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Flood Modelling Studies Using River Analysis System (HEC-RAS) For Flood Plain Area in Muar City

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Abstract: Floods are the most frequent type of natural disaster and occur when heavy precipitation for days or even weeks. Floods will cause extensive destruction, resulting in loss of life and disruption to personal property and vital infrastructure for public health. In this study, HEC-RAS model was used to identify the flood prone area and to determine cross section at floodplain area along the stream network. The study was conducted in the area Muar, Johor. The methodology involved collection of parameters such as length of stream, lateral & elevation of coordinates, streamline and flow data to perform a hydraulic simulation. Different value of flowrate had been used by using the manning equation to estimate the drainage or channel capability to manage the flowrate. The number of station for each cross section need to locate in order to simulate the cross section along the river or channel. Meanwhile, the result outcome will show the cross section for each station. From the result, the analysis of the cross section include with the affected area of floodplain was identified. According to the hydraulic model generated by HEC-RAS software, 7 of 20 stations found will be flood for the 10 years return period since they were unable to accommodate the water flow. By doing this research, the flood model will be developed and HEC-RAS software is one of the tool that can analyse and model for the floodplain area. In a meantime, the government can control and give an early warning about the flood incident.

Keywords: Floods, HEC-RAS, Hydraulic Simulation, Floodplain Area

1. Introduction

Natural disasters are one of human beings that cannot be prevent which humans can only reduce the maximum number of injuries and predict when it will happen. Among the natural disasters that often-hit Malaysia almost every year are floods. Natural disasters will give many negative effects on human beings and it is also a major human issue. Continuous rains can cause floods. When flooding from the sea, flood insulation will overflow and this natural fortress will be lost. Floods occur when an area, often low-lying areas, submerged in water.

Every year, it has been reported that Muar City area experiences seasonal floods from October to January. Recently, heavy rainfall has caused flash floods to hit 22 areas in Muar district. This flood event was reportedly happened due to heavy rainfall and high tide phenomenon which affected several areas under Muar Municipal Council (MPM) and caused damage to public assets and infrastructure such as houses, buildings, roads and others. The affected areas were Kampung Sabak Awor, Kampung Seri Menanti, Kampung Parit Tengah, Jalan Bentayan, Parit Perupok, Pekan Bukit Bakri, Taman Temiang Jaya, Jalan Kim Kee dan Kampung Dato Seri Amar Diraja.

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This study will focus on the area that prone to flood. The study conducted in Bakri, Muar in Johor and the area was 191 km^2. The areas of the study are concentrated on the area at Jalan Bakri. Bakri, a town in Muar district suffers from frequent floods that bring environmental importance and also property damage. An area hit by flood not only because of precipitation, but also because the overall flow rate of the drainage system exceeds the potential that can be accommodated by the system [1]. Determining the causes of flooding, its impact towards local population and the effectiveness of man-made drainage system in Muar town area as well as producing flood modelling and this study will be conducted to identified flood from recurring or reducing the flood impacts that further destroyed the public assets.

For the estimation of flood danger, flood modeling is important to demonstrate the severity of a flood to a certain probability of excess [2] while its function is to perform a flood mapping the area of study. Flood modelling can be performed by using computer model tools such as Hydrologic Engineering Center's River Analysis System (HEC-RAS). HEC-RAS is a good software to analyse channel flow and delineation of floodplains [3]. Flood modelling is an important tool to determine an area that is prone to flood. As in Muar City the resident bears a lot of economic loss due to the floods. The floods cause the damage of human property like house, furniture and other things that they have to suffer. The government also have to spend millions of money to repair the damages by flood such as road and traffic light. HEC-RAS can help to monitor floodplain management and can give an early warning if flood happen. Hence, this study aimed to identify the floodplain area in Muar and simulate cross section at flood prone area along the stream network so that the government can conduct a good disaster management.

2. HEC - RAS

Since years ago, floods are the one of the common natural disasters that causing significant economic and property destruction as well as the loss of human life. The mapping of the river flood is the process by comparing the river water levels to the surface elevation to identify flood levels and flood depth. The process requires an insight into fluid dynamics, topographical relations and the modeler's sound assessments [4]. The flood hazard maps may contain depth of water, extent of flooding, flow speeds and duration of flooding. This is a fundamental and important indicator for the development and regulation on the floodplain land use.

The Hydrologic Engineering Centre (HEC) of the US Army Engineering Corps initiated flood hazard mapping in 1988 in the United States. The study mainly aims to produce flood risk map for the national insurance programme (NFIP) because private insurance companies are reluctant to provide insurance policies as a consequence of disastrous losses [5]. The advances in technology such as Hydrologic Engineering Centre - River Analysis System (HEC-RAS) can make it possible to identify flood susceptible areas, prospective inundation depths, and areal extents which may then be utilized to build flood risk maps for specific places. The risk maps that have been created can be used to identify vital zones, send out early warnings to individuals in the event of a potential incident, and assist in making administrative choices in the event of an emergency [6].

The flood modelling software will be used to prepare flood analysis. Hence, this software will assist in identifying food prone areas and more flood plain will be created. In addition, urban planning and development can also be implemented without experiencing the high risk of flood disasters. The effectiveness of man-made drainage system can be improved in maximizing the flow rates of water during monsoon seasons. Short-term and long-term solutions will be suggested to achieve the objectives of this study. The HEC-RAS software is commonly used modelling piece of software to utilize flood modelling in hydrodynamic simulation [7], [8]. HEC-RAS (Hydraulic Engineering Centre River Analysis System) is a tool developed by the US Army Corps of Engineers for hydraulic modelling for a variety of application. This model can be used for both steady and unsteady flow [8]-[10]. This model is developed to perform simulations of 1D steady flow and 2D unsteady flow for a river flow analysis, as well as sediment transport and modelling of water temperature and water quality [7]. The software is readily available and has accurate calibration precision [11]. Since its inception, HEC-RAS has grown significantly over time. Many new features have been developed by this tool to overcome the problem of flooding in rivers and simulations the flood modelling. The earliest version of this software only allowed 1D steady flow analysis while for the version 3.0 had been released in January 2001, included the computation of 1D unsteady flow. For the latest version of HEC-RAS 5.0 released in 2016 allows two-dimensional unsteady flow calculations [12].

3. Materials and Method

3.1 Study Area

With an area of 19,210 km^2 and a population of about 3 million, Johor is the fifth largest and one of the most populated states in Malaysia [12]. Muar River Basin covers a wide range of catchments areas in different states which are Johor, Negeri Sembilan, and Pahang with a total area of 7600 km^2 shown in Fig. 1. Most of the water resources for the catchments are from rivers in Malacca. The starting point of Sungai Muar is Northwest of Gunung Telapak Buruk in Jelebu District with longitude 102 04' E and latitude 2 50' 35'' N with a height above sea level is 1,193 metres. Sungai Muar flow from the east to the south and continue to the west with approximately 288.20 km and flow to the Straits of Malacca at Bandar Maharani, Muar.

Topographically, the study area is surrounded by hills and coastline. Generally, the rivers of the study area originated from Kampung Lubok Kadam and flows in a predominantly easterly direction through Gemas before turning south near Segamat flowing to the South and turning west to reach the sea at Muar. In its lower reaches, the Sg Muar is characterised by numerous large meanders. Many of these rivers still preserved their natural form. However, some rivers are being straightened and diverted in accordance to Rancangan Tebatan Banjir Lembangan Sungai Muar (2010). Urban drainage is generally only found in town and residential areas. Villages or suburbs typically have no structured urban drainage. Almost all drains present are designed and constructed using the conventional stormwater management approach such as rapid disposal. This is evident through the extensive use of concrete drains with very minimal (almost none) stormwater control structures (except irrigation channel).

Fig. 1 - Muar river basin

Fig. 2 shows the study area that was conducted in Bakri, Muar. The area of the catchment consists of different land use such as agriculture, construction, housing area and also commercial area. The checkpoint was marked with yellow marks from the C1 until C20 as shown in Fig. 3. The upstream of the catchment is marked with C20 while for the downstream of the channel is C1. The water flows from C20 to C1.

Fig. 2 - Study area in Bakri, Muar

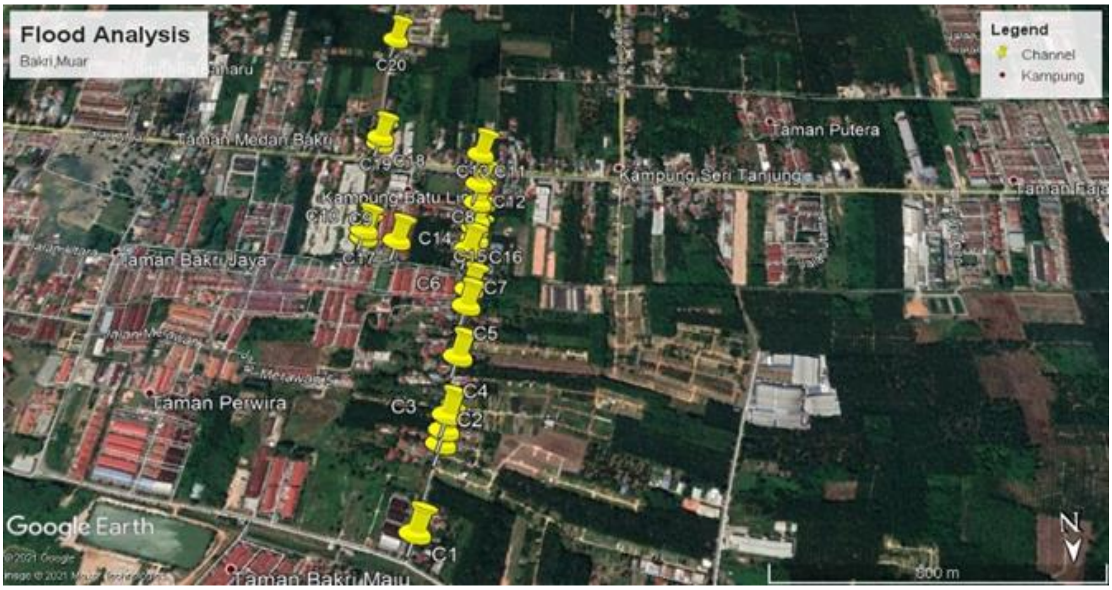

Fig. 3 - Flow of drainage in Bakri, Muar

The project area experiences a typical humid equatorial climate with high temperatures and humidity all year round. The average monthly low temperature is 23°C - 24°C and the high temperature is 31°C - 33°C. The highest air temperature usually occurs from April to May and the lowest is from December to January. The mean annual humidity is above 80%. The annual rainfall in the project area ranges from 1,300 mm to 2,400 mm. The heaviest rainfall is from the Northeast monsoon from November to December. From May to July, the Southwest monsoon brings moderate rainfall to the project area. The average monthly rainfall is 131 mm.

3.2 Data Collection

The two major flood events in recent years affecting the Sg Muar and Sg Segamat occurred in December 2006 and January 2007. The December 2006 flood arose from cold surges emanating from high-pressure system over Siberia was the main factor of the intensification in north-easterly wind speed over the South China Sea on 16 December 2006. This enhanced the cyclonic wind shear over our region, mainly over the southern Peninsular Malaysia from the 17 – 20 December 2006. Pahang and Johor started receiving heavy rainfall on 17 December, decreased on the morning of 18 December but re- intensified that evening. The total 48hour rainfall recorded reached over 300 mm.

Whereas the December 2006 and January 2007 flood events are the largest in recent times, there have been many other large floods over the past 40 years. From analyses of the water level/flow records undertaken as part of these studies, it shows the estimated average recurrence interval (ARI) of each flood at both Segamat and Muar. It is notable that the ARI's differ between the two sites, reflective of the fact that long-duration rainfall events (e.g., 48 – 72 hours) caused the largest floods in the Sg Muar, whereas, due to its smaller sized catchment, shorter duration high-intensity events (e.g. 12 – 24 hours) are more critical in the Segamat catchment. This aside, whereas December 2006 had high rainfall total over 3 days (i.e., 18 – 20 December), the shorter duration high rainfall intensities occurring on 20 December were the cause of the extreme flooding at Segamat. It is notable that, as development occurs, the natural landscapes are likely to be altered and this will tend to change their hydrology such that the following occurs:

- Catchment storage will decrease - this could for example take the form of deforestation, improvement of drainage, filling in of low-lying land or smoothing of in and out of bank surfaces near watercourses,
- Impervious surface will increase - this can be associated with paving of previously vegetated surfaces in towns or with agricultural practices which lead to compaction of soil and removal of accumulated surface cover (both of which will tend to reduce infiltrative capacity of the soil); and
- The volume of runoff downstream will increase the time to peak will decrease and the peak flow will increase

For the reliability of floodplain modelling, adequate and detailed data collections are essential. This will bring a good and significance outcome of study. The ground survey required to conduct first to determine and identify the flood prone areas and flood affected area. During the ground survey, the data such as the characteristic of the channel, existing flood condition, the water flow analysis need to be identified. Historical floods data is very important to be collected. From this data, the areas often flooded can be determined. This data can be gotten from the old newspaper, statistic flood from internet, previous article related flood and also can get from the department involved in control flood.

3.3 HEC-RAS Variable

A set of input variables are used by HEC-RAS software for the analysis of the stream channel shape and the analysis of the flow water [13]. To create a cross section along the stream by using the software these parameters are required as an input data. The positions of the stream banks are described in each cross-section and was divided into three parts which is left of bank, main channel and right of bank shown in Fig. 4. HEC-RAS uses multiple input parameters in each cross-section to explain shape, relative position and altitude along the stream [14]. The parameters need to be recorded in the HEC-RAS include, (i) the number of stations across the stream, (ii) the Lateral and Elevation of the coordinates, (iii) Left of bank and right of bank, (iv) Manning's, n values, and (v) Channel contraction and expansion coefficients.

In order to determine flood modelling, scientists and engineers nowadays always use computer modelling approaches. The Hydrologic Engineering Centre- River Analysis System (HEC-RAS) is one of the advance software to produce about Flood Modelling. The user can use this software to calculate one-dimensional steady flow, one and two-dimensional unsteady flow, sediment transport/mobile bed calculations, and water temperature/quality models. The user can use this software to calculate one-dimensional steady flow, one- and two-dimensional unsteady flow, sediment transport/mobile bed calculations, and water temperature/quality models. Fig. 4 shows the output of HEC-RAS model.

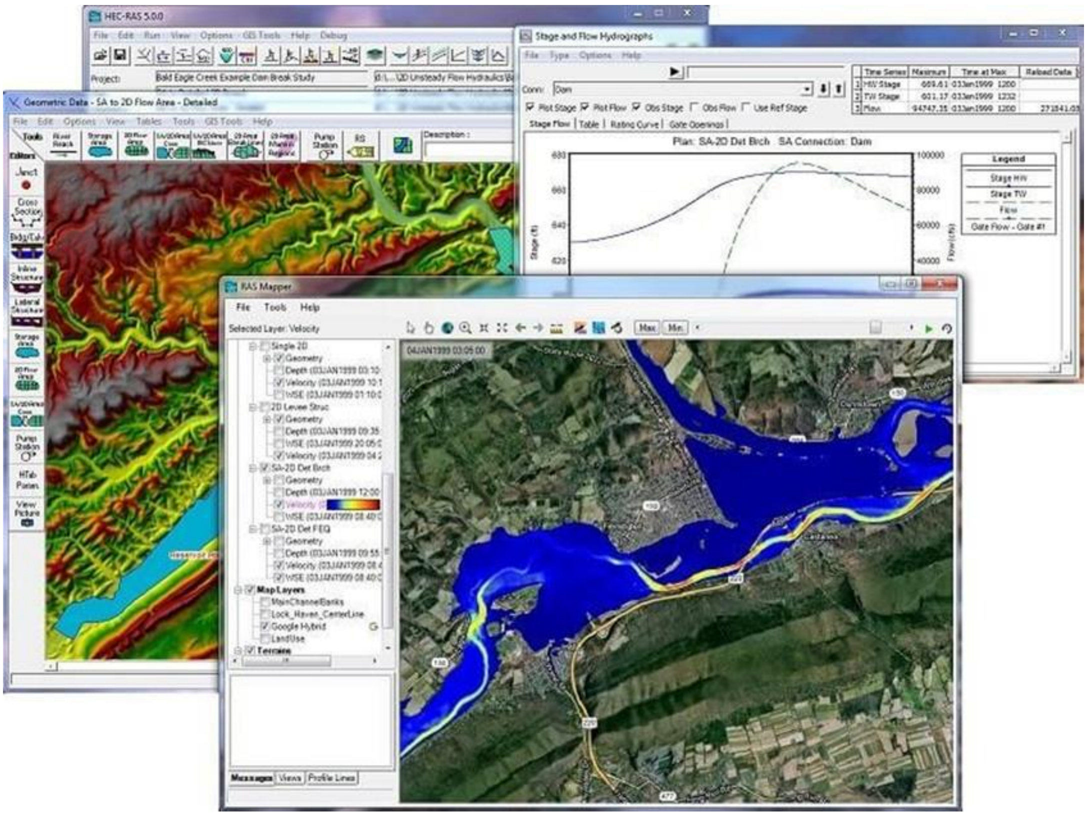

Fig. 4 - The output of the HEC-RAS

3.4 Open Channel Flow

Open channel flow can be called also as a free surface flow. Open channel flow meant by the free flow in a channel that subjected to atmospheric pressure. The example of open channel flow is natural streams and constructed drainage canals. Type of flow can be categorized into two type which is steady flow and unsteady flow. Steady flow is defined as a velocity of the flow at a particular fixed point does not change with time while for unsteady flow is defined as a velocity of the flow at a particular fixed point is change with time. The flow rate must be established or measured to determine the water surface elevations at distinct cross-sections [15]. The study should provide flow rates by using rational method to estimate the drainage or channel capability to manage the flow rate. Determine the existing stormwater and drainage system issues and problems such as:

- The extent of flood and the flood characteristics such as flood duration, flood levels, causes and estimated flood damages.
- Characterization of flow behavior within the study area during dry and wet weather flow.
- Determining the root cause of flooding and preventing mitigation measures.
- Determining which governing entity is the correct drainage authority.

Because of the non-stationary climate and increase in urbanization, urban drainage systems are generally failing in their functions. Sewer overflows and increased urban flooding, which result in a surge in pollutant loads to receiving water bodies, are becoming more common as these systems become less efficient. Fig. 5 shows the drainage system becomes less efficient due to urbanization. The soil cannot bear an enormous amount of water during heavy rainfall, and flooding will occur. To solve this problem, engineers come up with a solution that is to construct an engineered channel or man-made drainage system.

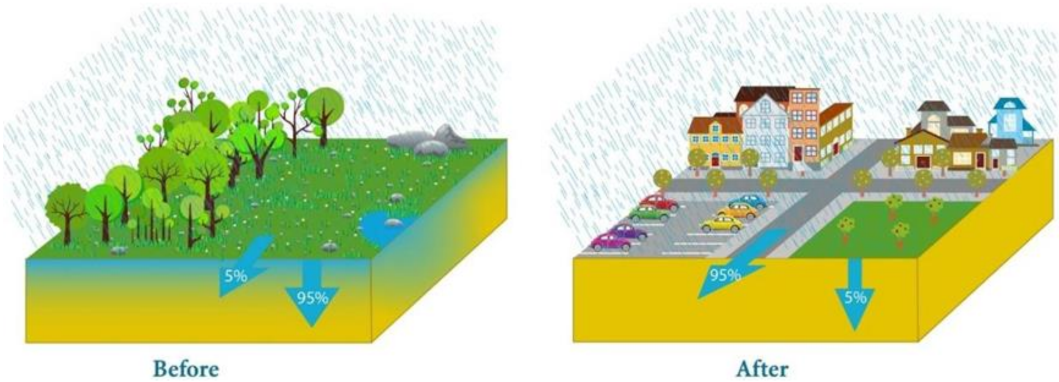

Fig. 5 - Urban drainage systems

4. Results and Discussion

4.1 Rainfall Data

The highest rainfall data with the maximum water level of the study area has been analyzed for the estimation of the velocity and discharge of the streamflow from station 1 to station 11. The rainfall data has been analyzed at every rainfall station in Muar. Fig. 6 shows is the annual rainfall distribution in the Muar River basin with 10 rainfall stations, where station 2225026 and station 2127017 are the nearest to this study area.

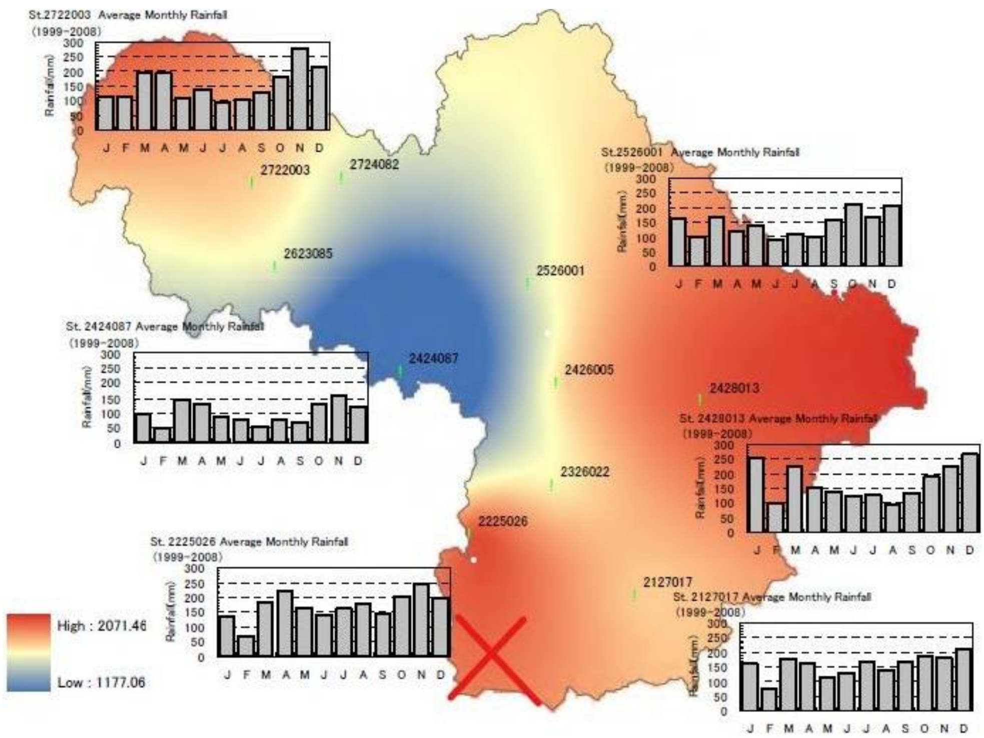

Fig. 6 - The annual rainfall distribution in Muar River basin (DID, Muar)

As shown in Fig. 7, rainfall data in the Muar River basin show an increasing trend in annual rainfall for both station 2225026 and station 2127017. While the difference in month-average precipitation from 1969 to 1988 and 1989 to 2008 is shown in Fig 8. All observed data, as well as basin average precipitation, show an increase in January and December, and decreasing in February and September, as shown in the figure.

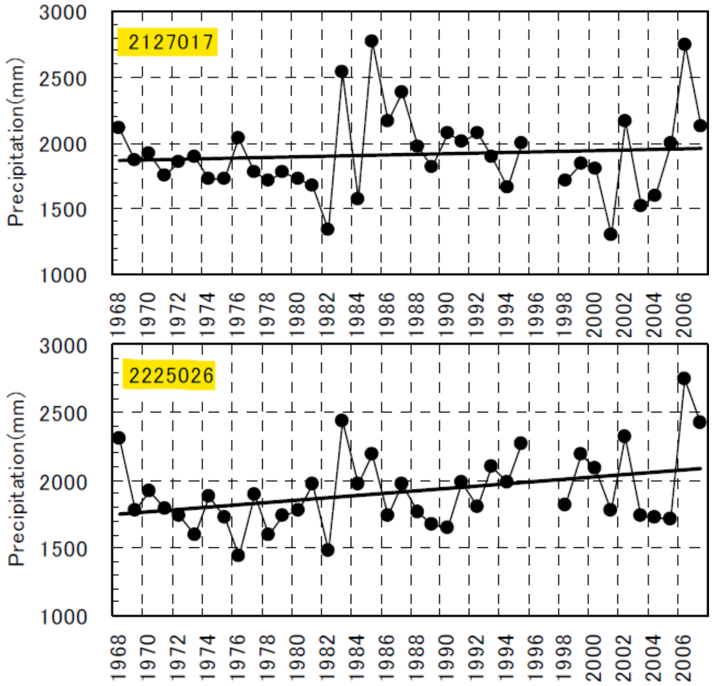

Fig. 7 - Observed annual rainfall (DID, Muar)

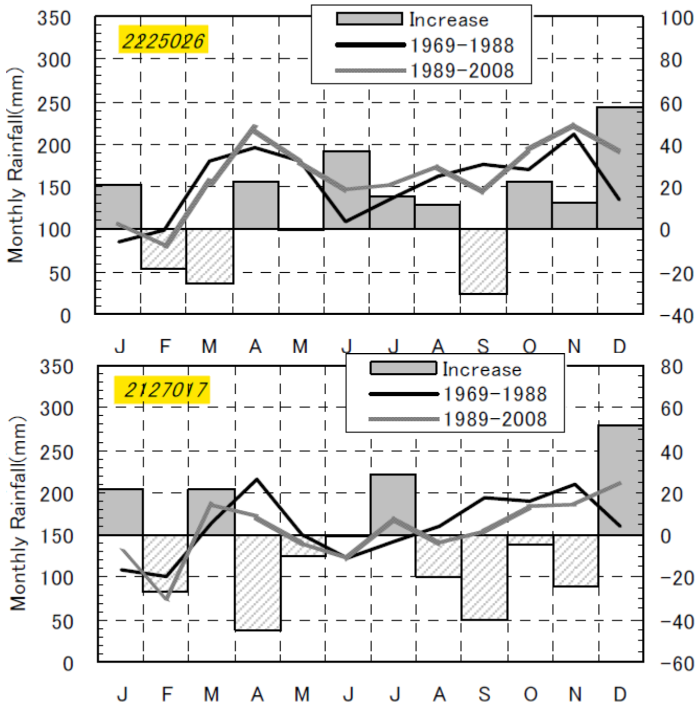

Fig. 8 - Month average precipitation (DID, Muar)

4.2 Flood Modelling (HEC RAS)

The Annual Rainfall Intensity (ARI) was calculated referring to the MSMA to design the water flow from catchment area in HEC-RAS software and this software will produce the result of effectiveness based on designated ARI 10 years, 50 years and 100 years. There are two equations use in this analysis, which is rational method to find flow rate for sub catchment and manning equation method to find flow rate for drainage. Due to the overflow of water into the river bank station, several stations were found to be flooded. Table 1 shows flooded stations with different Annual Rainfall Intensity (ARI). Table 1 showed that the station was about to flood. There were 7 stations that flooded straight from 10 years until 100 years. The shaded region represents the station that flood for straight 100 years ARI. Fig. 9 to Fig. 11 show examples of steady flow analysis findings for station 5.

Table 1- Flooded station with different ARI

ARI	10 years	50 years	100 years
1 (Parit Wahid)	flood		
2 (Parit Wahid)			
3 (Parit Wahid)			
4 (Parit Wahid)			
5 (Parit Wahid)		flood	flood
6 (Parit Wahid)			
7 (Parit Wahid)			
8 (Parit Pateri)			
9 (Parit Pateri)			
10 (Parit Pateri)			
11 (Parit Wahid)	flood	flood	flood
12 (Parit Wahid)		flood	flood
13 (Parit Wahid)		flood	flood
14 (Parit Wahid)		flood	flood
15 (Parit Wahid)	flood	flood	flood
16 (Parit Wahid)	flood	flood	flood
17 (Parit Pateri)	flood	flood	flood
18 (Parit Pateri)	flood	flood	flood
19 (Parit Pateri)	flood	flood	flood
20 (Parit Pateri)	flood	flood	flood

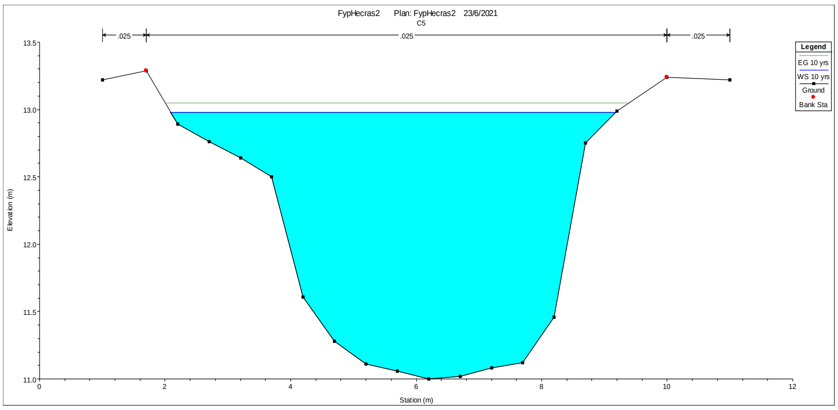

Fig. 9 - Cross section of station 5 for 10 years ARI

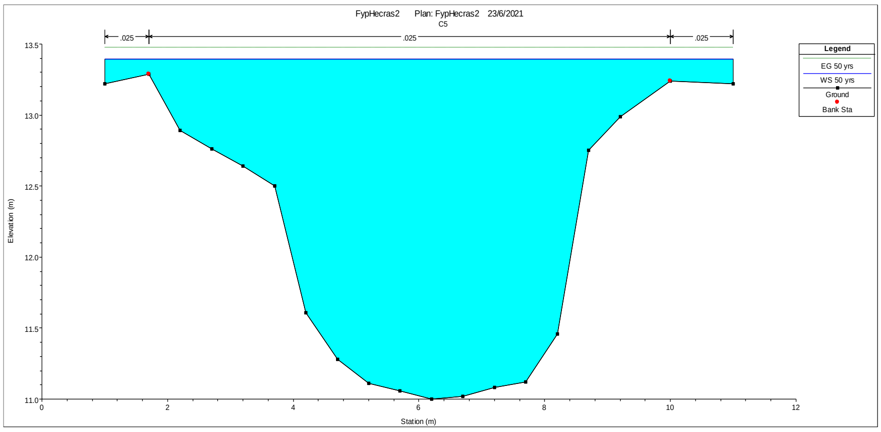

Fig. 10 - Cross section of station 5 for 50 years ARI

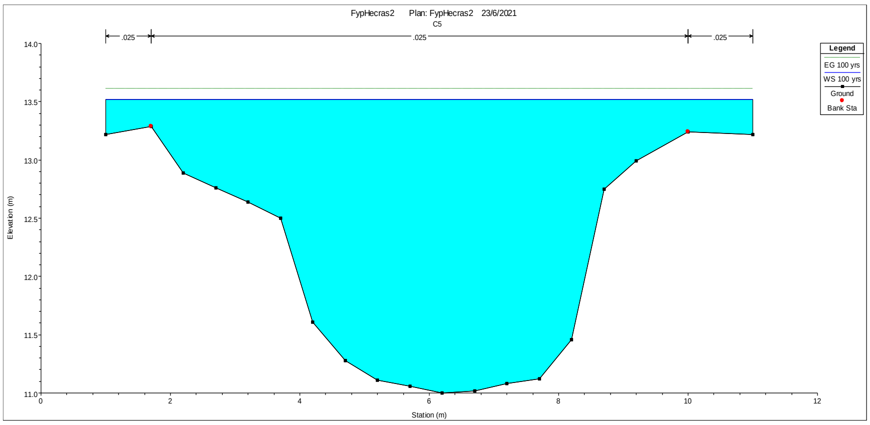

Fig. 11 - Cross section of station 5 for 100 years ARI

5. Conclusion

Flooding has severe consequences in terms of human relocation, loss of life, and infrastructure and property destruction. Flood modeling are one of the tools being used to reduce losses by providing early warnings to the community about the hazards. Creating a flood model necessitates a number of steps, including hydrological studies to determine the return period of a flood event and also hydraulic studies to determine peak discharge for the drainage. HEC-RAS is a software tool for creating floodplain maps that is both comprehensive and simple to use. The main objective of the study finally achieved. By using the HEC-RAS software, the floodplain area in Muar was identified. The cross section along the stream network also had been simulated by using HEC-RAS software and had showed some of the station that prone to flood. According to the hydraulic model generated by HEC-RAS software, 7 of 20 stations found will be flooded for the 10 years return period since they were unable to accommodate the water flow. Meanwhile, for the effectiveness of drainage system to accommodate peak discharge of sub catchment by using HEC-RAS software, this study showed that the existing drainage in that study area which is concrete and earth drain is less effective to minimize the occurrence of flooding in catchment area at that location. This profile will aid in the implementation of appropriate flood disaster mitigation measures. Flood profiles for various flood intensities and return periods can be plotted at any given river cross section using this model.

The findings also revealed that rainfall trends have an effect on flood behaviors patterns. More flooding will occur if rainfall trends continue to increase, particularly in low-lying areas. As a result of this result, a flood event in 100 years will be worse than a flood event in five years, or even in the current year.

As a conclusion, the use of contemporary survey equipment and the computer programmed HEC-RAS to analyze data is more feasible since it makes future engineer's work easier. The procedure of obtaining the needed data and time also can be minimized. Other than that, some authorities, such as the Department of Irrigation and Drainage, can utilize the results of this study to plan a more systematic and effective drainage system.

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