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Hydrodynamic Modelling and Flood Mapping of Sembrong Catchment Area

Marina MAZLAN[2], Mohd Adib MOHAMMED RAZI[1], Mohd Shalahuddin ADNAN[1], Mustaffa ANJANG AHMAD[1], Lai Wai TAN[1]

[1]*Faculty of Civil and Environmental Engineering, UniversitiTun Hussein Onn Malaysia, 86400 Parit Raja, BatuPahat, Johor, Malaysia*
[2]*Faculty of Civil and Environmental Engineering, UniversitiTun Hussein Onn Malaysia, 86400 Parit Raja, BatuPahat, Johor, Malaysia*
[*]*Corresponding author*
Email: msmarinamazlan@gmail.com, adib@uthm.edu.my, shalahudin@uthm.edu.my, mustafa@uthm.edu.my, laiwai@uthm.edu.my

ABSTRACT

With the increased frequency of natural disasters, there is an elevation of the usage of the integration of flood map and hydrodynamic models to assess the risks and impacts of flood at different temporal and spatial scales. In the past 15 years, there were massive changes in land usage in the study area; from virgin forest to palm oil plantation, industrial and housing areas. These changes had really influenced the infiltration, as well as the runoff rates in this area. The increase of runoff and decrease of infiltration rates could lead to serious flood problem. The main objective of this study was to determine the effectiveness of the existing drainage system of Sembrong river based on two models, namely (i) hydrodynamic model, which was developed using XPSWMM and (ii) flood map, which was developed using SURFER 9. A total of eight nodes and seven links of the Sembrong river were built using XPSWMM, which began from Ayer Hitam to Sri Gading. Based on the results, the peak flow rate for Sembrong river was 135.2180 m^3/s. The hydrodynamic model had indicated that Link 1, which was located at Ayer Hitam, Link 3 (Sabak Uni) and Link 5 (Parit Raja) were unable to accommodate the additional amount of surface runoff that went into the drainage system, thus led to flooding. Based on the flood map, the elevation in this area was quite low, which ranged from 3 to 14 m. By integrating the flood map and hydrodynamic map, it clearly shows that the results are more reliable and the affected area can be easily identified. The developed flood model could be a very useful and valuable tool in flood management of the Sembrong river. It may be used as a tool for river development planning, flood mitigation measures, addressing public awareness and flood evacuation planning.

KEYWORDS
Hydrodynamic model, Sungai Sembrong, XPSWMM, flood risk assessment, flood mapping, SURFER 9

INTRODUCTION
Flood is a natural phenomenon that occurs when the maximum flow rate of a drainage system exceeds the capacity that can be accommodated by the system. This lead to water overflows beyond the banks of the drainage system, causing flood in the area. Flood happens in the area of BatuPahat especially during the monsoon season when heavy and persistent rain occurs.Eventually, flood has led to unsustainable development in the urban area where various economic activities are concentrated. Due to the rapid development, the occurrence of flood, especially flash floods, is difficult to evade. The replacement of natural green forest with impervious urban area affected the infiltration process and as a result, almost all of the rainfall flows into the river drainage system at one time, thus reducing the capacities of most rivers to drain away the excessive rain water.Malaysia and the Johor state government had to bear loss worth millions of dollars due to the floods. Many public facilities and infrastructures were badly affected, major roads were cut off and indirectly led to transport network problems in many cities and areas. In addition, floods also often caused landslides, traffic congestion and property theft. Study on the effectiveness of natural drainage system is to determinewhether the natural drainage system is able to function effectively or otherwise. The main function of natural drainage system is to accommodate the volume of surface water runoff from rainfall and to convey it from one point to another. Failure of natural drainage system to function effectively will caused major problems such as flood, which has many harmful effects, including loss of lives, health problems, damage to property and others.Generally, this paper will present the hydrodynamic model and flood mapping of SembrongRiver's catchment area. The result will be discussed at the end of this paper in order to determine whether the waterway system of SembrongRiver is effectively functioning or otherwise. Figure 1 shows the location of study area.
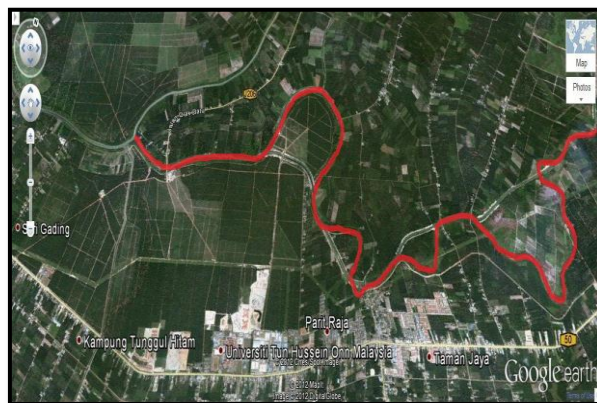

Figure 1.The location of study area; Sungai Sembrong, Johor.

AREA OF STUDY
Sembrong catchment in Johor, Malaysia was chosen as the area of study. Sembrong Riverwas selected to develop the flood inundation model. Sembrong River has a drainage length of 22.3km that covers 273km^2. It originates from Sembrong Dam and flows through south-eastern part of Johor and afterward flows into Bekok River and SimpangKanan River.

Sembrong River is located in theBatuPahat district area; it is a sub-catchment of BatuPahat River. However, for this study, the model only started from Ayer Hitam and ended at Sri Gading. The land usage activities along Sembrong River inclusive of industrial areas, residential areas and agriculture activities, such as palm oil mill and paddy fields. As a significant catchment area, a flood inundation model ought to be developed as to provide information to ease rescue-and-relief operations during flood event, specifically for this flood prone area.In December 2006, BatuPahat was affected by flood and it was reported that several downstream areas along Sembrong River were inundated. The magnitude of flooding was at its maximum level when heavy rainfall occurred. Figure 1 shows the selected catchment area of Sembrong River.

HYDRODYNAMIC MODELING

Model of one-dimension has been widely used for hydraulic modeling of the river. One-dimensional (1D) modeling is also a very practical choice as a flood management tool. 1D model can produce results that are more easily accepted and understood. XPSWMM is one type of river modeling tools available in the market. It is developed by XP Solutions. It is a comprehensive software package andis used to develop dynamic modelingforstormwater, sanitary or combined system, and as well as river systems. XPSWMM software is equipped with 1D hydrodynamic simulation of river, which is modeled through pre-processing data input, model calculations and results display of the next model. By XPSWMM, the whole model can be simulated within one system. Therefore, XPSWMM is chosen as the tool for hydrodynamic modeling. River cross sectional data, rainfall and infiltration data were the parameters used in developing this hydrodynamic model. XPSWMM has two main modes, which are Runoff Mode and Hydrology Mode. Runoff mode works by interpreting the rainfall data.The data analyzed in Runoff mode will give results on thevolume and velocity of water flowing out from the system. But the Runoff mode will not show the movement of water if the Hydrology mode is not activated. Hydrology mode works to analyze the results of the Runoff mode. Surface water Runoff mode will be used as inputs to the Hydrology mode, where the movement of water from rainfall data is then passed through the connecting lines representingthe Sembrong River. Figure 2 until Figure 6 indicate each and every step in developing the hydrodynamic model of Sembrong River.
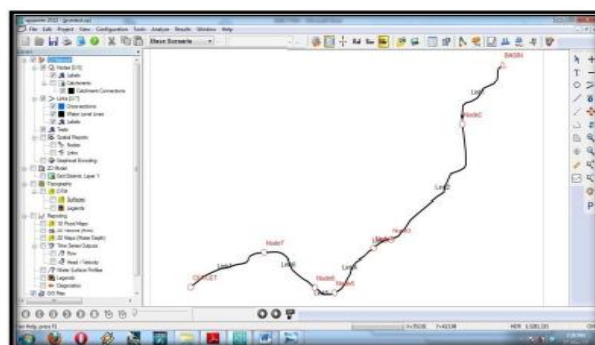

Figure 2. Background image input.

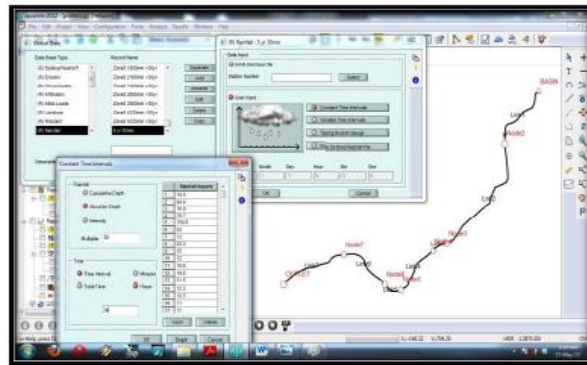Figure 3. Create nodes and links for Sungai Sembrong hydrodynamic model.

Figure 4. Precipitation and infiltration data input for Sungai Sembrong hydrodynamic model.
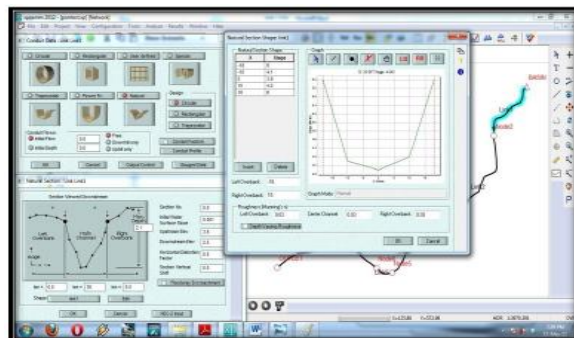

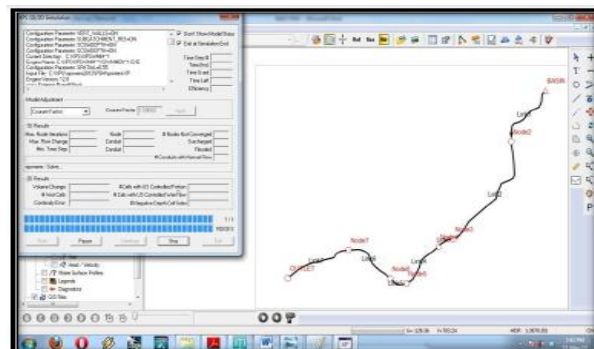Figure 5. River cross section data input of Sungai Sembrong.

Figure 6.Running analysis for Sungai Sembrong hydrodynamic model.

Figure 7 shows the precipitation rate versus time graph, where the graph was obtained after the analyzingrainfall data using XPSWMM. This generated graph used the daily precipitation data for the year 2011 from station number 1931003 located at Sembrong River Dam, Ayer Hitam. The maximum rainfall intensity recorded from the graph was 195mm/hour.
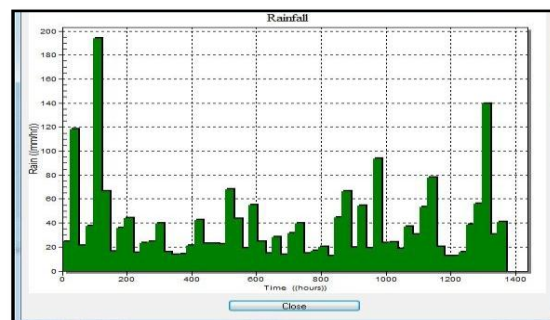

Figure 7. Graph of rainfall intensity rates versus time for rainfall data of year 2011 from station No.1931003 located at Empangan Sungai Sembrong, Ayer Hitam.

Peak flow rates obtained from each link forthis Sembrong River model showed similar values, where the differences that existedwere too small. This occurred due to the gradient of Sembrong River itself,which were not more than 9% for all links. Peak flow rate obtained was 135.2180m^3/s, which occurred in Link 1 and Link2.From these two links, Link2 had higher flow velocity than Link 1, which was4.96m/s. The hydrodynamic model analysis of Sembrong River indicated that Link 1, which was located at Ayer Hitam, Link 3 (SabakUniVillage) and Link 5 (Parit Raja)were unable to accommodate the amount of surface runoff that flowed into the river. So the water overflowed and caused flooding in the surrounding areas. Meanwhile, Link 2, Link 4 and Link 6 could accommodate the amount of runoff into the river. The river bank's elevation was recorded at Node 2 as 6.9m and the height of the water level was only 5.19m. The water level at Node 4 and Node 5 were constant at levels of 5.08m and 4.38m, while the river banks' of both nodes are 8.9m and 7.6m, respectively.The following Figure 8 is the longitudinal section view of the Sembrong River's hydrodynamic model. Dynamic sectional view of all links is displayed in this longitudinal sectional view. Meanwhile, Figure 9 is the dynamic plan view of the hydrodynamic model. Red line indicated the critical and high risk of flood areas. These are where Ayer Hitam, SabakUniVillage and Parit Raja are located.
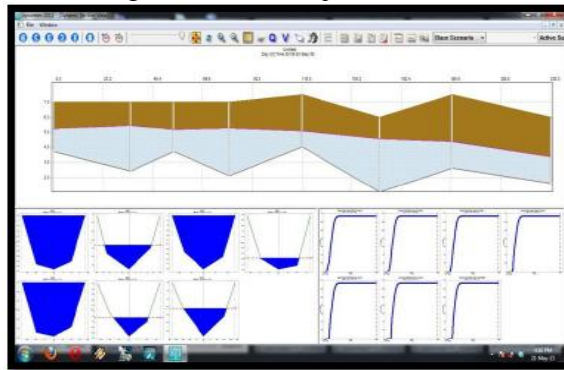

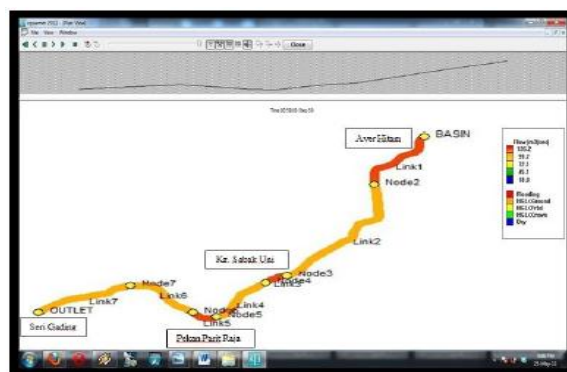Figure 8.Longitudinal section view for all links of Sungai Sembrong hydrodynamic model.

Figure 9.Dynamic plan view for Sungai Sembronghydrodynamic model.

1.0 FLOOD MAPPING

Mapping is the most proper approach used to describe flood pattern especially for flood mitigation. Generally, flood maps can be used to distinguish between flood hazard and flood risk; therefore, flood maps may exist in many different forms. The difference is that flood risk maps provide additional information about the consequences of flooding, such as damage to the economy, the number of people affected, and so on. Meanwhile, information about the probability and / or magnitude of a flood can be obtained in the flood hazard maps.

In addition to the two general types of flood maps, there are also other methods to quantify the danger and risk. Therefore, different types of flood maps correspond to the information needed. Flood maps are created by various institutions for various purposes. The most important producer of nation/basin wide maps is the governmental institutions, the insurance industry and trans-boundary river basin authorities (de Moel*et al.*, 2009). In this study, flood mapping of Sembrong River will be produced in order to obtain the contour map so that the lowland area can be determined. Field work datasets will include position, topography height, the time of observation and details of the spot. SURFER9 software will be used to develop flood map of Sembrong River's catchment area. SURFER9 is a contouring and 3D surface mapping program that runs under Microsoft Windows. It is a grid-based graphics program. SURFER 9 interpolates irregularly-spaced XYZ data into regularly-spaced grid. The XYZ data is a file containing at least three columns of data values. X and Y represent the coordinates of data point; whilst Z represents the value or the elevation level of the data point. Grids may also be imported from other sources. The saved grid data command is the most paramount data input used in developing flood map by SURFER 9. Data extracted from Google Earth will be quickly and easily converted into outstanding contour, surface, wireframe, vector, image, shaded relief and post maps. Wireframe maps as per Figure 10 will be created to identify the possible inundated flood prone area. The wireframe maps provide an impressive 3D display of the data (Junaidah*et al.*, 2010). The purpose of generating the contour map is to show the areas around Sembrong catchment and the location of Sembrong River. This contour map showcases the ground surface around Sembrong River. The elevation level around the catchment area of Sembrong can be seen through on this contour map. Figure 11 shows the contour map of Sembrong River's catchment area generated by SURFER9. In order to ease the identification of the highland and lowland area of Sembrong catchment, few colours are chosen to indicate certain value of elevation level:

    a) Green   - 3 meters above sea level.
    b) Yellow - 5 meters above sea level.
    c) Orange - 6 meters above sea level.
    d) Blue   - 14 meters above sea level.

Besides contour map by SURFER 9 as the mapping tool, few other types of maps may be generated by activating the command, as per the following figures, such as 3D wireframe map, vector grid map and flood map.
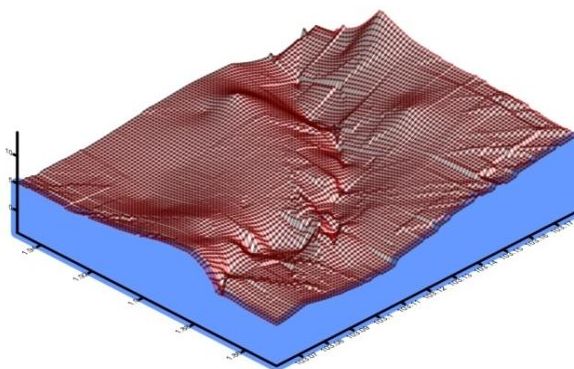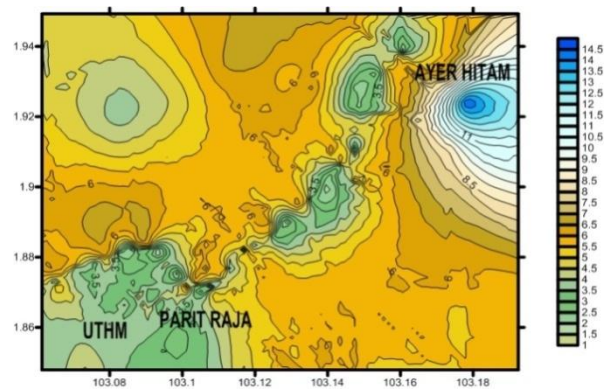

Figure 10.3D wireframe map of Sembrongcatachment area.

Figure 11.Contour map of Sembrong catchment area.

Flood map is produced to identify areas at risk of flooding along the Sembrong River. In addition, flood map also serves to provide preliminary information and to minimize the impact to the surrounding area of Sembrong River. Figure 12 shows surface runoffs which flowed into Sembrong River's catchment area, and Figure 13shows a flood map of Sembrong River, which showed the movement of water from Sembrong River to the lowland area. The water movement happened as Sembrong River is unable to accommodate the quantity of water at one time, and caused an outflow into the lower area around the river. There were two colours marked on this map to represent the area at risk of flooding. The green colour on the map was the most at risk to flooding because the elevation of this area is only 3 meters above sea level and almost at the same elevation with the river. The yellow coloured areas are with elevation of 6 meters above sea level. This area will also be at risk of flooding in the event of overflow from Sembrong River.
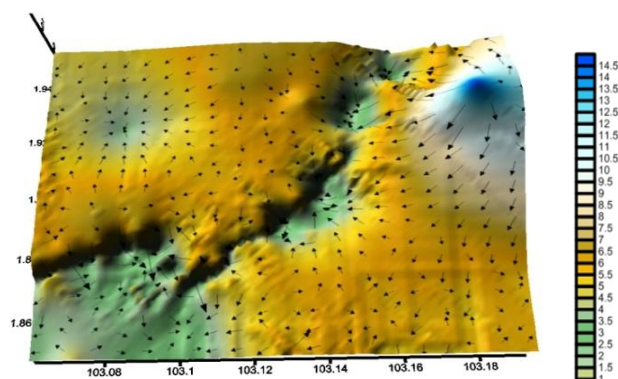

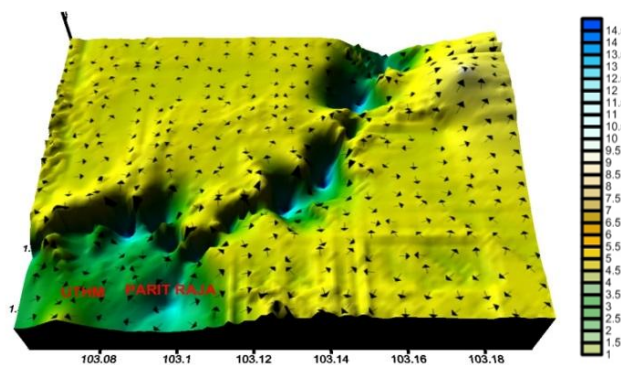Figure 12.Vector grid map of Sembrong catchment area shows the runoff flowing into the catchment.

Figure 13.Flood mapping of Sembrong catchment area.

2.0 CONCLUSION

From the hydrodynamic models generated from XPSWMM software, it was indicated that Link 1, which was located at Ayer Hitam, Link 3 (SabakUni) and Link 5 (Parit Raja) were unable to accommodate the amount of surface runoff that went into the drainage system, and thus will cause flooding in the area. This result is supported by the flood map generated by SURFER9, where UniversitiTun Hussein Onn Malaysia (UTHM) and Parit Raja were located in the area marked with green colour, which are the most flood-prone areas. Both of these areas had been reported as being flooded by Sembrong River's water in the year 2007. Flooded areas are close to the populated areas; therefore flood problems will cause a lot of troubles and losses to the public. Based on our observations, flood problem that occurred at the area of study is due to the condition of Sembrong River that is not properly maintained since the last realignment and river widening works in the year 1988 by DID BatuPahat. Flood problem must be fully resolved because it gives a lot of negative impacts to the public. Therefore, this kind of studies should be continued in the future, especially for areas that frequently experiencing flood problem. This study is paramount for providing useful information to the authorities, such as DID to plan a more systematic and efficient drainage system, so that flood problem can be resolved.With the development of flood map and hydrodynamic model of Sembrong River, it helps the authorities for future planning and the implementation of rescue task force to the local residents living in flood-prone areas.However, it is a difficult and complicated task to obtain the information needed to develop this model. Therefore, it is recommended that all flood information, data and developed models are compiled in a web-based system. This way, the information can be easily retrieved and disseminated by the public or the professionals.

3.0 ACKNOWLEDGEMENT

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