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Application of HEC-RAS Model for Flood Inundation Mapping in Sungai Golok, Rantau Panjang

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Abstract
Flooding is a constant concern to achieve the Sustainable Development Goals (SDGs) in Malaysia, particularly in the state of Kelantan. This study focused on the issue of floods triggered by Sungai Golok from a hydraulics viewpoint. The goal of this study was to develop a flood mapping along Sungai Golok in Rantau Panjang town that specifically aimed at reducing floods and impacts on SDGs. The dry and wet areas on the flood mapping were simulated using Average Recurrence Interval (ARI) for a staggered period of 10 years, 50 years, and 100 years. An unsteady flow analysis was performed with the aid of the Hydrological Engineering Centre – River Analysis System (HEC-RAS). In addition to that, this study deployed the QGIS tool to develop and re-project an appropriate topographical profile of the Rantau Panjang region. It was determined that the value of 0.035 for the Manning's was acceptable because all data for the initial calibration satisfies the condition of relative percentage difference RPD ≤ 25%. The HEC-RAS concluding outcome was calibrated and validated using statistical testing. The extent of the floods on 19 February 2016, and after 10 years later was found to be generally comparable in magnitude. After a period of 50 years, an increase in the discharge to 119 m^3/s caused the flood's magnitude to expand at a faster rate. With a peak flow of 140 m^3/s after a period of 100 years, it proved that the whole area will be inundated in floods. Highlighting these SDGs' aim at achieving healthier lives and well-being of the inhabitants, the flood mapping is essential in the flood risk area to forecast the varying patterns of floods, which in turn used to ascertain the level of flooding in Rantau Panjang and subsequently reduce the impacts.
Keywords: HEC-RAS, Flood, Mapping, Sungai Golok, Rantau Panjang

Introduction

The occurrence of floods in Kelantan over an extended time has worsened due to geological factors, leading to massive losses to humans and assets (Zaidee et al., 2018). The days of constant intense rainfall have exacerbated flooding. Since 2014, the monsoon heavy downpours have been the primary contributory cause of such catastrophic disaster in Kelantan. The prolonged rain has enlarged the impounded area, pushing the water level above the riverbanks, and causing flood in the surrounding areas. The annual flood has been portrayed as a calamity since it occurs every year during the monsoon season. Ipso facto, the consequences of the flash flood have brought about tremendous loss and destruction of properties. Collaboration between all parties in combatting the flood disaster is critical whilst ensuring the safety of livelihoods and environmental sustainability in the area. Although flood control strategies have been deployed to effectively mitigate flood damage, the area was still washed over with floodwaters due to persistent heavy rain. This uncertainty caused by the heavy downpour is the crucial issue. It needs to be addressed and understood by way of its pattern and impacts. Estimation of the surface runoff and flow rates of the Sungai Golok is required to foresee flooding event. As aforesaid, the most efficient feasible mitigation measures are those that require engineering works to resolve and prevent flood-related problems, including the use of HEC-RAS software to forecast flood occurrence (S. Jamaludin, 2017).

Literature Review

Flooding

As water levels and discharges rise over a set threshold, it becomes possible for water to leave its natural confines (E. Sathiamurthy et al., 2019). Severe rainfall in areas where the discharge capacity has been surpassed causes flooding to occur when a body of water had overflows (Abd Hamid et al., 2020). When a river or stream's capacity is exceeded, flooding will occur naturally. Excessive rainfall causes flooding because the soil's absorption capacity and the flow capacity of rivers in the affected area are overwhelmed (Shaari et al., 2016). As a result, the stream overflows its banks and floods adjacent land. Year after year, flooding conditions may deteriorate due to human activity on the Earth's surface. Residents of the impacted region were forced to cope with the situation, which necessitated their evacuation and relocation of personal belongings to a secure position (Ahmad et al., 2016). Due to the difficulty of forecasting floods, these unpredictable events must always be ready positioned to react.

Causes of Flooding

There has been an alarming rise in the flood danger in Malaysia in recent decades, according to studies (Zaidee et al., 2018). This is due to human actions, such as encroachment on flood-prone regions, destruction of forest, and hillside development, that have altered the hydrological system's physical properties. According to Bahar et al (2014), rapidly industrialising developing countries face an increased risk of environmental disaster. The study of flood hazards in Peninsular Malaysia exemplifies these concerns admirably. The evidence indicates that Malaysia's increasing flood hazard is primarily a result of the country's rapid urbanisation and development. Natural catastrophes and human activity are the two most prominent causes of flooding in Malaysia. When flooding happens due to natural factors, it is triggered by prolonged periods of heavy rainfall, resulting in flash flooding (Nayan et al., 2017). Moreover, heavy rains caused floods, which resulted in stagnation in some areas, which will result in flooding. Human activity has a significant impact on floods, as evidenced by the discharge of solid waste into rivers, the accumulation of silt from land clearing and construction, the expansion of impermeable surfaces, and the construction of dams and other barriers in rivers (Shaari et al., 2016).

Flood Map

Flood mapping is critical for the effective sustainable management of flood risks and risk reduction strategies. It helps to minimise the damage and losses caused by flooding (Ghazali et al., 2019). As a result of flood maps, the community is aware in seeking out flood-related information and attentively alert to any issued or warnings. Flood maps assist communities and individuals in determining flood risk and preparing appropriately (Desalegn et al., 2021). It is important to determine where the dry and wet areas were located when the flood taking place. Through community-based flood mapping exercises, it is possible to identify safe evacuation routes, areas for emergency shelters, and those primarily prone to floods.

Modelling using HEC-RAS

The Hydrologic Engineering Centre has created a series of hydrologic engineering software tools dubbed the modelling system. HEC-RAS is frequently used to simulate hydraulic models for flood prevention alternative. HEC-RAS is a fully integrated software system designed for interactive use in multi-tasking surroundings (Diedhiou et al., 2020). As contrast to hydrologic models, hydraulic models are marginally more accurate in depicting reality (Diedhiou et al., 2020). Hydraulic models can forecast changes and generate floodplains (Desalegn et al., 2021).

Components of a River Study

Open channels and floodplains are simulated in one, two, and combination one/two-dimensionally using the HEC-RAS modelling system component. In the module's unsteady flow computations module, subcritical, supercritical, hydraulic jumps, and drawdowns for subcritical, supercritical, and mixed flow regimes are calculated. The unsteady flow module inherited the steady flow component's hydraulic calculations for cross-sections, bridges, culverts, and other hydraulic structures (ShahiriParsa et al., 2016). The unsteady flow component enables extensive hydraulic structure analysis, breaching and overtopping, pumping stations, navigation dam operations, pressurised pipe systems, automated calibration features, user-defined rules, and combined one- and two-dimensional unsteady flow modelling.

Calibration and Validation

Models are only able to provide an approximation of the truth due to their inability to accurately depict the functioning of natural systems (Prafulkumar et al., 2011). The statistical testing is widely used to validate a model owing to its indicator that grouping the result into multiple groups either it passes or not. In most circumstances, statistical testing is often used to check a model owing to its indicator that grouping the result into multiple groups either it passes or not. A modification is made to the Manning's coefficient (n), and this is done so that HEC-RAS may be verified to ensure that it is functioning correctly in line with real-world conditions (Parhi et al., 2012). The water level of the river will be calibrated in relation to the real survey data once the simulation model has been completely run to completion. The value of the manning’s will be modified until the percentage difference between the simulated water level and the observed water level is less than the minimum standard (Pappenberger et al., 2005). As part of the process of validating the model, the corrected value of the calibrated parameter, also known as the new Manning's value, will be utilized by the verified model. The flood mapping is developed for potential future flood forecasting (e.g., 10 years, 50 years,100 years).

Methodology
Modeling Process
The flow of HEC-RAS modelling process is depicted in Figure 3.1. When utilizing HEC-RAS simulation, the most crucial component that will be inserted into the model is the necessary geometry and streamflow data.

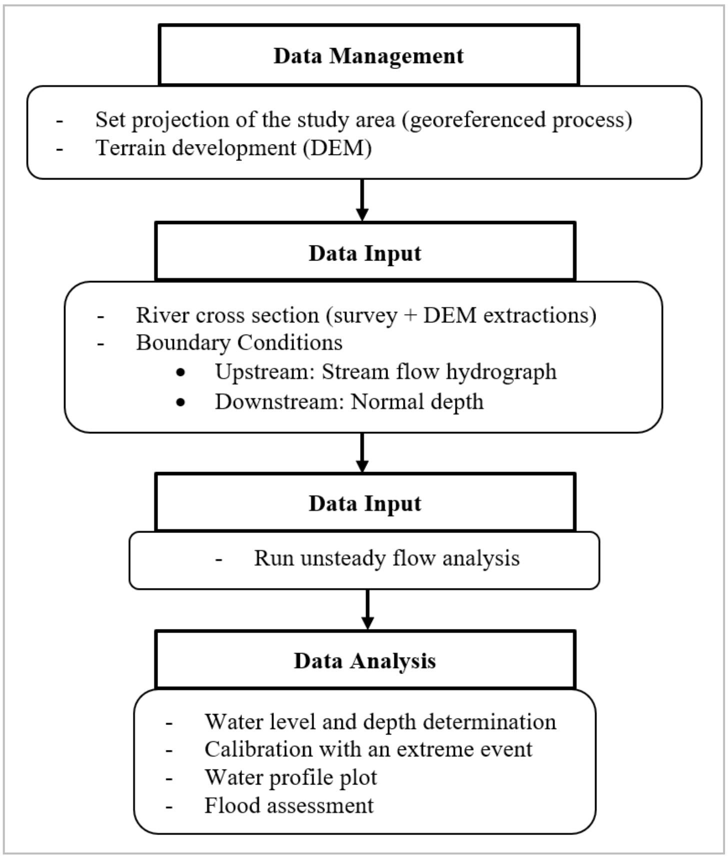


Figure 3.1: Conceptual flow chart of HEC-RAS model.

Model Development
The HEC-RAS software can develop the simulation by incorporating both geometry and streamflow data. HEC-RAS is a hydraulic analysis instrument that analyses stream channels based on various characteristics. The use of digital elevation models (DEMs) in flood inundation modelling is essential. Figure 3.2 displays the DEM acquisition via QGIS Tisler during this study. Since the interface of QGIS encompassed the entire world, to identify the area extent, it had to be done manually in QGIS. This is because QGIS has grids of values that represent differences in elevation throughout a region. In the following step, the generated DEM will be reprojected directly within the QGIS. This DEM, also known as a digital elevation model, utilizes the 'tiff' file type to present this topographical profile.

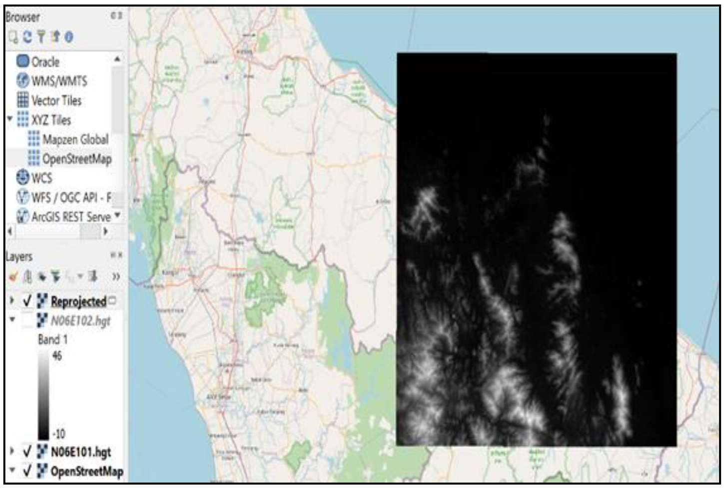


Figure 3.2: Conceptual flow chart of HEC-RAS model.

As shown in Figure 3.2, polygons are utilized in the process of assigning 2D flow regions. When working with flow regions in two dimensions, wetted-perimeter friction is considered at the boundary. The system will automatically refine the two-dimensional mesh to suit the geometry of the 2D flow region. The boundary condition then needs to be drawn both upstream and downstream of the river to complete the analysis. For the software system to be able to begin the calculating process, it is necessary to have a boundary condition that determines the beginning water level at the end of the river. To ensure that the flood event completely covers the floodplain, the manner of drawing must strictly comply to the rules that have been established. After the boundary condition line and the 2D Flow Area had been created,

The 2D Flow Area editor had been selected to create the mesh where the computation point will be generated, as shown in Figure 3.2. For the purposes of this study, a mesh grid of 10 m by 10 m was chosen to be used in the development of the polygons. When there is less of a gap between each element, the mesh produced is finer and the outcome is more accurate. For the first attempt, the value of Manning's Roughness that was decided upon was 0.035. According to the Masma 2nd Edition, a value of 0.035 indicates that the river has a grassed channel

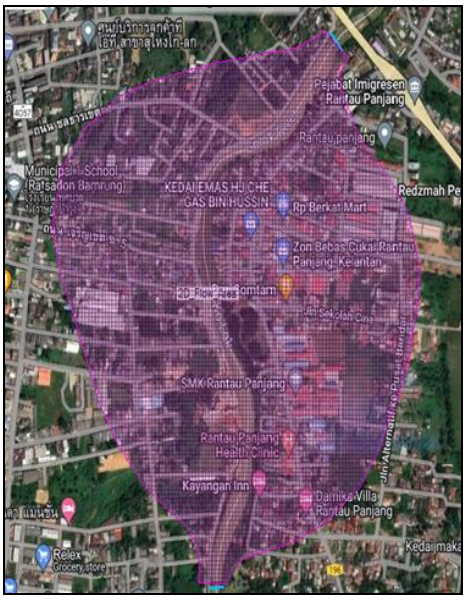


Figure 3.2: 2D flow area of the flood map.

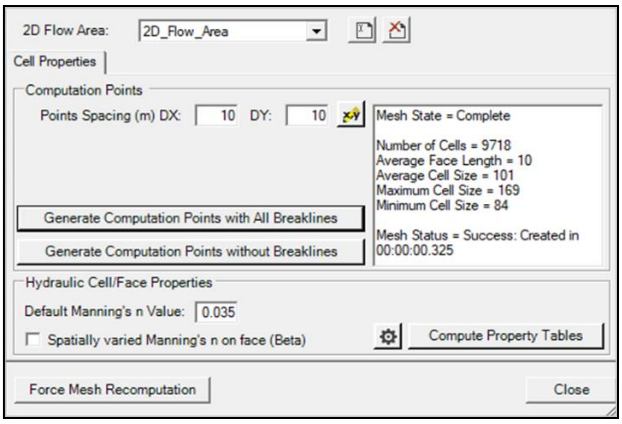


Figure 3.3: 2D flow area editor.

Using normal depth as a boundary condition in HEC-RAS signifies that it was assumed that the downstream cross section was flowing under uniform circumstances. It is more accurate. depicts the circumstances of the actual stream. As seen in Figure 3.4, the value of slope that was used is 0.001. The slope value was measured approximatively by utilizing a topographic map to locate the points where topographical lines intersect the stream, and then measuring the distance streamwise between those points.

Figure 3.5 illustrates how a flow hydrograph may serve as either an upstream or a downstream boundary condition, but it is more commonly utilized as an upstream boundary condition. To manually input the hydrograph ordinates, the proper date-time interval had to be chosen from the list of time intervals that were permitted. The Fixed Start Time option has been chosen, the hydrograph will be entered beginning at the time and date that the user has defined.

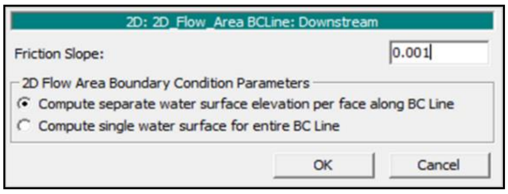
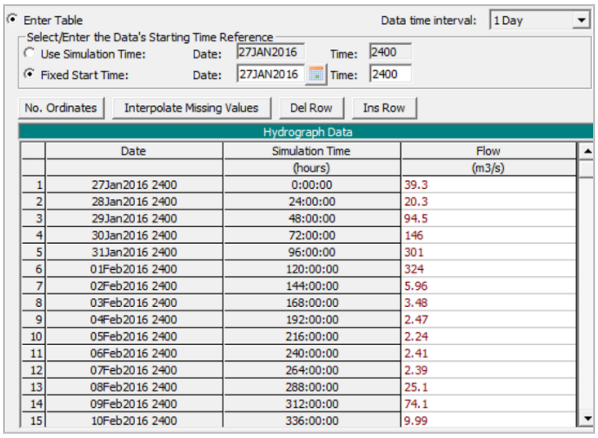


Figure 3.4: Normal depth at downstream boundary.



	Date	Simulation Time (hours)	Flow (m3/s)
1	27Jan2016 2400	0:00:00	39.3
2	28Jan2016 2400	24:00:00	20.3
3	29Jan2016 2400	48:00:00	94.5
4	30Jan2016 2400	72:00:00	146
5	31Jan2016 2400	96:00:00	301
6	01Feb2016 2400	120:00:00	324
7	02Feb2016 2400	144:00:00	5.96
8	03Feb2016 2400	168:00:00	3.48
9	04Feb2016 2400	192:00:00	2.47
10	05Feb2016 2400	216:00:00	2.24
11	06Feb2016 2400	240:00:00	2.41
12	07Feb2016 2400	264:00:00	2.39
13	08Feb2016 2400	288:00:00	25.1
14	09Feb2016 2400	312:00:00	74.1
15	10Feb2016 2400	336:00:00	9.99

Figure 3.5: Flow hydrograph at upstream boundary.

Figure 3.6 illustrates the need to do an unsteady flow analysis at the end of the procedure. The programmed will run with all its components, which include the Geometry Pre-processor,

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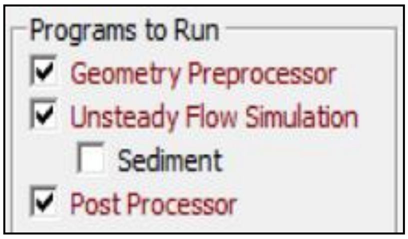
Unsteady Flow Simulation and Post-processor which is the most crucial component. The simulation may be computed. If there is any error, the alert notification will show up, and as a result, the computation cannot be continued. As seen in Figure 3.7, the presence of all three blue lines indicates that the computation was completed successfully, and the result is analyzed.



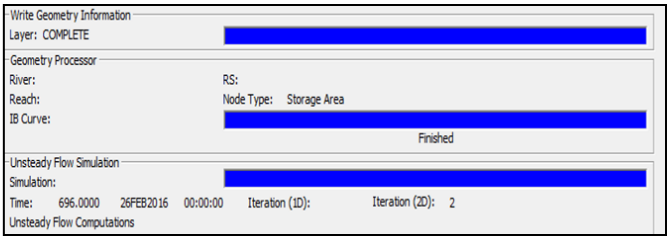


Figure 3.6: Unsteady flow analysis. Figure 3.7: HEC-RAS computation.

Calibration and Validation

During the calibration phase, all input cross-sections from upstream to downstream data points are merged into the model. Upon entering all relevant information, the HEC-RAS model is used to calculate the water level at each canal station, followed by comparing the simulated and observed water depths at each station. The procedure is repeated continuously until the distinction between the simulated and observed water depths is attained. HEC-RAS software is capable in generating flow discharge data. The percentage difference of the results will be calculated to facilitate the process of analyzing the flooding that occurs. Table 3.1 shows the classification of relative percentage difference which stated that if the percentage difference is rejected the calibration and validation process need to be repeated. The relative percentage difference (RPD) that will be determined using the formula in Equation (1).

$$RPD = \frac{Q_{Obs} - Q_{Sim}}{Q_{Obs}} \times 100 \qquad (1)$$

Table 3.1
The Classification of RPD.

Limit	Indicator
RPD ≤ ±10%	Very good
±10% < RPD ≤ ±15%	Good
±15 < RPD ≤ ±25%	Satisfactory
RPD > 25%	Unacceptable. Both calibration and validation process must be repeated

Validation of models is a technique for determining whether a model can accurately regenerate measurable data not used for validation within a specified accuracy range. This approach is used to find the criteria for model parameters that result in a minimum of variation between measured and simulated values. Validations are required to demonstrate the software's output's reliability. The accuracy of the calibrated parameter (Manning's "n") is determined by comparing it to the new simulated water level and real water depth for verification of the model. The model's relevancy is assessed by comparing the simulated and observed water depths using several statistical analyses.

Results and Discussion

First Calibration

The line graph depicted in Figure 4.1 shows the observed water level in comparison to the simulated water level. According to the graph, the maximum simulated water level occurred on 31 January 2010, at 14.36 m, whereas the highest observed water level occurred at 15.85 m is on 23 Jan 2010. The effectiveness of the software has been proven by the fact that the highest simulated water level is lower than the highest observed water level, which makes the result fulfil RPD requirements.

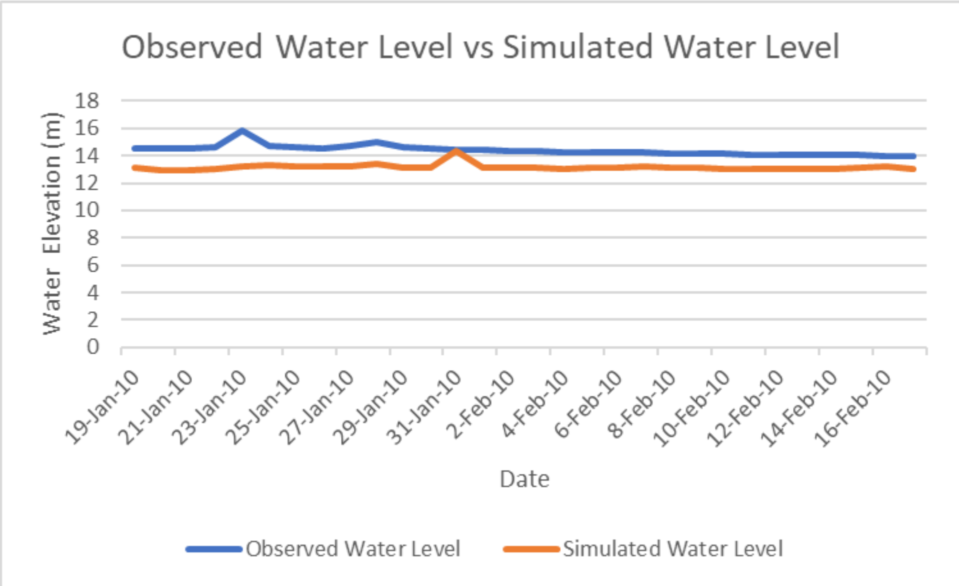


Figure 4.1: Observed Water Level vs Simulated Water Level for 1st Calibration.

Second Calibration

The line graph depicted in Figure 4.2 shows the observed water level in comparison to the simulated water level. According to the graph, the maximum simulated water level occurred on 2 January 2013, at 15.32 m, whereas the highest observed water level occurred at 17.99 m. The result fulfils RPD requirements.

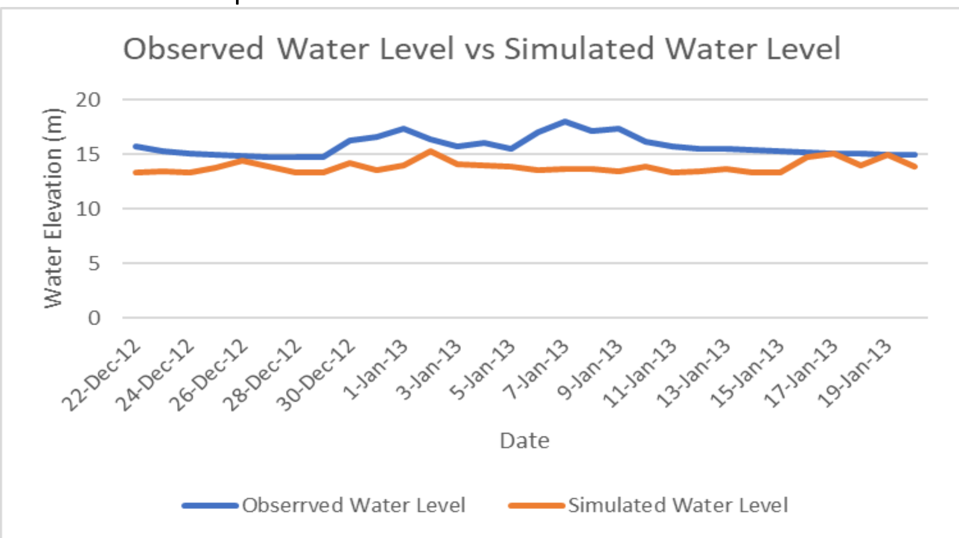


Figure 4.2: Observed Water Level vs Simulated Water Level for 2nd Calibration.

Validation

The line graph depicted in Figure 4.3 shows the observed water level in comparison to the simulated water level. According to the graph, the maximum simulated water level occurred on 19 February 2016, at 15.15 m, whereas the highest observed water level occurred at 14.88 m. The results meet RPD requirements shows that the simulation fit the validation pupose.

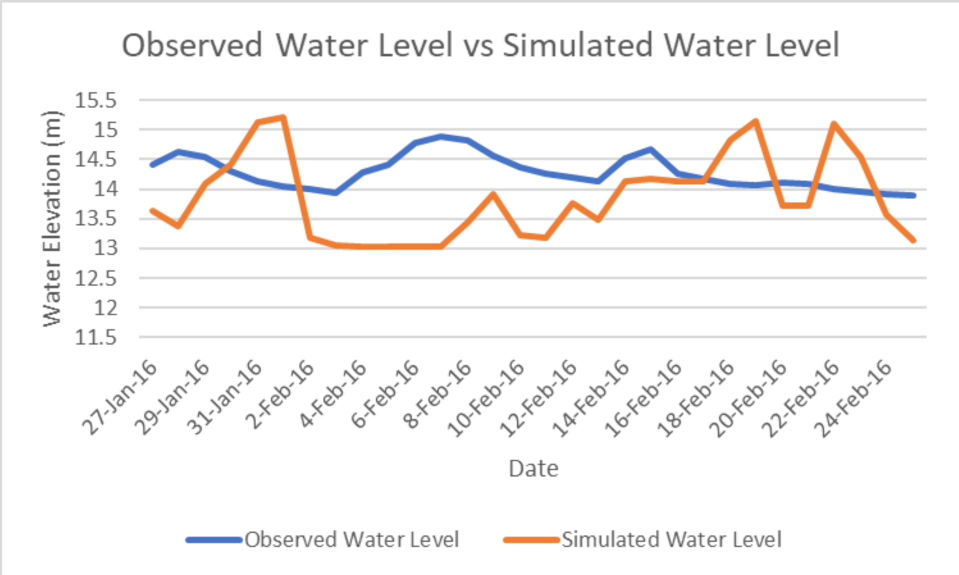


Figure 4.3: Observed Water Level vs Simulated Water Level for Validation

Gumbel's Distribution Method

The Gumbel Distribution is a representation of the distribution of samples with extreme values, either the maximum or the lowest of those employed in different distributions. In this study, the peak discharge of Sungai Golok along Rantau Panjang town was calculated for the next ARI 10 years, 50 years, and 100 years to anticipate the occurrence of floods in the future (Table 4.1).

Table 4.1: Peak Discharge Estimated Using Gumbel's Distribution.

Return Period, T	**Peak Discharge (m^3/s)**
10 years	68
50 years	119
100 years	140

Comparison of flood map based on ARI

The case study was conducted at the Sungai Golok in Rantau Panjang, Kelantan. The total length of Sungai Golok is 103 kilometers, the specific area chosen as study area is located at the center of city area. The comparison between the flood map produced is shown in Figure 4.4. The magnitude of the flooding had grown significantly because of the passage of time. The extent of the floods on 19 February 2016, and ARI 10 years are generally comparable in magnitude. The peak flow at 10 years ARI is 68 m^3/s. For ARI 50 years, the discharge is 119 m^3/s that shown in Figure 4,4 that the flood's magnitude has expanded on the map. During ARI 50 years, almost the whole area flooded and least spots of dry areas. With a peak flow of 140 m^3/s of 100 years ARI, there whole study area is inundated. The high value of discharge has caused the overflow from Sungai Golok, which subsequently submerged the region of Rantau Panjang town and at the same time caused flooding in the territory of Thailand. The modelled flood map, make it possible to anticipate the flooding disaster that will occur in the future and mitigation measures that may be taken.

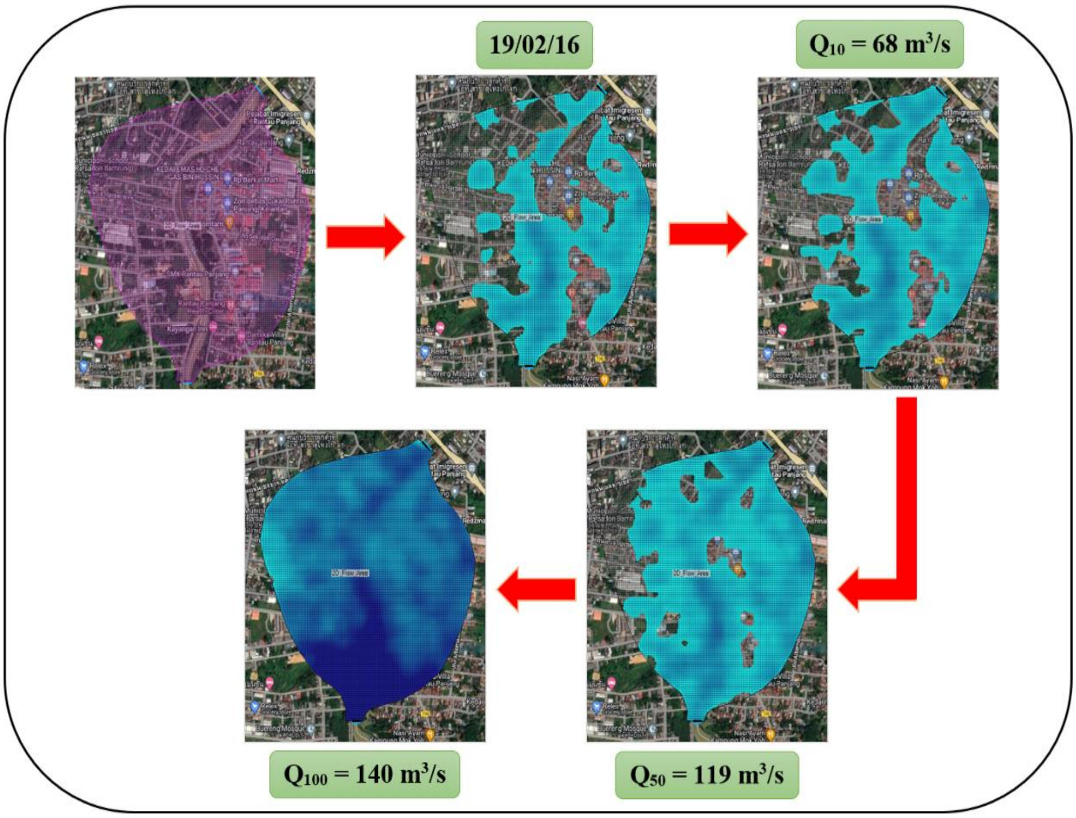


Figure 4.4: Comparisons of Flood Extent.

Conclusion

The 1D unsteady simulation was utilized for the purpose of calibration and validation, while the 2D unsteady simulation was utilized to acquire the flood mapping at Rantau Panjang. The increased socio flood mapping is essential for river basin that possess to flood risk. The flood maps the areas that are dry and those that are wet can be distinguished. In addition to that, the flood prediction for the following 10 years, 50 years, and 100 years have all been applied in this study. As a result, this will be used for early flood warning system and offer information for the surrounding community. The community can get themselves ready for the forthcoming flood disaster in the future. With a peak flow of 140 m^3/s after a period of 100 years, it proved that the whole area will be inundated in floods. Highlighting these SDGs' aim at achieving healthier lives and well-being of the inhabitants, the flood mapping is essential in the flood risk area to forecast the varying patterns of floods, which in turn used to ascertain the level of flooding in Rantau Panjang and subsequently reduce the impacts.

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