Effect of the Tide On Flood Modeling and Mapping in Kota Tinggi, Johor Malaysia

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Abstract

This study aimed at mapping the Kota Tinggi flood event in 2006/07 that had caused massive damages to properties and the environment. The flood was associated with unusually high intensity and continuous rainfall. Therefore, a reliable technique of floodplain mapping is crucial for the improvement of flood control strategies and for preparing an evacuation plan. The main objective of this study is to compare the effect of tide on flood modeling analysis. The inundated areas were mapped for various annual recurrent intervals using peak flow data from 1965 to 2010. The study used Light Detection and Ranging (LiDAR) data for flood modeling. HEC-HMS, HEC-RAS, and HEC-GeoRAS were used to develop the flood model. The results reaffirm that the GEV model is the best for fitting the annual flood. The HEC-HMS hydrologic model was calibrated and validated using observed hydrographs in Sep 2002 and Jan 2003, respectively. Upon successful calibration and validation, the model was used to simulate flood hydrograph in Jan 2007. The modeling took into account the tidal effect. When the tidal effect was not considered, the simulated flood depth was 43 % lower than the observed flood. However, the inclusion of the tidal effect has reduced the simulation error with an average similarity of 91.4%. The simulation results show that the river flow starts to over bank for ARIs exceeded 25 years.

1. Introduction

Flood has been recognized as the number one disaster in many parts of the world mainly affecting Asia and South America and cause tremendous damages to the properties, environment, and losses of life (Adikari et al. 2010; Marengo et al. 2013). Due to global warming, future rainfall is predicted to be more intense, resulting in increased flood peak, volume, and duration (Westra et al. 2014; Wang et al. 2014). In addition, the rate of sea-level rise is expected to be higher in the future which further amplifies the impacts of the flood (Nijland 2005). Significant damage from floods also happens due to the people living in high flood risk areas which are unsuitable for settlement (Elsheikh et al. 2015; Ghorbani et al. 2016).

Throughout history, Malaysia has faced several major floods. In particular, during the 2006/07 flood event, Kota Tinggi town in the State of Johor has recorded the highest, worst and costliest flood in history of the Johor River. The estimated total loss due to these disasters was RM 1.5 billion of which, RM 237.1 million was for damaged infrastructure alone (Hamzah et al. 2012; Tam et al. 2014). A total of 11,724 victims in the Dec 2006 flood event and 7,915 victims in Jan 2007 were evacuated (Hamzah et al. 2012; Tam et al. 2014; Karki 2019). In some cases, flood victims had to move to another relief center as the evacuation centers were also flooded.

It was found that the main cause of the flood was due to a large amount of rainfall, geographically low laying area, rapid land-use changes, and tidal effect (Tam et al. 2014; Karki 2019). The flood started on Dec 19, 2006, until Jan 16, 2007, where the first wave had inundated most of the Kota Tinggi town. Malaysia Metrological Department (MMD) reported high rainfall intensities from Dec 19, 2006, to Jan 12, 2007. The second wave continued on Jan 11, 2007, and this caused a huge disaster within a short period.

The rainfall total during the first wave double compared to the average monthly rainfall, and during the second wave, the rainfall was about 5 times higher compared to the average monthly rainfall in Dec and Jan at Kota Tinggi. It has been reported that the water level was up to 5.45 m during the second wave compared to 4.9 m during the first wave. The disaster was compounded by the low infiltration rate of the soils in the area. At the same time, the Department of Irrigation and Drainage (DID) reported that a high tide of about 2 m occurred at the river mouth causing a backwater phenomenon (Tam et al. 2014; Karki 2019). Consequently, the outflow of stormwater in tidal detach, creeks, and rivers was blocked by the increasing sea water level. This problem is expected to recur year after year.

Flood modeling is an important tool in predicting the consequences of floods which provides useful information in managing the potential risks caused by flooding (Nkwunonwo et al. 2020). To cater to the needs to further understand the short- and long-term flood events, there is an increasing interest to develop a new hydrologic and hydrodynamic model in order to achieve better flood modeling results in terms of visualization and characterization. Typically, a model needs to be chosen based on appropriate catchment characteristics, model input parameters, and boundary conditions. HEC-HMS is one example of a semi-distributed and integrated hydrological modeling system. It models precipitation runoff with hydrological channel routing methods. It is applicable in a wide range of geographic areas for solving the widest possible range of water availability, flow forecasting, urban drainage, future urbanization impact, reservoir spillway design, flood damage reduction, floodplain regulation, and systems operation. In Malaysia, HEC-HMS was frequently used by consultancy projects and most preferred by university students because it is free and easy to download from the US Army Corps website (Howe Lim and Melvin Lye 2003). In addition, HEC-HMS was used by DID Malaysia for the Kelantan River Flood Forecasting program (Ramachandra Rao and Hamed 2019). For hydrological simulation, HEC-HMS provides an event-based on fully hydrological and metrological parameters. It has many references to be a guide for the simulation process.

In flood modeling, the tide level became one of the important elements especially when the area affected is close to the sea. HEC-RAS is one of the most widely used models, offered a known water surface as model input for tide level (Fan et al. 2012; Romali et al. 2018; Muñoz et al. 2021). This model computes water surface profiles and energy grade lines in 1D, steady-state, and gradually varied flow analyses. It has been applied extensively in studying the hydraulic characteristic of rivers (Thakur et al. 2017; Ogras and Onen 2020). Natale et al. (Natale et al. 2007) and El-Naqa and Jaber (El-Naqa and Jaber 2018) used HEC-RAS and HEC-GeoRAS as hydraulic model software to run the flood modeling with the contribution of tidal effect. Their analysis of floodplain showed the effect of floodplain modeling is much better in terms of flood extent and depth. A previous study by Shabri et al. (Shabri et al. 2011), showed high accuracy of the HEC-RAS model in simulating unsteady tidal flow under natural conditions. Therefore, flood modeling will be more significant with consideration taken on the tidal effect at downstream boundary conditions. In addition, the integration of HEC-GeoRAS into the hydrologic and hydraulic modeling provides detailing on flood mapping in the form of flood depth, the velocity of flow, and flood duration.

To complement the flood model, flood frequency analysis has been primarily used to analyze annual peak flow for large and mid-size catchments (Shiau and Shen 2001). Flood frequency analysis is usually applied for model validation of the observed and simulated hydro-climatic variables such as rainfall and streamflow (Ramachandra Rao and Hamed 2019). Various types of statistical distribution methods were applied and developed by researchers all over the world to determine the most appropriate data distribution for flood frequency analysis and to model the long-term flood characteristics (Sraj et al. 2015; Machado et al. 2015; Gizaw and Gan 2016; Serago and Vogel 2018). In general, a distribution with a larger number of flexible parameters such as GEV will be able to model the input data more (Ramachandra Rao and Hamed 2019). However, the present study will examine the performance of five probability distribution models, namely GEV, Lognormal, Pearson 5, Weibull, and Gamma for modeling the annual flood of the Johor River basin (JRB). These models were chosen because they are commonly recommended by many researchers (Kim et al. 2017; Langat et al. 2019).

As mentioned above, flood mapping at Kota Tinggi town is important to predict the possibility of flood occurrences and formulate an emergency action plan, insurance policy, and development planning. 2D numerical hydraulic models are considered advanced enough for the prediction of flood extent, depth, and flow velocities (Romali et al. 2018; Muñoz et al. 2021). Thus, the present analysis develops 2D flood mapping using the hydrodynamics model in order to estimate the present and future floods. One of the common practices in hydrology is estimating the Annual Exceedance Probability (AEP) and Average Recurrent Interval (ARI) (Ramachandra Rao and Hamed 2019). ARI refers to the return period in time between the events that have the same magnitude, volume, and duration. Information on ARI derived from frequency analysis is crucial for hydrologic analysis and designing hydraulic structures. This study concerned with developing an appropriate method for flood mapping by estimating the ARI of an annual flood using flood frequency analysis, examining the effect of the tide on flood modeling results, and mapping the 2006/07 flood and the simulated floods for 25, 50, 100 and 200 year return periods.

2. Study Area

The study area was in the JRB as shown in Fig. 1(a). The basin covers 6319 km^2, lies in the eastern part of the State of Johor with 122.7 km in length of the main river. The basin is exposed to the northeast (NE) monsoon which brings heavy rain from November to March (Wong et al. 2009). The average rainfall is 2,470 mm per year. The average slope degree is about 0.1 % degree, which means, Johor River is a low lying and flat area. About 65% of the land use in the JRB is covered by various crops, mainly oil palm and rubber forest (23%), residential and commercial areas (8%), and water bodies (4%). Based on the land use pattern, the JRB has a higher impervious area due to the bigger coverage of vegetation land use type. Kota Tinggi is a district in Johor State. The distance between Kota Tinggi town to Rantau Panjang gauging station is about 12 km along the river. The area upstream of this station is about 3489 km^2, which consists of agriculture, business, and mining activities. For HEC-HMS hydrological modeling, the Rantau Panjang catchment was construct whereas the Rantau Panjang gauging station acts as the basin outlet. The Rantau Panjang catchment consists of two reaches, Sungai Ulu Sebol and Sungai Sayong.

The Rantau Panjang catchment was then divided into a total of 11 sub-catchment as shown in Fig. 1(b). A digital elevation model (DEM) based on LiDAR data with 1 m and 15 cm accuracy of horizontal and vertical positioning was collected from DID Malaysia for this study. Based on the ground verification in Kota Tinggi town, the LiDAR data was good to be used in flood modeling. It has been found that the topography is rather flat with an elevation between 0 to 50 m. The gradient becomes steeper toward the northeast with elevation up to 150 meters where the Linggiu dam is located.

3. Data

Hydro-meteorological information used in this study comprised of rainfall, evapotranspiration, streamflow, and tide level collected from DID Malaysia. 15 rainfall stations fairly distributed with sufficient period were selected and the location and details were shown in Fig. 1(b) and Table 1. The hourly data for the period of 1965 to 2010 was used. The percentage of areal rainfall in 11 sub-catchment in the Rantau Panjang catchment was computed based on Thiessen Polygon Method as shown in Table 2.

Table 1
List of 15 rainfall station for hydrological modelling.

Sub-catchment	St. No.	St. Name	River	Lat	Lon
1	1636001	Balai Polis Kg. Seelong	Tebrau	1.63	103.70
2	1735125	Ldg. Sedenak	Skudai	1.71	103.53
3	1734001	Loji Pembersih Bkt. Batu	Pontian Besar	1.73	103.44
4	1834122	Ldg Rengam	Sayong	1.89	103.42
5	1933121	Ldg. Getah See Sun	Sayong	1.90	103.40
6	1833123	Ldg. Benut	Benut	1.84	103.35
7	1833092	Ldg. Simpang Rengam	Benut	1.86	103.34
8	2034001	Felda Kahang Barat	Kahang	2.03	103.42
9	2235001	Sek. Men. Kahang	Kahang	2.23	103.56
10	2336001	Felda Nitar	Tambang	2.24	103.72
11	1737001	Sek. Men. Bkt. Besar	Johor	1.76	103.72
12	1737127	Bkt. Besar Felda	Linggui	1.77	103.70
13	1836001	Rancangan Ulu Sebol	Sebol	1.88	103.64
14	1835001	Ldg. Pekan Layang Layang	Sayong	1.86	103.59
15	1834001	Stesen Tele. Ulu Remis	Sayong	1.85	103.48

Table 2
The percentage (%) of areal rainfall for each sub-catchment in the Rantau Panjang catchment.

	Sub-basin										
St. No.	1	2	3	4	5	6	7	8	9	10	11
1833123	0	0	0	0	0	0	0	0	10.9	0	0
1734001	0	0	0	0	0	0	0	0	17.4	0	0
1834122	0	0	0	0	0	0	6.9	47.5	33.5	0	0
1735125	0	29.6	0	0	0	0	0	0	21.8	0	0
1835001	0	68.9	6.9	0	0	7.8	70.4	52.5	9.8	1.2	0
1833092	0	0	0	0	0	0	0	0	0.2	0	0
1933121	0	0	0	0	0	0	0	0	6.4	0	0
2034001	0	0	0	0	0	12	5.6	0	0	0	0
1836001	80.5	1.5	93.1	100	90.9	80.2	17	0	0	98.8	88.3
2336001	0	0	0	0	4	0	0	0	0	0	0
2038001	0	0	0	0	5.1	0	0	0	0	0	6.3
1739003	19.5	0	0	0	0	0	0	0	0	0	5.3

This study used evapotranspiration data from the Senai Meteorological station, which was the closest to the JRB. The hourly streamflow data from 1965 to 2010, recorded at Rantau Panjang gauging station (Latitude: 01° 46’ 50”, and longitude: 103° 44’ 45”) located about 12 km upstream of Kota Tinggi town was used in this study. There is about seven water year of missing data, which was defined as three or four months continuously missing data. This is partly due to technical problems such as the failure of the data logger. As a result, 38 out of 45 annual maximum data were used in this study. Estimation of annual maximum streamflow for the selected water year was shown in Table 3.

Table 3
The annual maximum discharge from 1965 to 2010.

Year	Q(m3/s)	Year	Q(m3/s)	Year	Q(m3/s)	Year	Q(m3/s)	Year	Q(m3/s)
1965	98.666	1975	-	1985	363.301	1995	724.734	2005	234.605
1966	310.024	1976	204.320	1986	203.149	1996	192.824	2006	361.213
1967	-	1977	141.708	1987	204.276	1997	86.800	2007	-
1968	-	1978	263.037	1988	173.175	1998	166.181	2008	90.186
1969	587.903	1979	336.451	1989	511.985	1999	165.053	2009	135.495
1970	281.363	1980	118.434	1990	105.950	2000	231.291	2010	200.350
1971	134.950	1981	278.257	1991	246.903	2001	186.729		
1972	-	1982	539.315	1992	220.555	2002	140.284		
1973	79.055	1983	549.600	1993	-	2003	-		
1974	109.343	1984	301.118	1994	255.875	2004	226.472		

At the downstream boundary condition, the hourly tide level was used from 00:00 to 24:00, started from 11 Dec 2006 to 20 Jan 2007. Figure 2 shows the highest tide level at 1.45 meters during the 2006/07 flood event at Kota Tinggi. The phenomena occurred twice, which was on 11 Dec 2006 and 20 Jan 2007. The highest tide that occurred during that flood event was 1.90 meters.

4. Methods

4.1 Procedure

In this study, land use, DEM, river catchment, river profile, rainfall, streamflow, and tide level were compiled, corrected, and validated. Then, frequency analysis was analyzed to determine the return periods of flood by using several distribution models, namely GEV, Gamma, Lognormal, Pearson 5, and Weibull. The best distribution model for annual maximum flow from 1965 to 2010 was determined based on the goodness-of-fit (GOF) performance by using Kolmogorov-Smirnov (K-S) test. HEC-HMS hydrological model was then used to route the hydrograph from Rantau Panjang gauging station to Kota Tinggi Town. The final output was flow hydrography in 2006/07. After that, the simulated hydrographs were used as the main input for HEC-RAS hydraulic modeling and HEC-GeoRAS for flood mapping, respectively. In HEC-RAS, the boundary condition considered the tidal and without tidal effect. Conversion of the floodplain from 1D to 2D visualization was generated using HEC-GeoRAS based on the historical 2006/07 flood event at Kota Tinggi town. The flood was verified with the existing flood marks. Finally, the study simulated floodplains for 25, 50, 100, and 200 ARI.

4.2 Distribution model

Distribution models such as GEV, Gamma, Lognormal, Pearson 5, and Weibull were run accordingly for 38 years available dataset. The best-fitted model was analyzed by using EasyFit Software and then tested by using GOF to estimate the return period of 10, 25, 50, and 200 years.

4.3 Hydrological Model

The purposed of HEC-HMS hydrological modeling in this study was to route the flow of hydrograph from the upstream of Rantau Panjang gauging station to downstream of Kota Tinggi town. Then, the hydrograph in Kota Tinggi was used for HEC-RAS hydraulic modeling. The basic input requirements for the HEC-HMS consist of the hydrological model parameter, initial soil moisture condition, meteorological data (evaporation and rainfall), and streamflow data for model calibration and validation. The options for rainfall excess transformation include kinematic wave U-H methods. The synthetic U-H and quasi U-H methods that are available include Snyder, Clark Time Area, SCS, and Santa Barbara U-H. Soils Moisture Accounting (SMA) was used for losses method to suit the type of environment and land use in the JRB. SMA was calculated based on the soils, canopy, roughness, and groundwater storage. Since field measurement was not carried out, the hydrological parameters were estimated based on MaSMA Malaysia. The soil moisture accounting was selected using loss method, simple canopy for canopy method, simple surface for surface method.

For modeling, the catchment was divided into eleven sub-catchments (nodes in HEC-HMS) as shown in Fig. 1(b), assumed as a lumped model for SMA parameters. The selections of nodes are based on the consideration of certain aspects of the catchment characteristics and locations where the determination of flow is required. Meanwhile, the transform method used Clark Unit Hydrograph and linear reservoir for the baseflow method. The simulated hydrograph was calibrated in Sep 2002 and validated in Jan 2007. The model efficiency was estimated by using the Nash Sutcliffe method. Rainfall-runoff simulations were run for every sub-catchment and the results were then combined to produce the main hydrograph.

4.3.1 Hydrological Model Parameter

The input for method set-up and properties of hydrological losses were shown in Fig. 3. The input for percent of soil loss was based on *Harimau Malay* soil characteristics and the groundwater movement depends on the geological condition of the area. The maximum infiltration is 15 mm/hr. The impervious area is 25% as an agricultural area. Soil storage is 150 mm and tension storage is 50 mm. Meanwhile, soil percolation is 3 mm/hr, Groundwater 1 Storage is 1000mm, Groundwater 1 Percolation is 2 mm/hr, and GW 1 Coefficient is 5 hr. However, Groundwater 2 storage is 2 mm/hr and GW 2 Coefficient is 25 hr. All the properties of losses were set to all sub-catchments.

On the hydrological transform method, the candidate parameters of time of concentration (T_c) and storage coefficient (S_c) in the hourly unit were calculated. The two parameters were used for the development of a synthetic unit hydrograph. The T_c are estimated by using the Barnsby-William formula. The resulting hydrographs were then compared with the observed hydrographs. If the match is not satisfactory, the parameters were tuned until the best match is obtained. The T_c and S_c for the Rantau

Panjang catchment were found to be 102.2 hr and 9.8 hr. The Linear Reservoir method for baseflow models was used to assess the overall retention capacity of the catchment in terms of both peak response and baseflow. The GW 1 Initial was defined as 5 m^3/s, with the GW 1 Coefficient of 4.

4.3.2 Routed flow from Rantau Panjang gauging station to Kota Tinggi town

Five junctions were installed in the HEC-HMS model for hydrologic flow routing (Fig. 4). The flow at the upstream (Rantau Panjang gauging station) can be observed but not the downstream (Kota Tinggi town). Therefore, the flow downstream has to be estimated by routing the observed flow from the upstream. This was carried out by routing the flow using the Muskingum routing method. The distance from Rantau Panjang to Kota Tinggi town is about 15 km. By adding the travel time for each reach and a weighting between the influence of inflow and outflow, it is possible to approximate the flow attenuation.

4.4 Hydraulic modeling

For HEC-RAS hydrodynamic model, additional data on river cross-sections, river basin maps, sub-catchment maps, and tidal were computed. The purpose of hydraulic modeling is to estimate the water level in relation to flow discharge. There are five hydraulic components in the model, namely, river alignment and flow path model, structures of banks, cross-section filtered, hydraulics component, and boundary condition for upstream and downstream. In this study, a tide level was inserted at the downstream boundary condition while a flow hydrograph was set at the upstream. The tide level was based on the 2006/07 flood event. Figure 5(a) shows the geometrical model setup for flood simulation at Kota Tinggi town. Cross-sections gathered from LiDAR data are located at relatively short intervals along the stream to characterize the flow carrying capacity of the stream and its adjacent floodplain. Cross-sections are required at representative locations throughout the stream and at locations where changes occur in discharge, slope, shape, and roughness at locations. All the cross-sections were adjusted and corrected, in terms of the location of banks and points of the cross-section. The coefficient of manning was standardized into one value reflecting the large swath of vegetation covering the study area.

Based on important parameters marked in Fig. 5(b), the inlet was determined as the upstream boundary condition, with main input data are hourly flow and tide level derived from downstream boundary condition. The selected cross-section was perpendicular to the river channel to ensure stability of HEC-RAS modeling. Additionally, flow can be changed at any location within the river system. This analysis used unsteady flow because the upstream boundary condition during the flood event was high velocity which caused flooding. The study used a subcritical flow regime for the downstream boundary conditions and an open free-flow method for the upstream. Connections to junctions are considered internal boundary conditions, which are automatically listed based on how the river system is defined in the geometric data editor. For the downstream boundary condition, the tidal cycle was considered in order to make an effect of tidal during flood simulation.

4.5 Flood Mapping with HEC-GeoRAS Model

The 2006/07 floodplain was simulated in 1D result and then converted into 2D by using HEC-GeoRAS. The HEC-GeoRAS mapping tool generates the flooding extents, by intersecting the water-surface elevations at each cross-section with the digital terrain surface. The geographical representations of floodplain depths, velocities, and extents provide great insight into the model response, and ideally the behavior of the natural system. The flood boundary was computed by maximizing the cross-section extent for inundated after running the model. The proposed upwind conservative scheme is based on the finite explicit volume method. Where the water will inundate towards the lowest pixel. For instance, the higher topography for some areas defined as the higher pixel value, and the lower topography for some areas defined as the lower pixel value. Therefore, the total inundated area (total pixel) in the main channel will overtop the bank and topography if the value is much higher than the topography itself. In the end, the simulated 2006/07 floodplain was verified with the observed flood marks at the actual site.

4.6 Average Recurrent Interval (ARI)

Once the simulated floodplain is verified, the model will simulate the inundated area based on the ARI. An ARI represents an average number of years between similar events over a very long period of record. It can be determined by using Eq. 1;

$$P = 1 - (1 - \frac{1}{T_r})^N \quad (1)$$

where P is the probability of a returning value, T_r is the return period, and N is equivalent to the interval of years. The ARI refers to the return period of discharge value, where the average length of the time between events has the same magnitude, volume, and duration. Specifically, the return period, T_r, is given by

$$T_r = \frac{1}{P} \quad (2)$$

where T_r is in years and P is the AEP in percent. Hence, 1% of AEP has ARI for 100 years. A design flood is a probabilistic or statistical estimation being generally based in some form of probability analysis of flood and rainfall data. In hydrology, a design is not only for routine flow design, but more important is for maximum flood estimation or maximum peak flow for several calculated years. The design is intended to obtain the value with an extremely low probability of exceedance. For the flood design, the boundary condition needs to be considered and assumed. The distribution function of x is given by Rao and Hamed (Ramachandra Rao and Hamed 2019) ;

$$x = u + \frac{a}{x_{avg}}[1 - (-logF)^K] \quad (3)$$

The probability of a flood to occur in any year given by;

$$P_x = 1 - \frac{1}{T_r} \quad (4)$$

where T_r is the return period, the T-year quantile can be estimated by Eq. 24.

$$x_T = u + \frac{a}{k}\left[1 - \left\{-\log\left(1 - \left\{-\log\left(1 - \frac{1}{T}\right)\right\}\right)\right\}^k\right] \quad (5)$$

In Malaysia, a 100-year ARI is a standard design flood protection for channels and bridges (Romali et al. 2018). Given the more frequent occurrence extreme in the recent decades, it was suggested the design standard be extended to 200-year return periods for urban drainage construction and flood control design (Deni and Jemain 2008). In this study, 25, 50, 100, and 200 ARIs was considered.

5. Results And Discussion

5.1 Hydrological Distribution Model

Figure 6 showed the annual flood variation from 1965 to 2010. The highest flow of 724.7 m^3/s was recorded in 1985 and the lowest in 1973, which was 76.4m^3/s. There are six biggest floods over the 45 years period, which occurred in 1969, 1979, 1982, 1989, 1995 and 2006/07. In the 2006/07 flood event, one of the major contributors to the flood was the tidal effect downstream. The maximum, minimum, and mean of the annual flood are 724.73, 76.89, and 251.59 m^3/s respectively. The data was positively skewed with a coefficient of variation of 61%.

Table 4 present the performance ranking of the distribution models based on the Kolmogorov Smirnov GOF tests. The parameters are shape parameter (∝, k), continuous scale parameter (σ, β), and continuous location parameter (μ, γ). GEV is ranked first, followed by Pearson 5, Lognormal, Weibull, and Gamma. A closer P-value to one indicates a better-fit distribution. In this analysis, the GEV with a P-value of 0.99 emerges as the best distribution model. In addition, based on the results of the probability difference and P-P plots for the five models, the GEV model is the closest to the line and selected as the best-fitted model distribution.

Table 4
Fitting results and goodness-of-fit test ranking for the probability distribution of annual flood.

		Kolmogorov Smirnov	
Distribution	Parameters	P	Rank
Gen. Extreme Value	k = 0.19646, σ = 93.782, μ = 175.09	0.99010	1
Pearson 5	σ = 3.8871, β = 762.79, γ=-8.3373	0.98806	2
Lognormal	σ = 0.74468, μ = 5.0606, γ = 46.792	0.97408	3
Weibull	α = 1.0908, β = 178.53, γ = 78.521	0.97101	4
Gamma	α = 1.091, β = 158.6, γ = 78.569	0.90748	5

5.2 Hydrological Model Calibration and validation

A set of single storm event data was used to calibrate the optimized HEC-HMS hydrological parameters for the Rantau Panjang catchment. The model calibration used rainfall and flow data from Sept 7–12, 2002. The results in Fig. 7 showed the losses (in red) and net precipitation (in blue) during model calibration. The losses are defined as the loss of water from a river channel due to leakage, seepage, evaporation, and others. The simulated peak flow for the event in Sep 2002 was 17.9 m^3/s, which was close to the observed peak discharge of 18.10 m^3/s. For this event, the total precipitation was 15.20 mm; the total loss was 9.47 mm, and the base flow 1.58 mm. The validation set of storm event data was used to validate the HEC-HMS model based on the optimized model parameters obtained during calibration. The model validation used rainfall and flow data from Jan 19–31, 2003. Again, the observed peak discharge (140.28 m^3/s) was close to the observed peak discharge (137.2) m^3/s. The total areal precipitation during this event was 78.50 mm, of which 25.60 mm was losses and 5.35 mm as baseflow. Initially, the results show a similar pattern, but after the hydrograph start to decrease, the simulated pattern was slightly different compared to the observed. It seems that the water from the upstream travelled faster to downstream compare to the observed hydrograph. The validation results were shown in Table 5. The ME for the calibration and validation results is 87.34% and 73.00% respectively which is generally acceptable.

Table 5. The minimum relative error (MRE), model efficiency (ME), and peak flow for the calibration and validation of the HEC-HMS hydrological model on Sep 2002 and Jan 2003 respectively.

						Peak flow (m^3/s)	
	Avg (Obs)	MRE	Sum ($Diff^2$)	Sum ($Avg Obs)^2$	ME (%)	Sim	Obs
Calibration	10.4	0.1	230	1814.0	87.34	17.90	18.90
Validation	75.2	0.2	75262	245770.5	73.00	137.20	140.28
Storm event 2006						625.30	314.20
Storm event 2007						743.90	361.21

5.3 Hydrological Model Parameterization

The results of the hydrological model showed that the shape of the highest peak flow of the simulated hydrograph during the 2006/07 flood event reasonably matches the shape of the observed hydrograph (Table 5). For optimization, the study adjusts the time of concentration and storage coefficient. The peak flows for calibration and validation phases were more than 70% accurate. However, the peak flows during the 2006 and 2007 floods were about double the observed values. This happens due to the river flow has spilled over the banks and the water level-flow rating curve is no longer valid. These underestimations of peak flow were corrected by simulating the hydrograph using the model coefficients for the calibration and validation stages. Finally, the optimized model parameters were defined as shown in Table 6.

Table 6
Optimized model parameter values for soil moisture accounting technique in HEC-HMS.

SMA	Canopy (%)	50	Surface storage (mm)	5	GW1 storage (mm)	1000
	Surface (%)	10	Max infiltration (mm/hr)	15	GW1 percolation (mm)	2
	Soil (%)	40	Impervious (%)	25	GW1 coefficient (hr)	5
	GW1 (%)	30	Soil Storage (mm)	150	GW2 storage (mm)	1000
	GW2 (%)	25	Tension storage	50	GW2 percolation (mm/hr)	2
	Canopy storage (mm)	4.9	Soil percolation (mm/hr)	3	GW2 coefficient (hr)	25
Baseflow	Initial type	Discharge	GW1 initial (m^3/s)	5	GW1 coefficient (hr)	4
	GW1 reservoir	1	GW2 initial (m^3/s)	0	GW2 coefficient (hr)	0
	GW2 reservoir	1				
Clark Transformation	Time of concentration (hr)	102.2	Storage coefficient (mm)	9.8		

5.4 Simulation of 2006/07 Flood Event

The result of the simulation at Kota Tinggi town is shown in Fig. 8. It was found that the simulated hydrograph was much higher than the observed hydrograph. This was due to flood overflows the riverbank, thus the level-discharge rating curve during a flood event is not valid. Simulation of hydrograph using hydrological model using rainfall as the main input data provides an opportunity to correct the data. Despite having 3 days of heavy rainfall of 366 mm during floods in Dec 2006 and 416 mm in Jan 2007, the observed peak discharges were low, 314 m^3/s and 361.21 m^3/s, respectively. The simulated hydrographs provide more reasonable results of 625.3 m^3/s for the Dec 2006 flood and 743.9 m^3/s for the Jan 2007 flood. Out of 573.23 mm total precipitation in Dec 2006, 98.18 mm was lost and 7.93 mm appeared as base flow. The results of the model calibration and validation closely follow the same pattern with the observed hydrographs as far as the water level does not exceed the river bank. This suggests that the optimized hydrological parameters for hydrological losses, runoff transformation, and baseflow could be used for filling in missing hydrograph records during the large flood.

Figure 9 showed the 1D Water Level Simulation for the 2006/07 Flood Event. The second wave caused a deeper flood with a wider inundated area. Besides, there is slightly higher total rainfall during the second wave where the water storage in terms of soil moisture, pond, and depressions are already filled up by the first event. As such, a larger portion of the rainfall appeared as storm flow.

5.5 Routed Flow from Rantau Panjang to Kota Tinggi Town

Figure 10 showed the simulated hydrograph at Rantau Panjang station and the routed hydrograph at the Kota Tinggi town. The highest simulated peak flow at Kota Tinggi town was 590 m^3/s in Dec 2006 (1st event) and 723 m^3/s in Jan 2007 (2nd event).

5.6 Tidal Effect on Flood Modelling

Figure 11(a)-(b) compares 1D cross-section profile with tidal and without tidal effect. Figure 11(a) showed that the maximum simulated water level (5.3 m) when the tidal effect was factored in which is quite close to the observed maximum level (flood mark) of 5.45 m. However, when the tidal effect is not considered, the simulated maximum flood level is only 3.3 m as shown in Figure 11(b). Therefore, it is crucial to consider tidal in any flood modeling especially when the affected area is flat or close to river mouth which can cause backwater phenomena. Figure 12(a) showed the inundated area with and without tidal effect. Figure 12(b) showed that the difference in flood coverage with and without tidal effect was 43.16%.

5.7 Kota Tinggi town Flood Mapping for 2006/07 Flood Event

The result of the HEC-RAS model was exported to HEC-GeoRAS to map the flood extent. 1D cross-section profile for water level was converted to 2D flood using shallow water equation. Figure 13 showed the flood progression from 12th to 28th Dec 2006. Between 21st and 23th Dec, the heavy rainfall had caused water overflow to as far as 1.5 km from the river bank. The peak flow of 625 m^3/s occurred on 23rd Dec consequently resulted in a maximum depth of 5 m above the ground. The river started to overflow on 11th Jan, by first inundating Kampung Kelantan, which is located in a tributary catchment as shown in the dash line box. Within 2 days, the flood has inundated the whole of Kota Tinggi town. The time to peak during the second wave took only 2 days compared to 5 days during the first wave.

The flashier flood during the second wave suggests a smaller capacity of the catchment to store additional water as the storage has been filled up by the first wave. The flood chronology started with the overbank flow on the tributaries, especially at Sungai Kundang. The simulated floodplain is very similar to the actual flood in terms of flood boundary, depth, and duration. To demonstrate more clearly the differences between the two flood waves, their flood layers were overlaid as shown in Fig. 14. An additional 3.83 km^2 was affected by the second wave or equal to 7.3% bigger compared to the first event.

5.8 Flood Mark for 2006/07 Flood Event

To check the model's approximation in the real world, it is necessary to calibrate and verified the model against a set of observed flood data or flood evidence (Howe Lim and Melvin Lye 2003). Figure 15 showed the water spilled from the main channel and flooded the areas up to 1.3 km from the riverbank. The red triangles are observed flood marks in the study area. The study was validated by comparing the simulated flood against the observed value at 12 stations for January 2007 flood event. The simulated flood boundary was also found to be close to the actual flood boundary. Table 7 provides a detailed comparison in terms of flood depth between the observed flood mark and simulated flood level. The simulated flood depth was compared with and without tidal effects. The results showed that the difference with tidal effect is more than 90% and without tidal is more than 40%.

Table 7
The percentage differences between observed (Obs.) and simulated (Sim.) inundated area at Kota Tinggi town during the January 2007 Flood Event. WL = Water level.

St. No.	Location	Obs. WL (m)	Sim.WL with tidal effect (m)	Sim.WL without tidal effect (m)
1	Kota Tinggi bridge	5.5	4.9	4.7
2	Family Mart	2.12	2.08	1.05
3	TNB Family Mart	2.5	2.37	1.9
4	Maybank	2.15	2.28	1.5
5	Kg. Kelantan	1.88	1.7	0
6	Big Clock	2.33	2.32	1.65
7	Kota Tinggi hospital	0.88	0.95	0
8	Kota Tinggi High School	2.4	2.22	1.92
9	Football field 1	3.74	2.25	0
10	Football field 2	2.8	2.1	0
		Accuracy	91.37%	43.16%

5.9 Flood Maps for 25, 50, 100, and 200 Return Period with Tidal Effect

Figure 16 showed the water level of various ARIs derived from the simulated hydrographs. The simulated flood depths are 3.8 m, 6 m, and 7 m for 25, 50, 100, and 200 ARIs, respectively. The simulated peak flows were used in HEC-RAS to model water level and the inundated area. In the HEC-RAS model, the discharge values used for 25 ARI, 50 ARI, 100 ARI, and 200 ARI were 595 m^3/s, 691 m^3/s, 786 m^3/s, and 852 m^3/s respectively.

The flood maps for 25, 50, 100 and 200 ARIs are shown in Fig. 17. The result indicates that the numerical model gives a realistic detection of the flow of floodplain together with a good calibration data model. It was found that the simulated 100 years flood has very similar coverage and depth with the Jan 2007 flood event at Kota Tinggi. For 25 ARI, the total inundate area was covered for about 654.09 ha. While the water level above 3 m was about 15.15 ha. Based on the flood simulation, the water level started to overflow at the tributary. In summary, the flood map for 25, 50, 100, and 200 return periods is useful for flood mitigation strategy especially for determining flood structure design.

6. Conclusion

The study provides knowledge and understanding of the use of HEC-HMS, HEC-RAS, and HEC-GeoRAS for hydrological and flood modeling. The study helps in understanding the components and characteristics of tidal on flood modeling. The result showed that the GEV gave the best fit for distribution to estimate the return period for the JRB. The estimated peak flows for 25, 50, 100, and 200 ARIs were 466m^3/s, 595m^3/s, 691m^3/s, and 786 m^3/s, respectively. The hydrological modeling using HEC-HMS gave 73% model efficiencies for calibration, and 83% for validation. From this result, the hydrological model is considered reliable for simulating hydrographs. The observed peak flow in 2006 was only 314.20 m^3/s, which is about half of the simulated peak flow of 625.3 m^3/s. Meanwhile, in the 2007 flood event, the observed peak flow was 361.21 m^3/s, and the simulated was 743.9 m^3/s. The much lower observed peak flows were due to overbank flow and under such a situation, the stage-discharge rating curve is not applicable.

The simulated flood coverage for the 2006/07 flood event closely matches the actual flood at Kota Tinggi. In addition, the simulated water levels for the second wave show more than 90% similarities at 11 flood marks when the tidal effect is considered in the modeling. Based on the flood map, the 2006/07 flood event is quite similar to the simulated flood map for 50 years ARI. In addition, results of frequency analysis, hydrological modeling, flood routing, and flood mapping are useful as a basis for improving strategies to manage the future flood. In addition, local authorities could have better planning for flood mitigation, and flood evacuation strategies.

Declarations

Ethical Approval

Not applicable

Consent to Participate

Not applicable

Consent to Publish

We, (Zulfaqar Sa’adi, Ahmad Zuhdi Ismail, Zulkifli Yusop, Zainab Mohamad Yusof) hereby declare that We participated in the study in the development of the manuscript titled (Effect of the tide on flood modeling and mapping in Kota Tinggi, Johor Malaysia). We have read the final version and give our consent for the article to be published in Natural Hazards.

Authors Contributions

All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by Ahmad Zuhdi Ismail, Zulkifli Yusop, Zulfaqar Sa'adi and Zainab Mohamad Yusof. Zulfaqar Sa'adi wrote the first draft of the manuscript. All authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Conceptualization: Ahmad Zuhdi Ismail, Zulkifli Yusop, Zainab Mohamad Yusof; Data curation: Zulfaqar Sa’adi, Ahmad Zuhdi Ismail; Formal Analysis: Ahmad Zuhdi Ismail Zulfaqar Sa'adi; Funding acquisition: Zulkifli Yusop; Investigation; Ahmad Zuhdi Ismail, Zulkifli Yusop, Zulfaqar Sa'adi; Methodology: Ahmad Zuhdi Ismail, Zulkifli Yusop; Project administration: Zulkifli Yusop; Resources: Zulkifli Yusop, Zainab Mohamad Yusof; Software: Ahmad Zuhdi Ismail, Zulfaqar Sa'adi; Supervision: Zulkifli Yusop, Zainab Mohamad Yusof; Validation: Ahmad Zuhdi Ismail, Zulfaqar Sa'adi; Visualization: Ahmad Zuhdi Ismail, Zulfaqar Sa'adi; Writing – original draft: Zulfaqar Sa'adi; Writing – review & editing: Zulfaqar Sa'adi, Zulkifli Yusop.

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Competing interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Availability of data and material

Not applicable

Code availability

Not applicable

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Figures

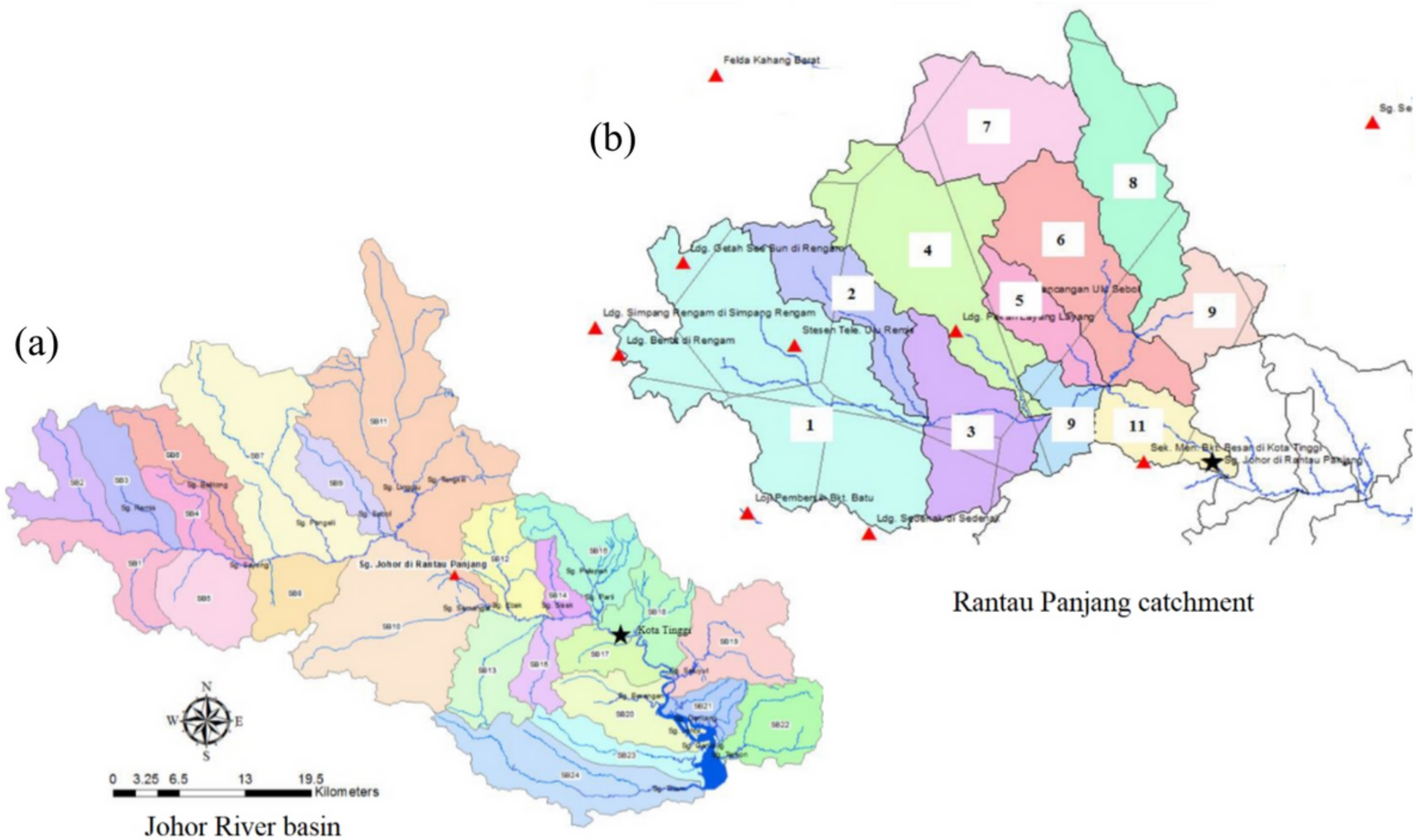


Figure 1

(a) The 24 sub-catchments in the JRB. The red triangular is the location of the Rantau Panjang gauging station in the middle of Johor River. (b) The 11 lumped sub-catchments of the Rantau Panjang catchment. The location of rainfall stations (red triangle) and Rantau Panjang gauging station (★).

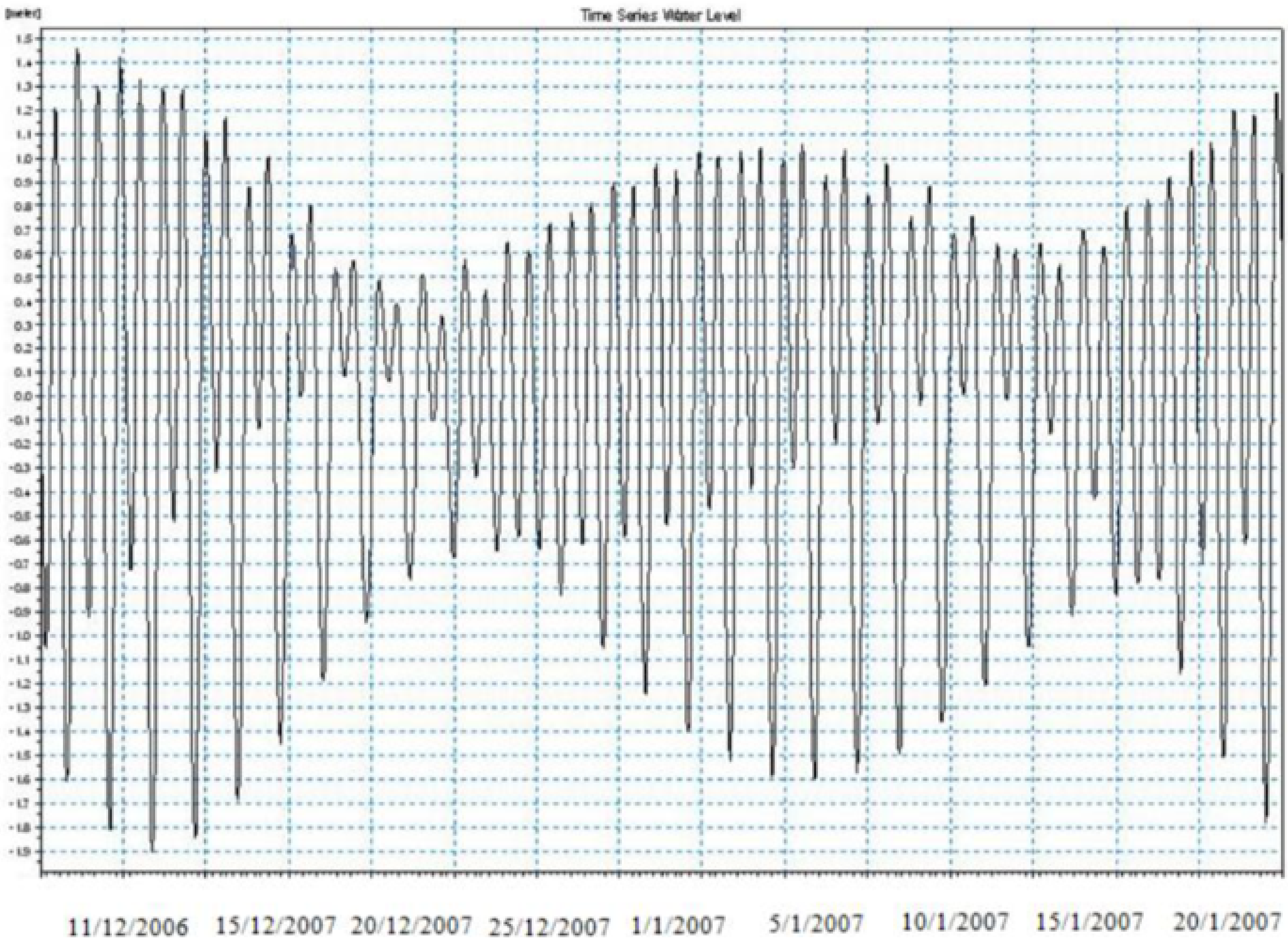


Figure 2

Observed tidal cycle between 11 Dec 2006 and 20 Jan 2007 at the estuary of JRB.

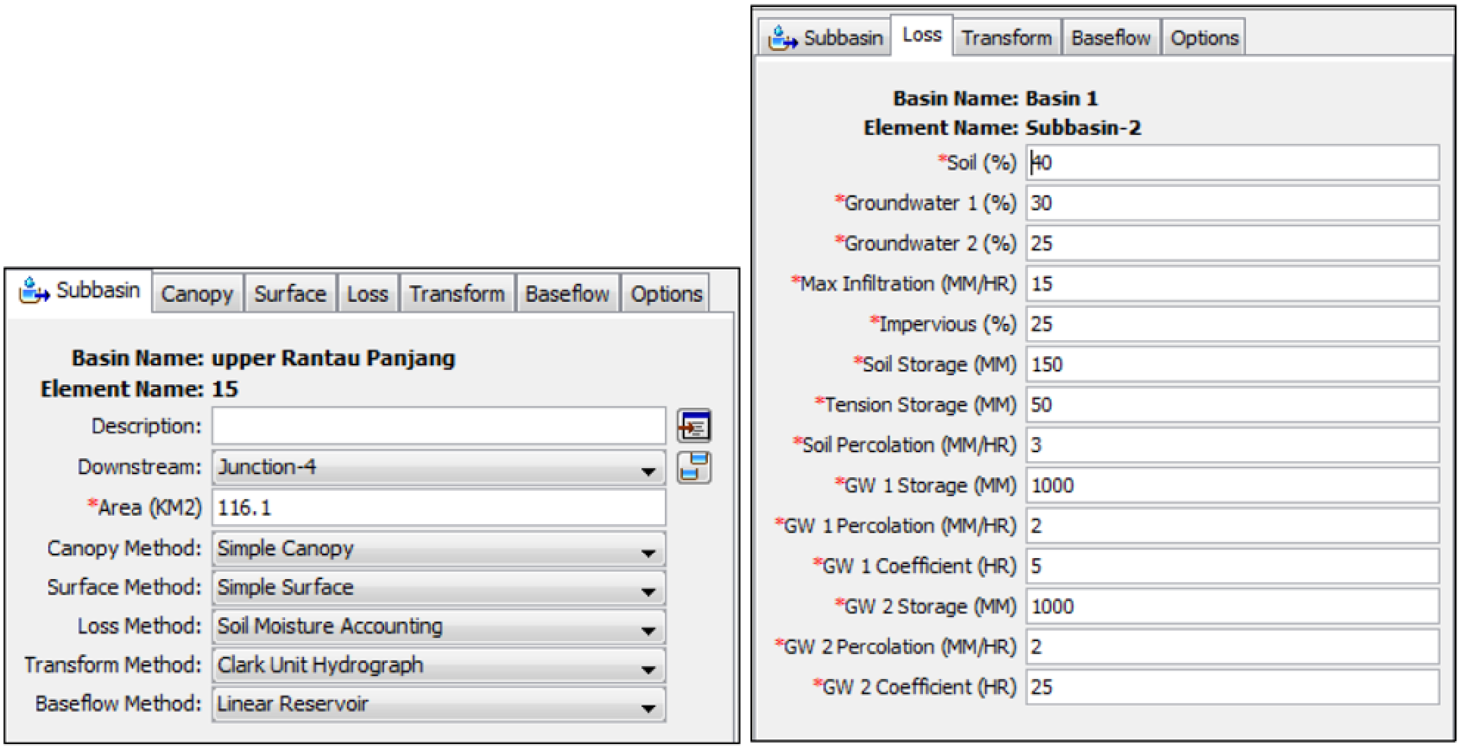


Figure 3

The interface and input of HEC-HMS method setup and loss parameter in this study.

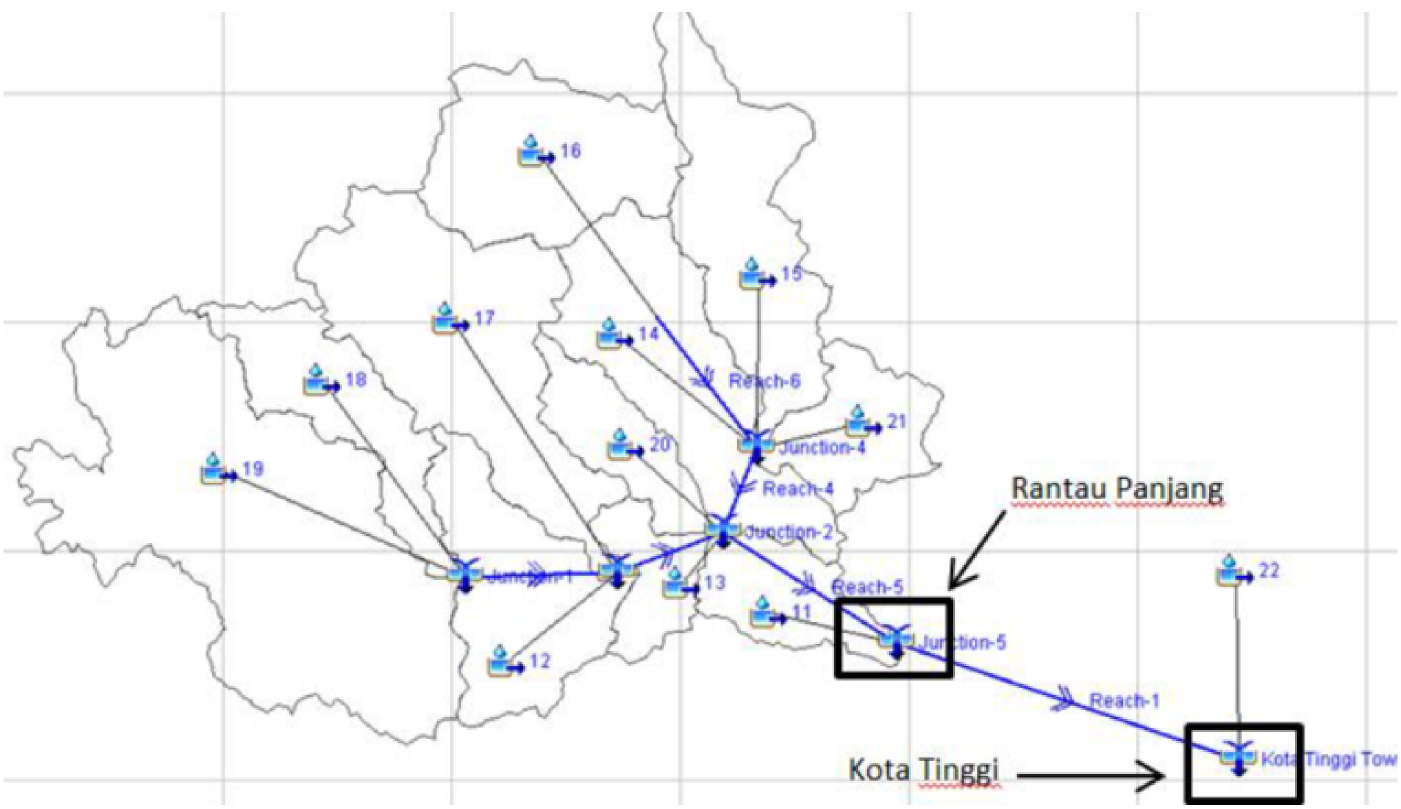


Figure 4

Routing Model from Rantau Panjang Gauging to Kota Tinggi Town.

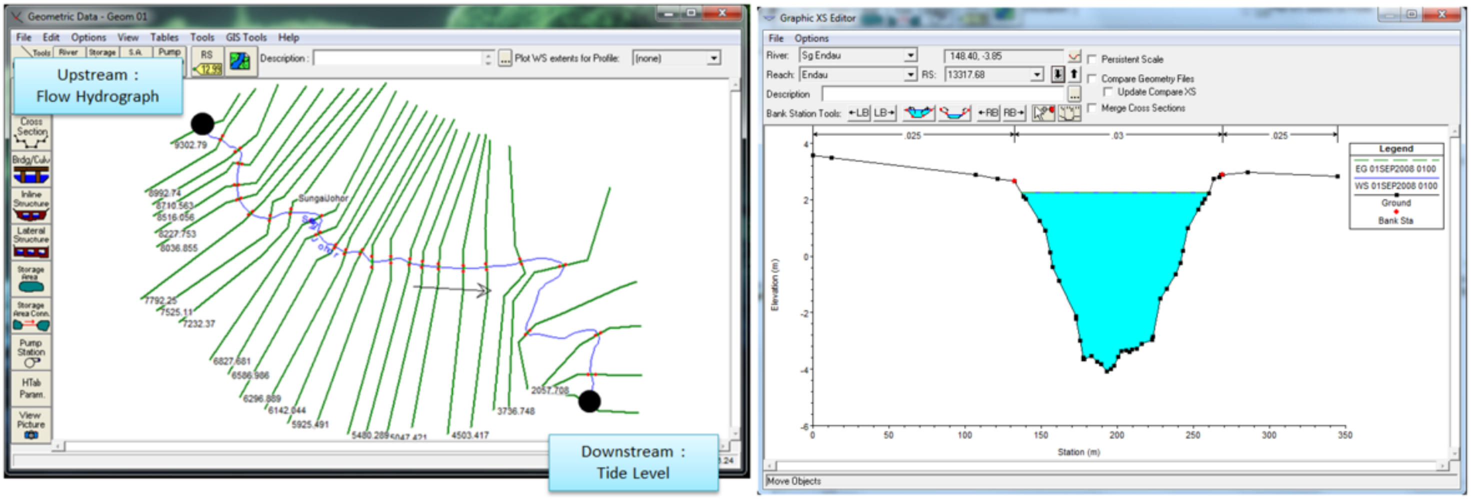
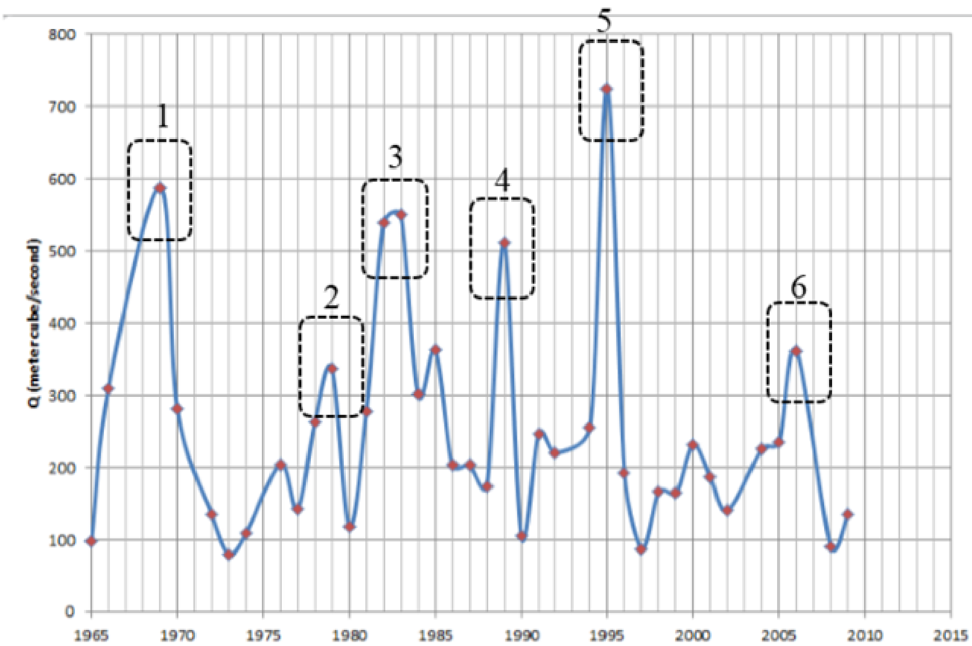


Figure 5

(a) The geometry model setup in HEC-RAS at Kota Tinggi and (b) the cross-section editor in HEC-RAS.



Statistic	Value
Sample size	38
Range	645.68
Min	76.89
Max	724.73
Mean	251.59
Variance	23527.0
Std.Dev	153.38
Coef.of Variation	60.9%
Std. Error	24.88
Skewness	1.43
Excess Kurtosis	1.77

Figure 6

The annual peak flow and descriptive statistics of annual flood at Rantau Panjang gauging station from 1965 to 2010.

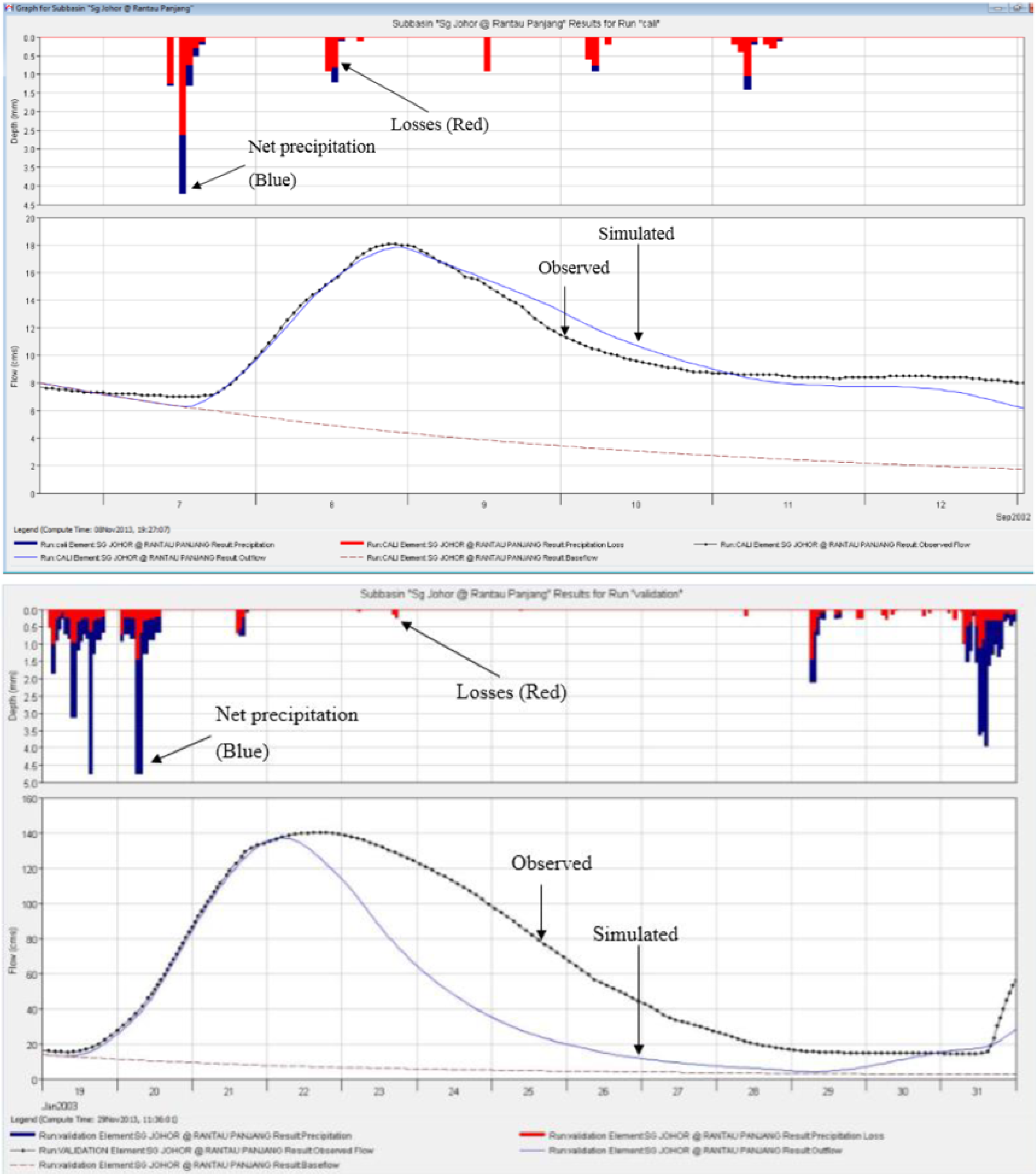


Figure 7

Calibrated and validated hydrographs in Sept 2002 and Jan 2003 respectively for HEC-HMS hydrological model.

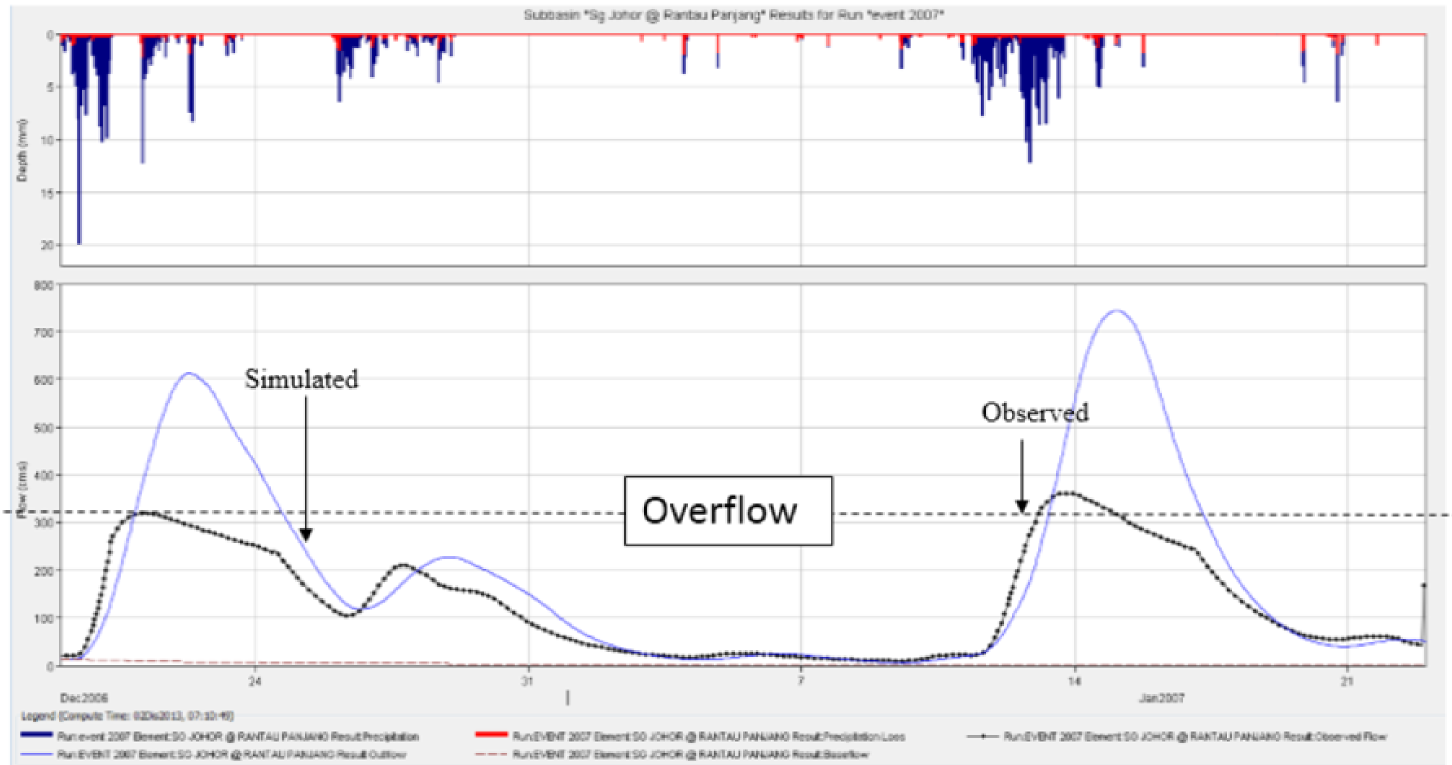


Figure 8

The simulated and observed hydrograph data from 19th Dec 2006 to 23rd Jan 2007.

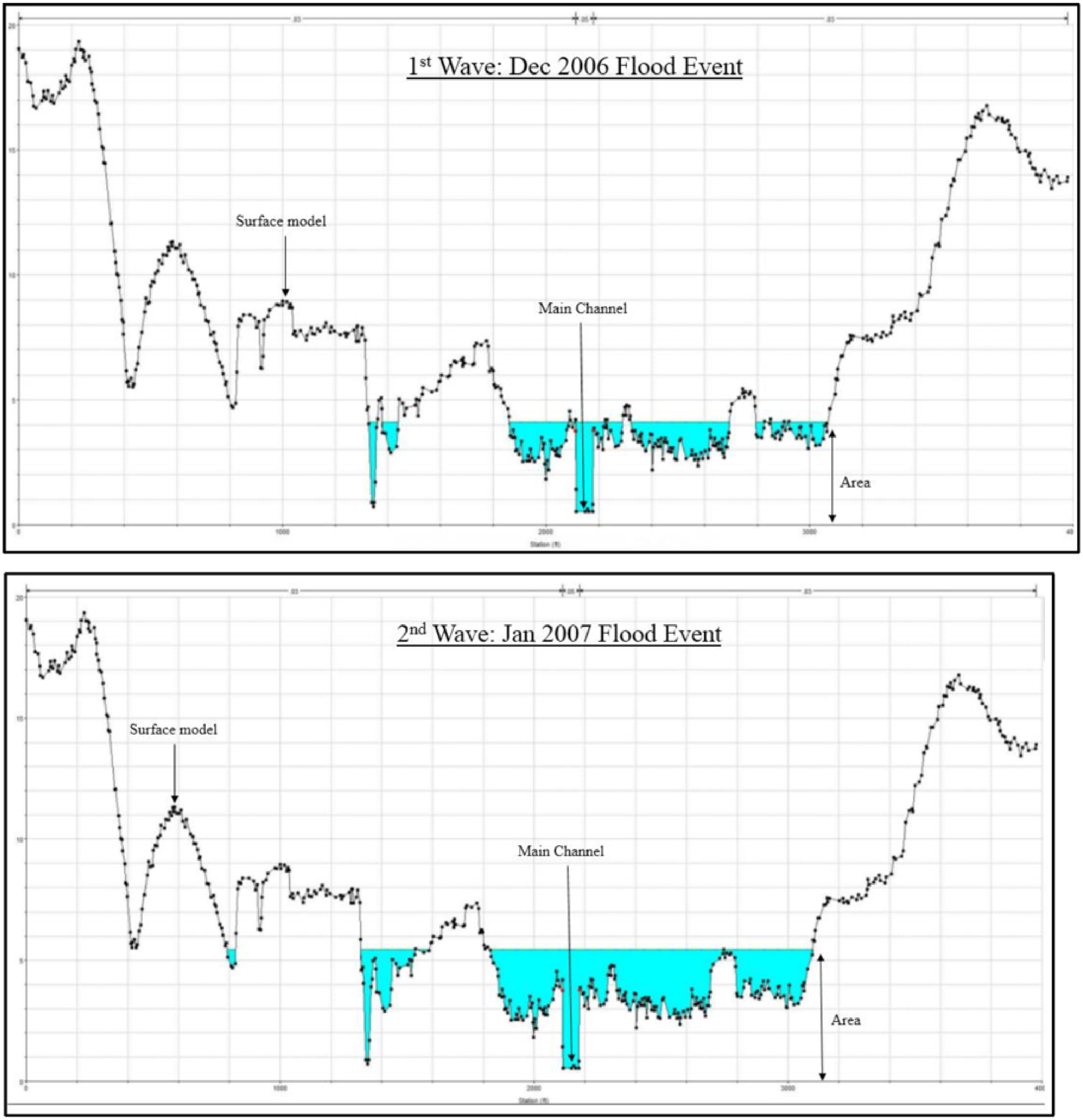


Figure 9

The 1D cross-section profile for peak flow during the 1st and 2nd wave in Dec 2006 flood event at Kota Tinggi.

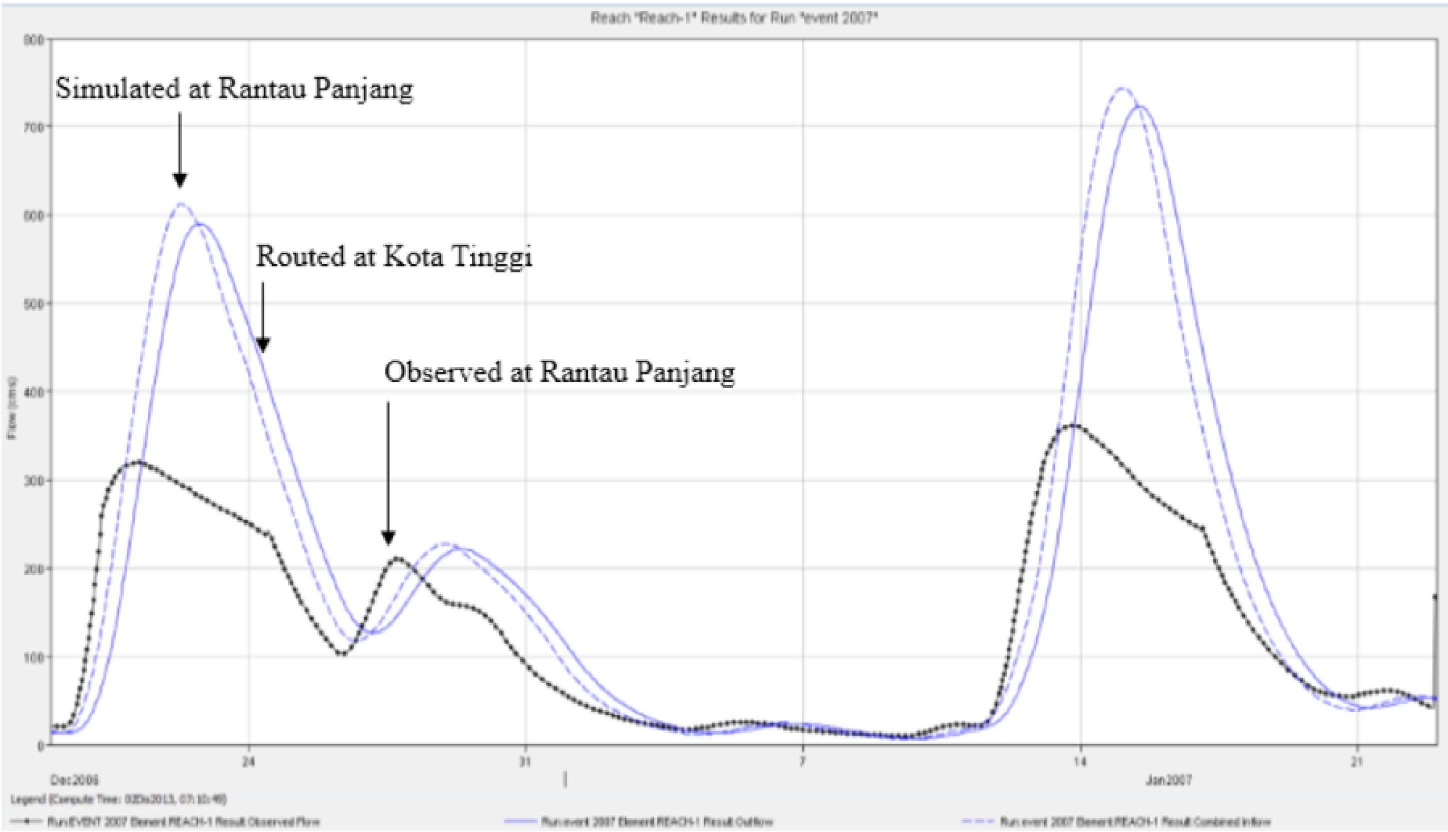


Figure 10

Comparison between the routed flow at Kota Tinggi town and the simulated hydrograph at the upstream Rantau Panjang.

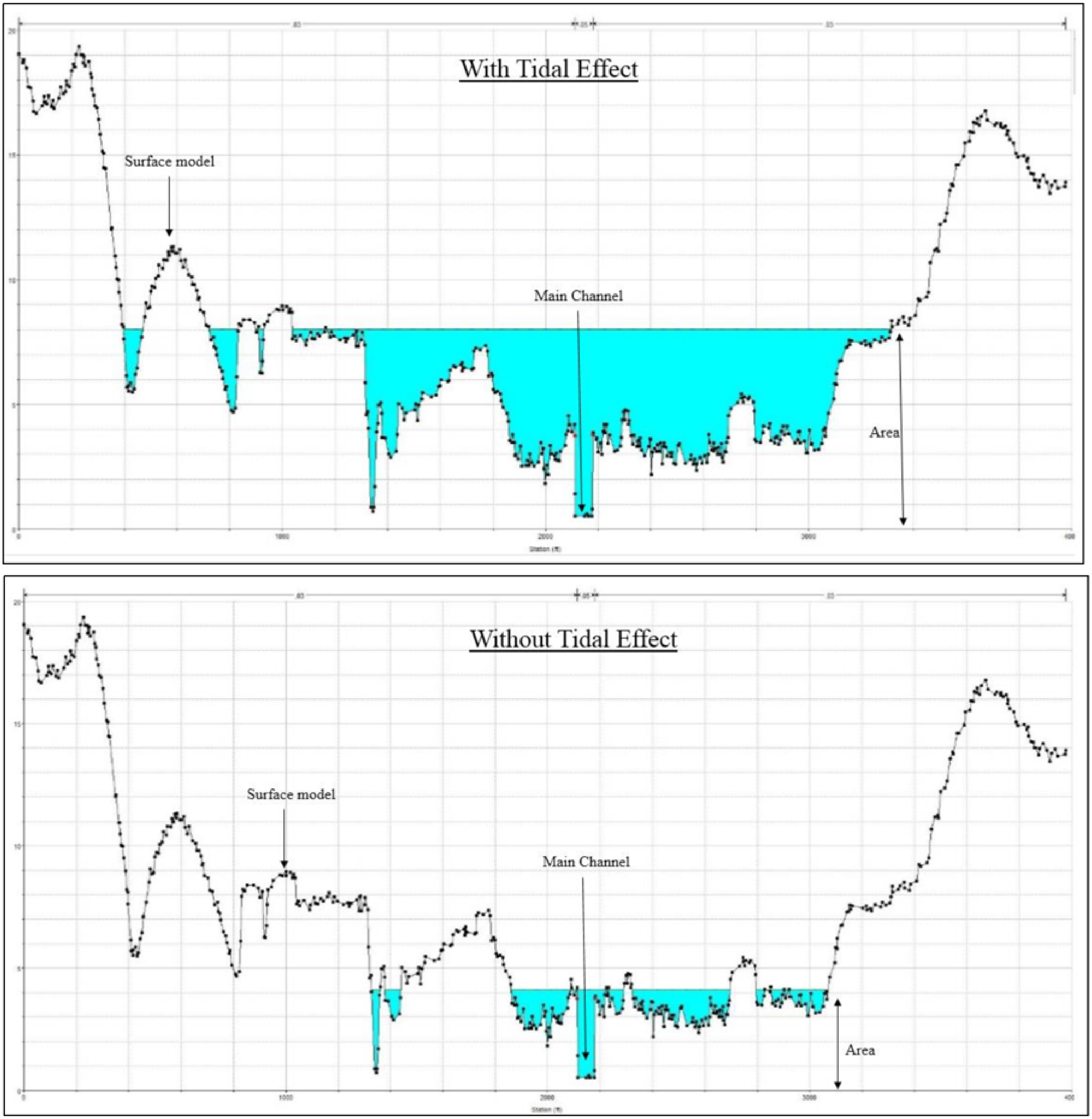


Figure 11

Simulated flood level with (a) and without (b) tidal effect at cross-section AB.

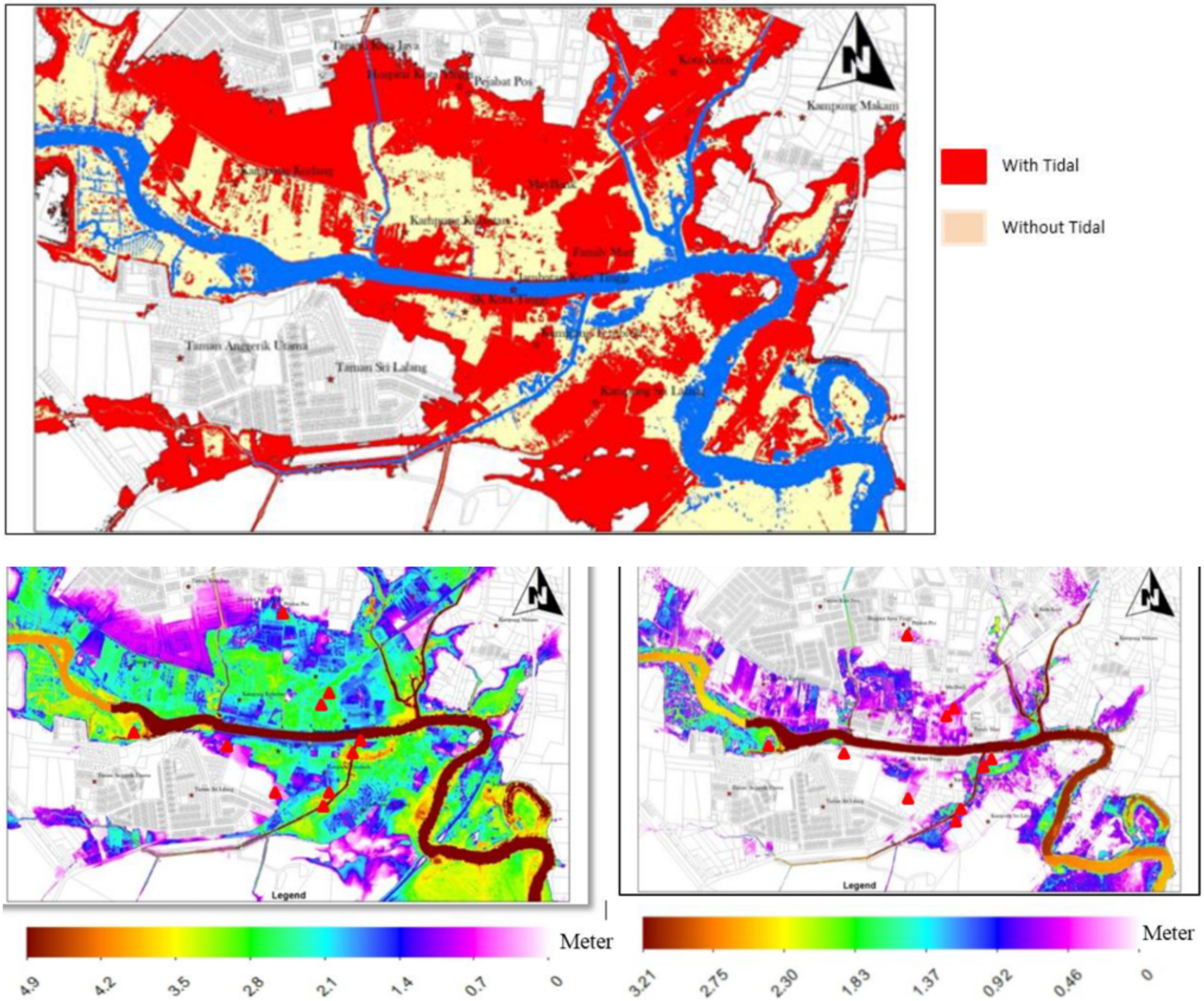


Figure 12

(a). The differences in the inundated area at Kota Tinggi during the 2006/07 flood event with (red) and without (cream) considering tidal effect. (b) Inundated area during the 2006/07 flood event with and without tidal effect.

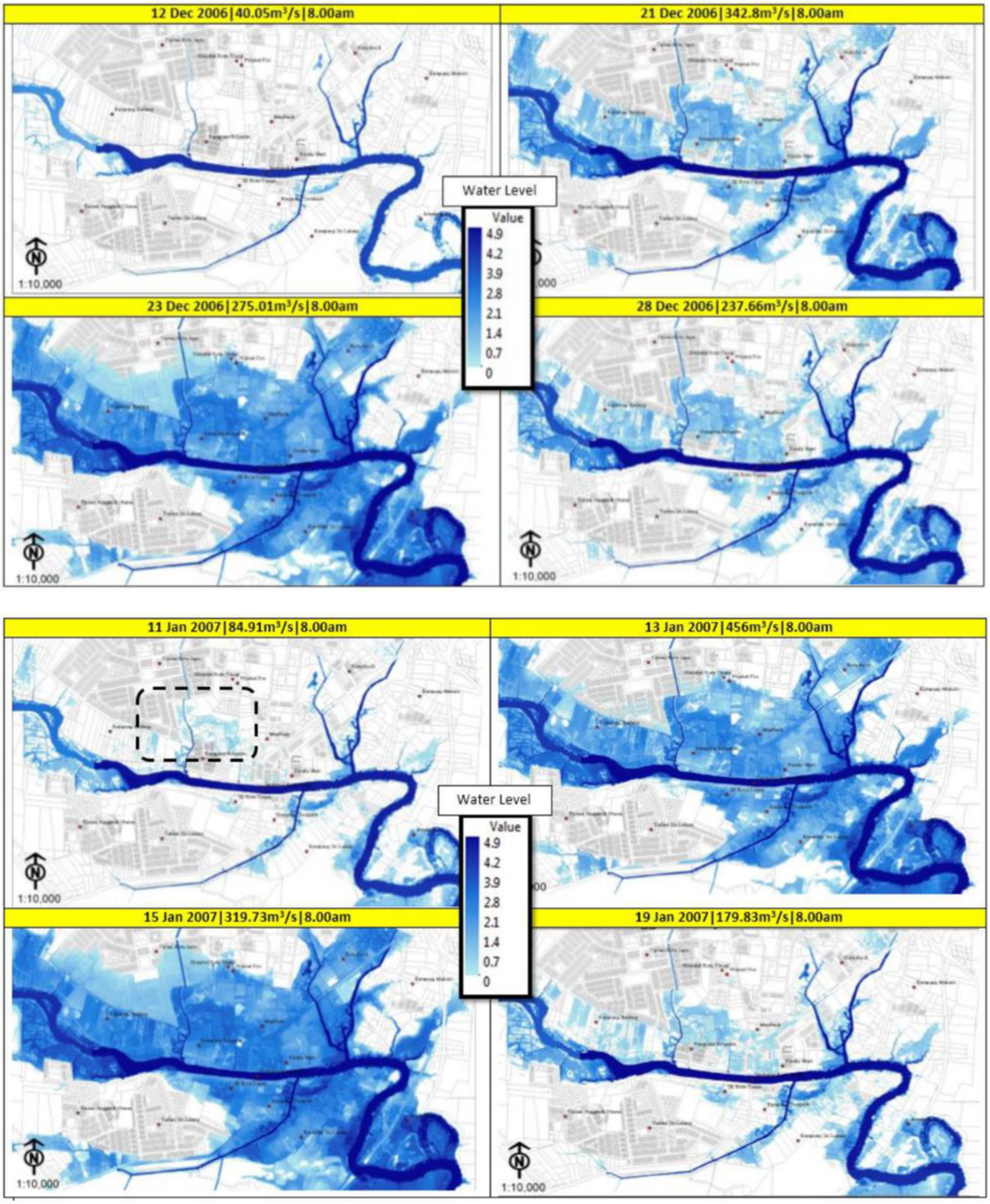


Figure 13

The simulated inundated areas as the floods progress and recede during the 1st and 2nd flood waves in Dec 2006 and Jan 2007, respectively.

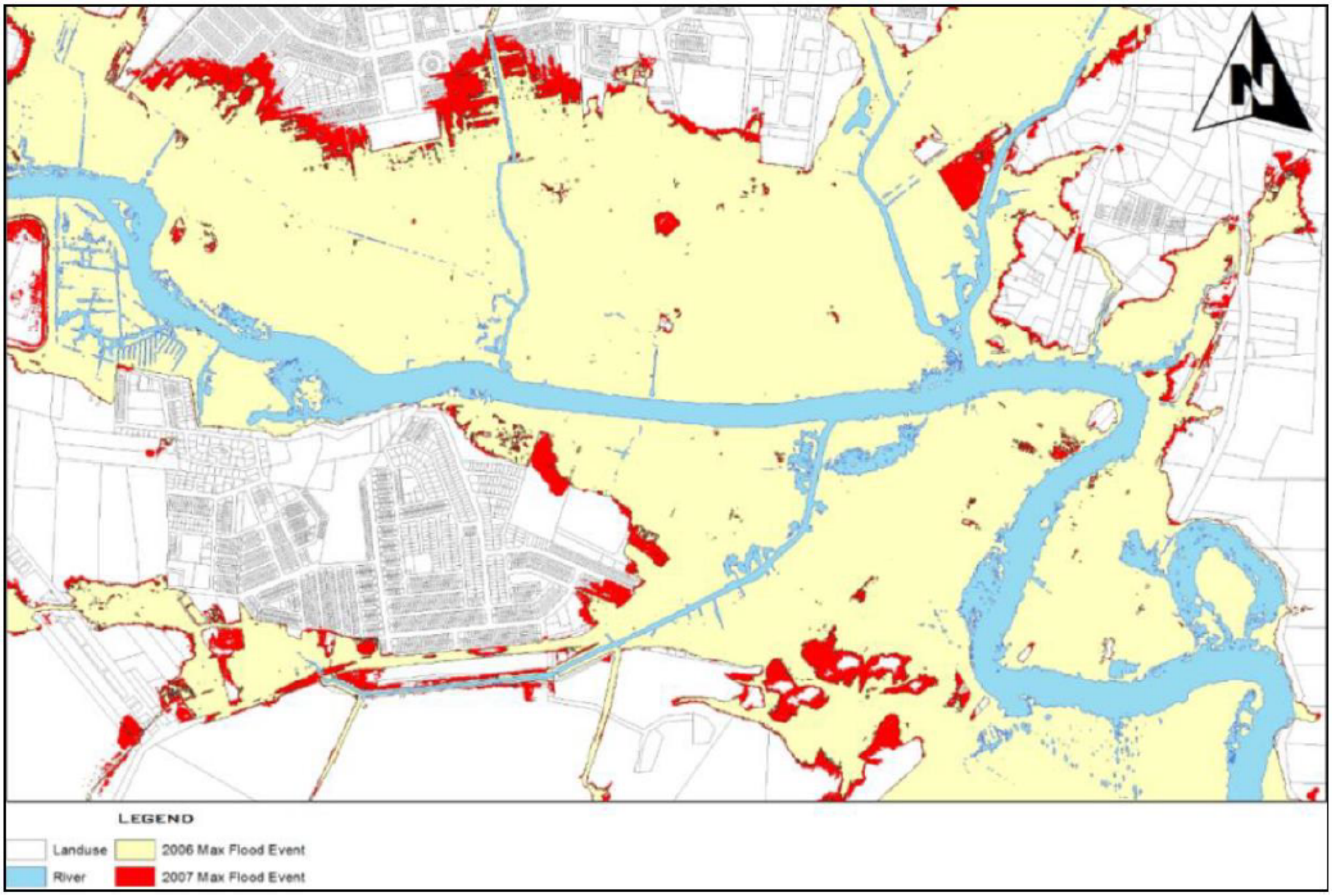


Figure 14

Additional flooded area in Jan 2007 (red) compared to flood coverage in Dec 2006 (cream).

Figure 15

The location of flood marks (triangle) for the 2007 flood event.

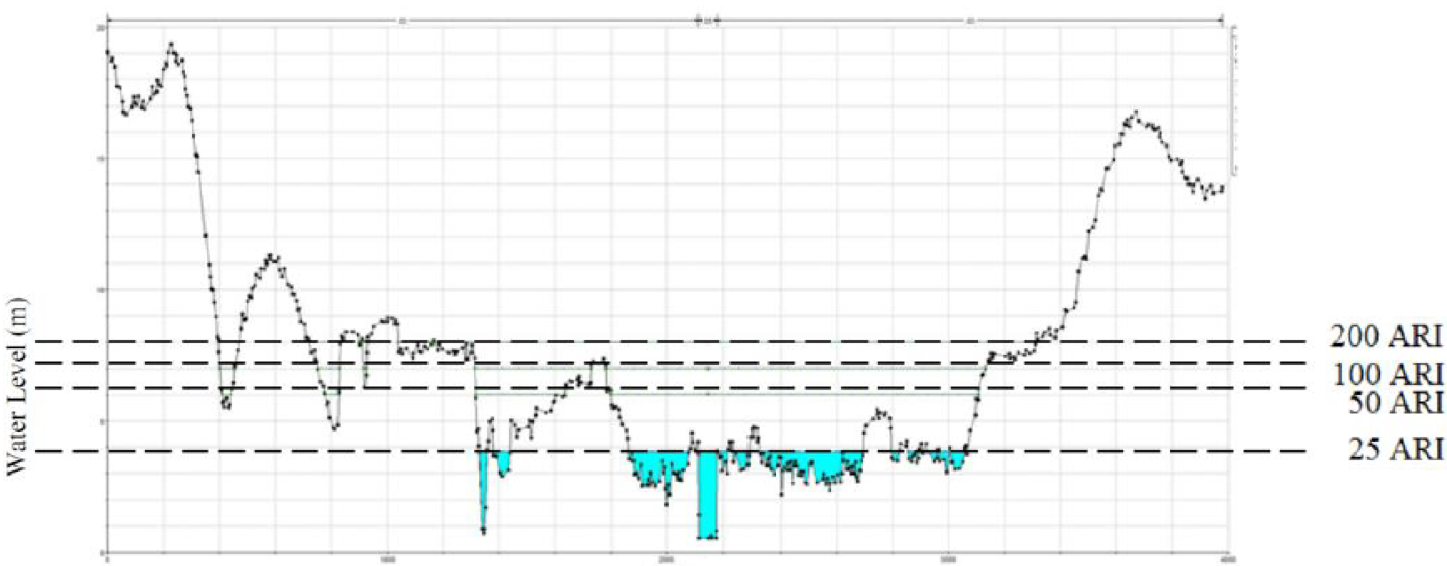


Figure 16

Simulated water levels for various ARIs (Kota Tinggi town).

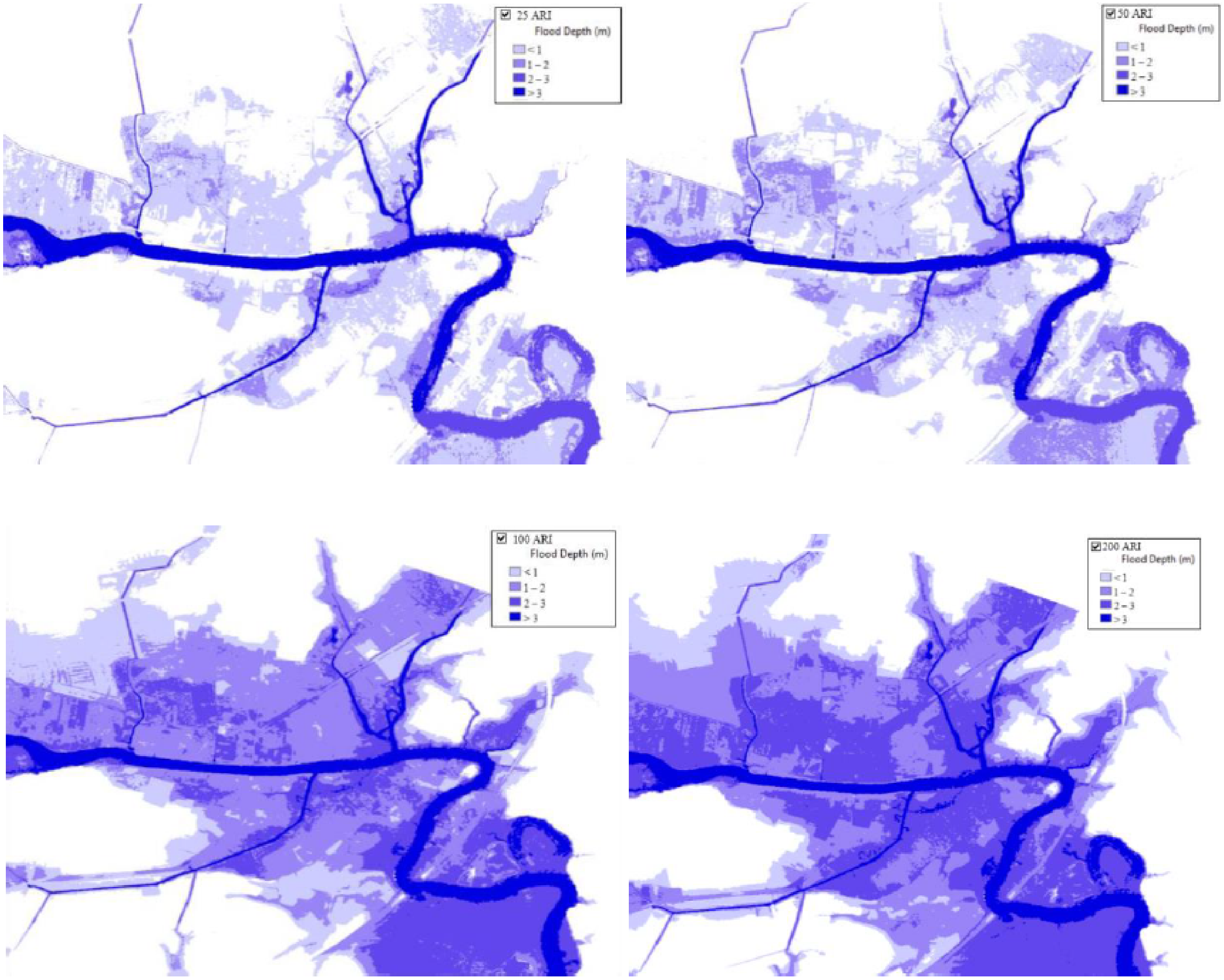


Figure 17

Inundated area for 25, 50, 100, and 200 ARI. The darker blue indicates a deeper level and is very much related to the elevation profile.