removal on the upstream of a catchment will eventually flow into the dam and settled at the bottom of the dam. As time goes by, the increasing volume of sediment will affect the dam water level. This will cause the water level of the dam to increase [6].

The environmental issues that had occurred also contribute to an increase in water level in the dam. The effects on the local hydrologic system when a rural area is turned into an area full of housing developments, shopping centers, industrial buildings, and roads that are increased in rate of erosion and volume of sedimentation in river channel at downstream [7,8].

Since the commissioning of the dam in 1968, the dam has been classified as a large dam having a high downstream hazard. A recent study by Opatoyinbo [9] described that the once designated flood plain is now occupied by the human population and agricultural activities. The original river reserve downstream at Sungai Bertam was gazetted in 1996 at 60 m from each bank providing at least a total river width for flood flows at 130 – 150 m^3/s. Present field inspection reveals that at a certain location, there are only 2-3 m of river width left from population and agriculture activities.

When water levels rise above the spillway, the dam restricts the amount flowing through the opening gates thus decreasing peak flood flow. Sediment accumulation, restriction of water flow to downstream communities and ecosystems, and breaching during very extreme flood events can be minimized or avoided altogether since flow through dams minimally affect rivers natural flows.

Thus, this study is to investigate the impact on various discharges released from SAB dam to 4 km range downstream of Sungai Bertam. It is important to choose a model which need less comprehensive input data and gives reasonable precision results. HEC-RAS software is most suitable to be used in simulating the SAB dam release in two-dimension (2D) as it meets all the selection criteria and has been widely used in many hydrological studies.

The Hydrologic Engineering Center's River Analysis System, or HEC-RAS, is a widely-used one-dimensional method for studying stream reaches [10]. HEC-RAS is used within multiple water management groups throughout the United States for dam failure analyses within regulated catchments. Halgren [11] presented that HEC-RAS also allows river forecasters to use recorded data to model river reaches for daily flow approximations.

As mentioned previously, HEC-RAS can be used for a variety of types of river simulation studies, and for steady, unsteady, and mixed flow regimes [12]. In the past, Iosub and Oana [13] wrote that the program has been used for dam failure analyses, flood mapping, completing flood frequency studies and to simulate everyday flows through a reach. Studying typical daily flow (low flow) conditions in a river allows a user to better understand typical elevations and flow patterns within a stream. HEC-RAS also has the capability to be used with other software and programs, including the HEC Data Storage System (HEC-DSS) and Geographic Information System (GIS) applications, among others [14].

A study done by Gharbi [15] showed that HEC-RAS uses the standard direct step method for water surface profile calculations, assuming that flow is one-dimensional, gradually varied, and steady. The program computes water surfaces as either a subcritical flow profile or a supercritical profile. Mixed subcritical and supercritical profiles are not computed simultaneously. If the computations indicate that the profile should cross critical depth, the water surface elevation used for continuing the computations to the next cross-section is the critical water surface elevation.

This paper is focused on using two-dimensional (2D) of HEC-RAS software in order to simulate the water discharge from the dam. The focus area is along 4 km of Sungai Bertam which is Bertam Valley, situated downstream of SAB dam.

2. AREA OF STUDY

Cameron Highlands (Sultan Abu Bakar) Hydroelectric Power Project Malaysia is located at Sungai Bertam, Ringlet, Pahang, Malaysia and it locates at coordinates of Latitude= 4.4229, Longitude= 101.3894 as shown in Figure 1. This infrastructure is a Hydro Power Plant with a design capacity of 100 MWe. It has 6 unit(s) of the turbine with a capacity of 16.67 Mwe. The hydropower plant was commissioned in 1963. It is operated by Tenaga Nasional Berhad (TNB) (Ranjangupta, 2011). The SAB dam is situated on the Sungai Bertam in the mukim of Ringlet in the Cameron Highland district. The reservoir is formed by impounding the waters of the Sungai Bertam and its tributaries and those of Sungai Telom, Sungai Plau'ur, Sungai Kodol and Sungai Kial which have been diverted from the Telom catchment through the Telom Tunnel into the Bertam catchment.

Figure 1 shows the study area downstream of SAB dam which is consist of 4 km of Sungai Bertam. It also shows the location of SAB dam and SJK (C) Bertam Valley which is also active as a relief center in that area.

Bertam Valley is an agriculture village which is home to a population of local and migrant farmers. Most of the residents operate numerous flower nurseries and vegetable farms perched along the banks of Sungai Bertam. Bertam Valley is located about 1.5 km off Ringlet town. The total catchment area of Cameron Highlands Scheme is 180 km^2 comprising of 110 km^2 of Telom Catchment and 70 km^2 of Bertam Catchment. Ringlet Reservoir was designed for gross storage of 6.3 million m^3, of which 4.7 million m^3 is the active or live storage while 1.6 million m^3 is the inactive or dead storage. The dead storage was designed for a useful lifespan of approximately 80 years which can be translated to 20,000 m^3/year of sediment inflow [16].

3. METHODOLOGY

The hydraulic model used in this study is HEC-RAS software. The input data needed to run the simulation are DEM and discharge values from the dam. DEM data was prepared by TNB Researcher (TNBR) and discharge data were obtained based on the previous study done by some researchers**.**

3.1 Preprocessing

DEM data was prepared by TNBR. DEM is a

computerized representation of the earth surface Triangulated Irregular Networks (TIN), regular grids, contour lines and scattered data points. The value of each pixel is associated with a specific topographic height described a DEM either by a wire frame model or an image matrix. DEM data elevation. The most usual format exists are were collected along the 4 km and 200 m of Sungai Bertam using a drone. Figure 2 shows the type of drone used to collect data and Google Map image.

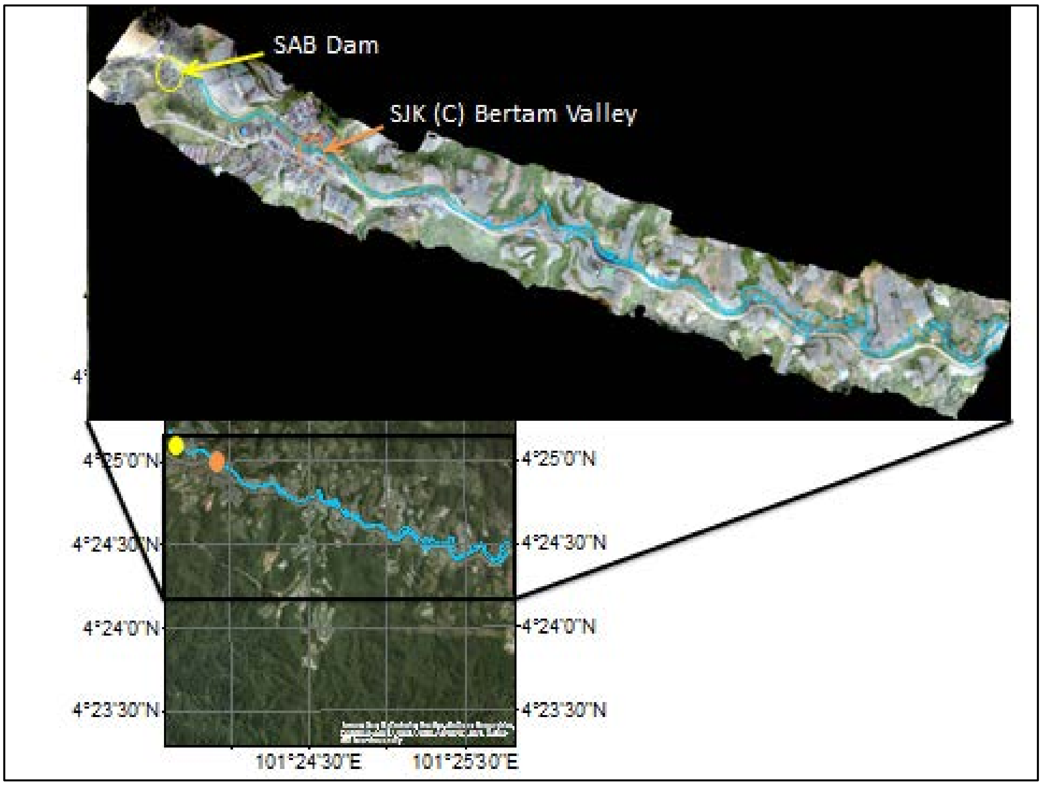

Figure 1: Downstream of SAB Dam in Cameron Highland from Esri, DigitalGlobe, GeoEye

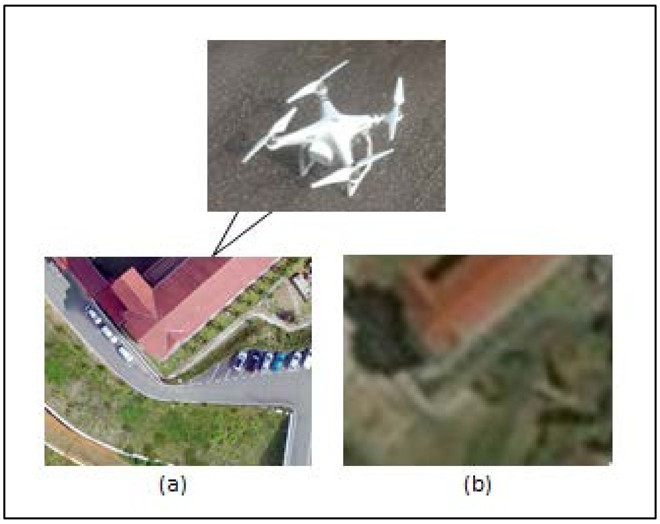

Figure 2: Images of SJK (C) Bertam Valley from (a) drone DJI Phantom4 and (b) Google Map

Other than giving a bird's-eye view of the landscape, drone also allows capturing high-resolution images of things on the ground. The resolution used was 0.5 m x 0.5 m. The area covered by the drone was 4 km and 200 m width as the impact of the dam released were the worst from the dam down to 4 km of Sungai Bertam and the flood plain along the side of the river. Figure 2 also explain the comparison of resolution between images of SJK(C) Bertam Valley captured by drone and satellite. Images collected by drone were called orthographic image which is higher in resolution thus give a more precise data in terms of topographic and elevation data.

3.2 Processing

2D flow modeling was accomplished by adding the 2D flow area elements into the model in the same manner as adding a storage area. A 2D flow area was added by drawing a 2D flow area polygon and developing the 2D computational mesh and directly connecting boundary conditions to the 2D areas.

The HEC-RAS project was started by setting the Spatial Reference Projection. It is an existing ".prj" file (ESRI projection file) that contains the correct coordinate system of the project.

In order to make terrain model, grid files were selected and placed in the appropriate order thus RAS Mapper had converted the grids into the GeoTIFF (*.tif) file format which is in compressed form. The GeoTIFF file structure supports tiled and pyramided data. Tiled data useless area of the terrain by removing the "NoData" values, while pyramided data stores multiple terrain layers of varying resolutions. Once the GeoTIFF flies were created, RAS Mapper also created a *.hdf file and a *.vrt file. The *.hdf (Hierarchical Data Format) file contains information on how the multiple GeoTIFF flies are stitched together. The *.vrt (Virtual Raster Translator) file is an XML file that contains information about all the raster files (*.tif). Once RAS Mapper has completed the conversion of the files to GeoTIFF and then created the HDF and VRT file, the new terrain layer was visible in the window.

The HEC-RAS 2D modeling capability uses a Finite-Volume solution scheme. This algorithm is developed to allow for the use of a structured or unstructured computational mesh. This step was to develop the 2D Computational Mesh. The computational meshing consists of Cell Center, Cell Faces and Cell Face Points.

Geometric data was edited by drawing a polygon boundary for the 2D area. The 2D flow area polygon represents the boundary of the 2D area. The best way to do this in HEC-RAS was to first bring in terrain data and aerial image into HEC-RAS mapper. Next, a computational point spacing in terms of DX=20 and DY=20 was entered. This defines the spacing between the computational grid-cell centers. As a result, a computational mesh that has grids was 20x20 everywhere except the outer boundary. The software will compute a series of X and Y coordinates for the cell centers.

The computational mesh will control the movement of water through the 2D flow area. Specifically, one water surface elevation is calculated for each grid cell center at each time step. The computational cell faces controlling the flow movement from cell to cell. Within HEC-RAS, the underlying terrain and the computational mesh are processed in order to develop detailed elevation-volume relationships for each cell and also detailed hydraulic property curves for each cell face (elevation vs. wetted perimeter, area and roughness). Manning's n value used was 0.04 which can be used to override the base Manning's n values where polygons and roughness are defined.

Unsteady Flow Data was edited by using external 2D flow area boundary conditions which were Normal Depth and Flow Hydrograph.

Normal Depth boundary conditions can only be used at locations where flow will leave a 2D flow area. In this project, it was used to set as the downstream boundary. The friction slope was 0.04 which was based on the land slope in the vicinity of the 2D flow area boundary condition line. The friction slope is used in manning's equation to compute a normal depth for each given flow, based on the cross section underneath the 2D boundary condition line.

Flow Hydrograph was used as the boundary condition for upstream as it represents the positive flow values that will send flow into a 2D flow area and negative values will take flow out of a 2D flow area. The required data for this boundary condition type is 1) flow hydrograph (Q vs time) and 2) energy slope (for computing normal depth). Energy slope is used to compute normal depth from the given flow rate and the underlying terrain data along the boundary. At any given time step, only a portion of the boundary condition line may be wet thus only the cells in which the water surface elevation is higher than their outer boundary face terrain will receive water. However, if the computed normal depth water surface is higher than all the boundary face elevation data along the boundary condition line, then all the cells will receive water based on a conveyance weighting approach.

Table 1: The Control Discharge Scenarios of SAB Dam

Discharge, m^3/s	Action
10	When necessary
25-30	Full opening of the hollow jet valve at 1070.76 m
50-100	Full opening of tilting gate located in spillway when the water level reached 1071.07 m

230	Two radial gates in operation at 1071.09 m
300	All gates are in operation at 1071.37 m

Table 1 shows the flow data as input in Flow Hydrograph. The flow was based on the opening of tilting and radial gates of SAB dam. Thus, the flow of 25, 30, 50, 100, 230 and 300 m^3/s was used as the discharge to simulate the discharge from the SAB dam.

The last stage in processing was to run the unsteady flow model. HEC-RAS applied Diffusive Wave and Saint-Venant equations in this model. Either one of these equations will be used based on the study. In this case, Diffusive Wave equations were set as default.

The computations were performed by making a plan by selecting the geometry that contains the 2D data, unsteady-flow file for the event to run was selected, the Plan was given a Title and a Short-ID. Programs to Run which are Geometry Processor, Unsteady Flow Simulation, Post Processor and Floodplain Mapping were selected. The Simulation Time Window was filled based on the time entered in the Flow Hydrograph. The model was simulated on February 1^{st,} 2017 24:00 until February 2^{nd,} 2017 04:00 The Computational Settings were set for 1 minute.

After the program has completed the unsteady flow computations, a separate process called "ComputeFloodMAps.exe" was run in order to generate a depth grid (stored to disk) of the maximum inundation that occurred at all locations in the model.

3.3 Postprocessing

By default, after a successful HEC-RAS model run, three result layers called depth, velocity and elevation were displayed. Inundation boundary map was produced by adding a new map and computed it. The data from inundation boundary map was saved and exported in shapefile. These data were used to develop a flood hazard map. The data was added in ArcGIS v.10. Shapefile data then produced lines of the colored boundary along Sungai Bertam. The combination of lines shows the extent of water based on the discharge from the SAB dam. Flood Hazard Map was produced as shown in Figure 3.

4. DISCUSSION

Figure 3 shows the Flood Hazard Map resulted from the simulation of the SAB dam release. For a clearer view, the point was observed from the riverbank of Sungai Bertam towards the selected location. SJK (C) Bertam Valley was taken as a reference as it acts as a relief center in Bertam Valley. Based on Google Map, it is located at the coordinate of (4.416681, 101.399053) and approximately at a distance of 704 m from the SAB dam. SJK(C) Bertam Valley is located 28.72 m away from the riverbank.

Table 2: Comparison of Water Discharge from the Dam Towards SJK (C) Bertam.

Discharge, Q (m^3/s)	The depth of Water, y (m)	The velocity of Water, v (m/s)	Arrival Time, t (hour)
10	1.49	0.76	0.43
25	2.25	1.38	0.40
30	2.93	1.53	0.40
50	3.86	1.68	0.37
100	5.46	2.08	0.35
230	7.62	2.96	0.33
300	8.85	3.18	0.32

As shown in Table 2, discharge of 25 m^3/s has already inundated the SJK(C) Bertam Valley area with depth and velocity of 2.25 m and 1.38 m/s respectively. This explains that residents of Bertam Valley unable to use the school as the relief centre as water level that inundates the area will increase as the water discharge increase. The time observed for the discharge to arrive at the school was 0.4 hour (24 minutes) which is less than an hour.

The depth of water resulted from water discharge of 100 m^3/s is 5.46 and the velocity is 2.08 m/s. The simulation shows that the depth and velocity of water increase as the flow increase. The arrival time has become shortened to 0.35 hour which equals to 21 minutes before the flow reached SJK(C) Bertam Valley. This could lead to loss of lives and damage of properties.

Water discharge of 50m^3/s has already flooded the riverbank near to SJK (C) Bertam Valley. This shows that locations near the riverbank of Sungai Bertam were prone to flood plain area.

Different water released data inflow hydrograph give different spatial extent area of inundation boundary. Inundation boundary is a combination of maximum velocity and maximum depth resulted from the simulation of water released from the dam. The higher the amount of water discharge, the wider the spatial extent of inundation boundary.

Inundation boundary was a result of the maximum depth from the unsteady flow simulation. It also shows the spatial extent and depth of flooding at specific water-level (stream-stage) intervals along an individual stream section.

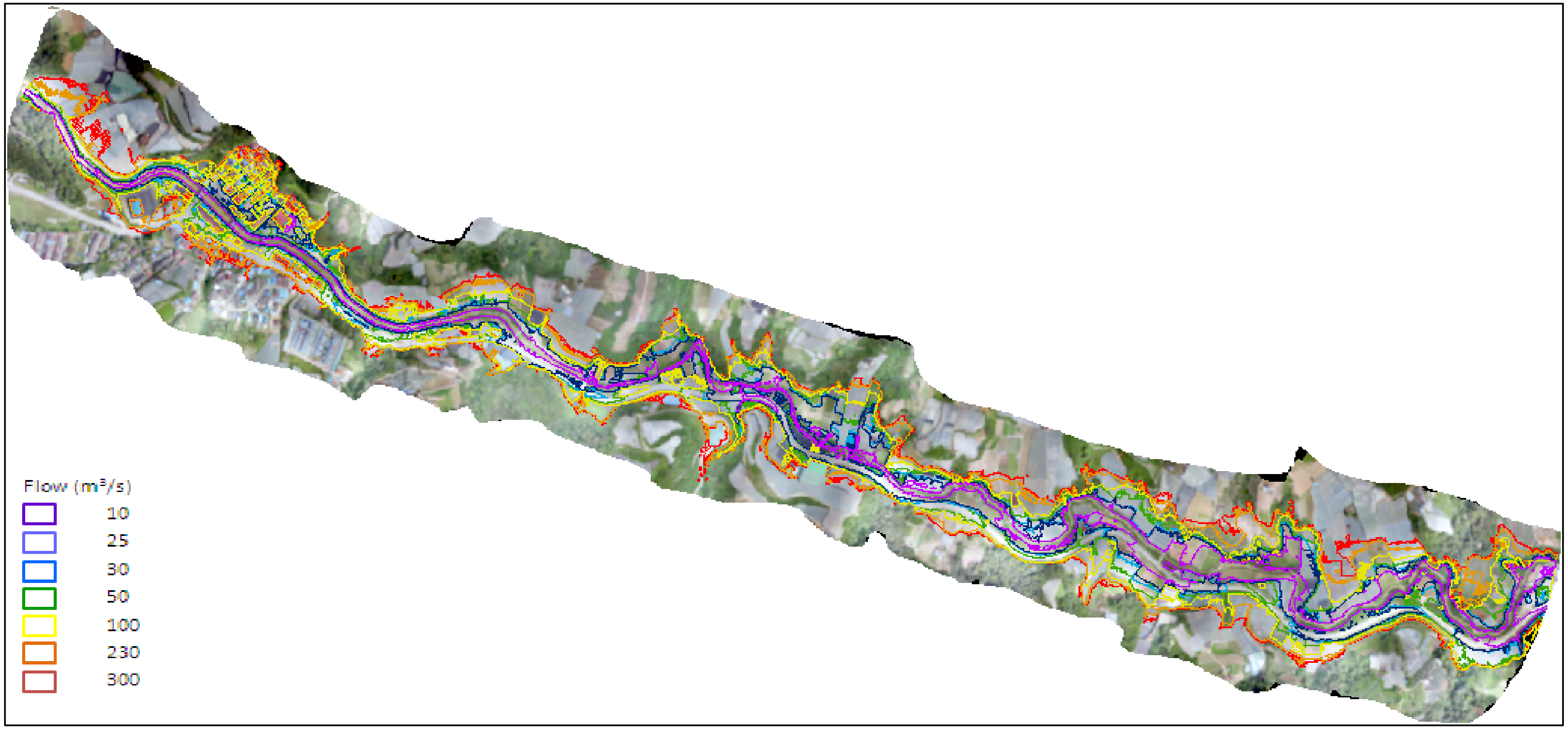

Figure **3**: Flood Hazard Map based on Release from SAB Dam

The data from inundation boundary helps to produce flood hazard map for downstream of SAB dam. Figure 3 shows that water discharge from the dam which was 10, 25, 30, 50, 100, 230 and 300 m^3/s has resulted in a combination of the different level of hazard. As the water discharge increase, the level of hazard increase.

In this study, the unsteady flow simulation results in flood hazard map which shows the flooding on the flood plain area. In order to produce a flood hazard map, a simulation of water released from the SAB dam to the downstream area was required. Thus, from the unsteady flow simulation, a maximum velocity, maximum depth, and arrival time maps were produced. The output from the simulation helps in getting a clearer view of what will happen in the flood plain area based on different water released.

The maximum velocity indicates the flood wave's energy as it flows along Sungai Bertam. At lowest water released which was 10 m^3/s has produced a maximum velocity of 2.54 m/s at 4 km downstream area. This situation shows that high velocity of water can cause significant damage to residents' house and agriculture farms along the river.

Arrival time indicates the time for the flood wave to arrive at specific locations downstream of the SAB dam along Sungai Bertam. As for water released of 10 m^3/s, the arrival time at 4 km of Sungai Bertam was 2.65 hour which equals to 159 minutes. Compare to the discharge of 100 m^3/s, the time of arrival at the similar location was only 133 minute (2.210 hours). The energy from the velocity of water released helps in increasing the arrival time of the flow to reach the downstream area. Arrival time helps the residents of the village along the Sungai Bertam to predict the time taken for the flood wave to reach their resident location. Thus, this will give time for preparation after heard the siren warning from the upstream dam.

Maximum depth indicates the extent of water flow can reach on land. The maximum depth resulting from water released of 10 m^3/s was 2.32 m. This scenario shows that the water from the river has overflowed from the riverbank and flooded the flood plain area.

The simulation result shows that the flood event had inundated the downstream area of Sungai Bertam village. The hydrograph shows that release from SAB dam with 50 m^3/s has inundated the downstream area.

Based on the previous study, maximum opening of the dam's gate which includes three full opening radial gates in order to release water produced 300m^3/s of water discharge. 300 m^3/s of water released from the dam will lead to a huge disaster and loss based on flood hazard map in Figure 3.

5. CONCLUSIONS

Floods occur in Sungai Bertam on 23 October 2013 probably due to uncontrolled discharge released from Sultan Abu Bakar (SAB) dam. The increasing of flood events in Sungai Bertam can cause a nuisance to the residence and destroy agriculture farms. A two-dimensional model was applied in this study to simulate SAB dam release. The objectives in this study were to evaluate flood inundation area and to produce flood hazard map which able to predict risk area of flooding.

The two-dimensional modeling and Digital Elevation Data (DEM) has been created by using HEC-RAS and ArcGIS software. The numerical result shows that the 2D model based on Diffusive Wave equation can capture the behavior of water released while showing unsteady flow features. Input for unsteady flow data was based on the dam release operated by SAB dam authorities which were 10, 25, 30, 50, 100, 230 and 300 m^3/s for three hours period. The results are presented in mapping formats of maximum velocity, arrival time, maximum depth and inundation boundary based on water discharge from SAB dam. As a result, flood hazard map was produced. Authorities and villagers of Bertam Valley should aware with this information and use it in case a big volume of water needs to be discharged from the SAB dam.

The simulation shows that water release more than 50 m^3/s of will cause river overflows from its riverbank. The flood plain area is indicated based on the maximum depth of water extent. It can be stated that this model using relatively auto input data, DEM captured by drone can simulate the water level and flood-affected areas. In conclusion, HEC-RAS is a useful tool in producing flood hazard map resultant from a combination of inundation boundary. Both of the objectives in this study were achieved.

6. ACKNOWLEDGMENTS

The authors acknowledge TNB Research Sdn Bhd for providing a grant for this project 'Gated Spillway Hydraulics Modeling of SAB Dam and the Structural Analysis of Tilting Gate'.

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