

## DEVELOPMENT OF A FLOOD EVACUATION DECISION SUPPORT SYSTEM FOR KUALA KRAI BASIN

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### ABSTRACT

Floods are the most severe natural disaster threat in Malaysia. More than 200,000 people were affected during the December 2014 – January 2015 flood crisis, in that event uncovering inadequacies in the existing flood management mechanisms such as ineffective warning systems, delayed evacuation response, lack of coordination and dissemination of information. Underlying factors being overreliance on the government's 'structural approach' and the bureaucratic characteristic of the response mechanisms have in turn led to a consequential fallout in the community's ability to respond to floods, particularly in the areas of readiness and relief. The objective of this study is to develop an integrated Decision Support System (DSS) for inundation risk evaluation and emergency management. The DSS is to optimise the process of flood response through resilience building among victims by bridging the information gap between them and the disaster managers. This study focuses on the 2014 flood crisis happened in Kuala Krai, Kelantan, and the flood analysis was undertaken with the aid of hydrologic and two-dimensional hydraulic modelling software to recreate the historical flood conditions. In developing the Flood Evacuation Decision Support System (FEDSS), a well-integrated system comprising the database management system, knowledge-based analytical system and a user interface are required to capitalise on the flood representation data extracted from flood modelling. The FEDSS developed in this study is capable of evaluating hazard conditions on the basis of real-time analysis. The FEDSS improves the existing decision-making process by providing a summary of critical flood information such as locations at risk, time-related information, suggestions of closest flood evacuation centre, mainly for public's usage. Other parties benefited from this initiative include emergency managers and the relevant authorities who are responsible to make decision calls that potentially save many lives and properties from harms. This paper aims at documenting the FEDSS development procedures, and the capabilities of the prototype are to be presented in the form of a series of demonstrations.

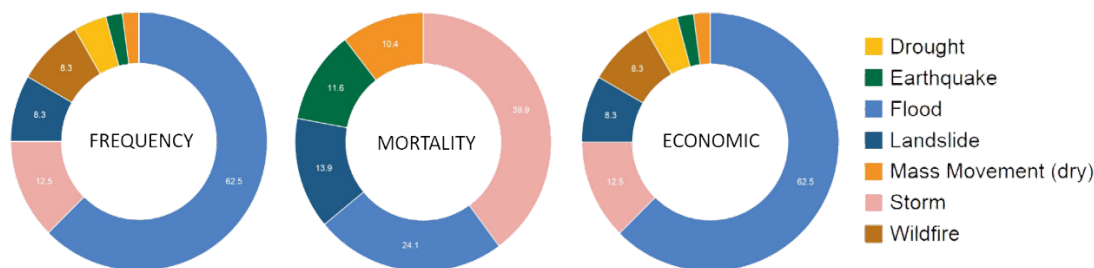
Keywords: Flood response, decision support system, flood evacuation, Kuala Krai, flood information

### 1. INTRODUCTION

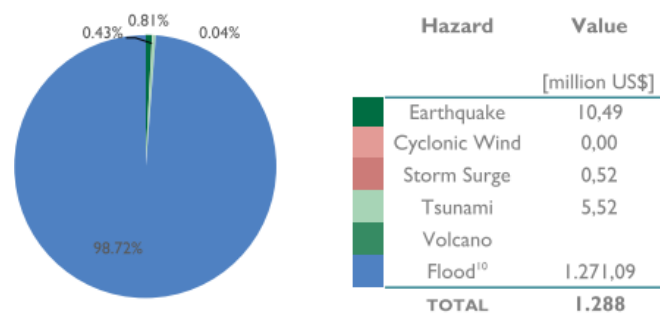
Floods are the most severe natural disaster threat in Malaysia. Figure 1 shows Malaysia's internationally reported losses from natural hazards in terms of frequency, mortality and economics, indicating the relative vulnerability of the country against floods (PreventionWeb, 2014). According to UNISDR (2015), Malaysia faces an Average Annual Loss (AAL) of USD1,271.09 million due to flood, which is significantly higher as compared to other disasters.

Figure 2 shows the AAL of different hazards to provide a visualisation of disaster risk ranking in Malaysia.

Figure 1: Malaysia's reported losses from disasters between 1990 – 2014 (PreventionWeb, 2014)



**Figure 2: Malaysia's AAL by hazard (UNISDR, 2015)**



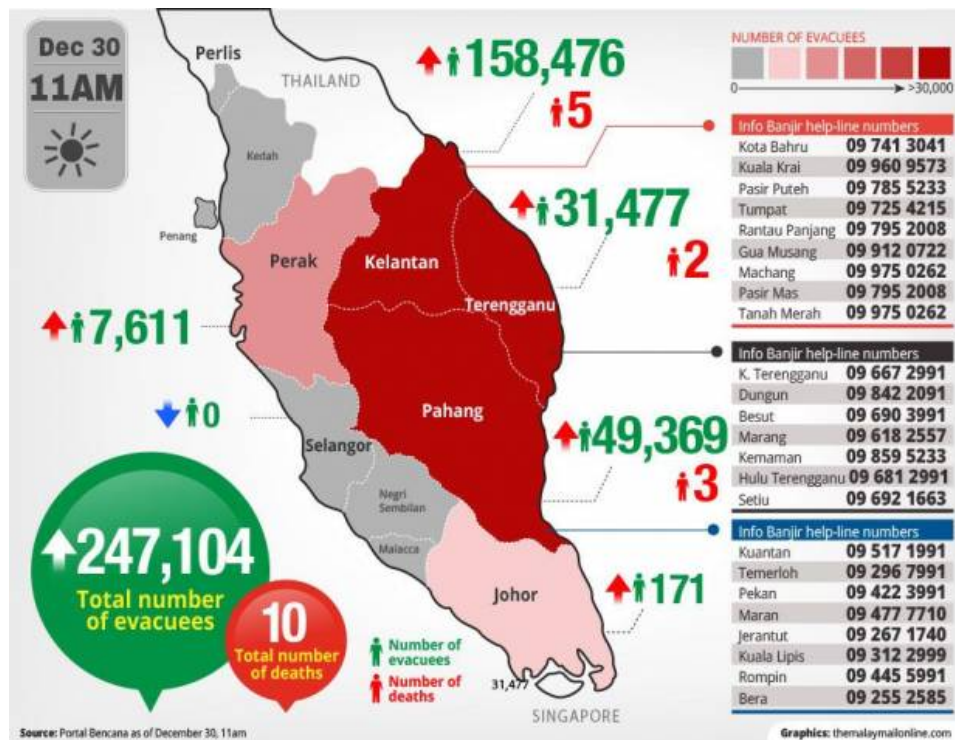
Because of the annual recurrence of the monsoon floods, flood mitigation and management efforts have been undertaken by various agencies to minimise damages caused by the devastating floods (Asian Disaster Reduction Center, 2005). More importantly though, is the fact that the flooding accounts for significant socio-economic impact, inflicting a heavy toll on both people (in terms of casualties and property damage) and the government (in terms of money spent on disaster management and rehabilitation) (Liu & Chan, 2003). Flood relief management have proven to be quite difficult to implement, in which if not implemented effectively will further implicate suffering for flood victims as the flood progresses.

Overall, traditional flood risk management in many countries including Malaysia has inclined towards a structural (hard) approach, which involves the construction of flood control structures. In recent years, however, the growing effects of climate change and rapid urbanisation has exposed the inadequacy of this approach, driving a paradigm shift for governments to take a more proactive, 'non-structural' (soft) approach for flood risk management (Levy, Gopalakrishnan, & Lin, 2005). According to Liu and Chan (2003), flood management in Malaysia has inadvertently leaned towards a structural approach, resulting in a false sense of security among people as well as an overreliance on the government. Furthermore, disaster management systems in place are generally bureaucratic, often responding to flood events with a 'reactive' approach.

Today, many developed nations, especially European countries, have already seen positive results from their strategy shift, revealing the significance of implementing soft flood management approaches such as upstream land management, floodplain mapping and proactive disaster planning. In the case of Malaysia, proactive disaster planning and management has now become the general interest of all stakeholders in light of the increasing population at risk to floods. Not only that, recent flood crisis have exposed controversies revolving around flood information (Palansamy, 2014), therefore raising concerns on the competency of existing flood management mechanism and readiness.

Following the Malaysia flood crisis in 2014, Centre for Public Policy Studies (2015) has highlighted several key weaknesses in the current mechanism, namely being ineffective warning systems, delayed evacuation response, lack of coordination and dissemination of information. This has exposed a consequential overlook in the community's ability to respond to floods, further emphasising the urgency to improve aspects in the areas of readiness and relief such as dissemination of information, emergency response and the process of evacuation in Malaysia. Figure 3 gives an overview of the affected areas and people in Peninsular Malaysia during the 2014 Malaysia floods. With more than 200,000 people involved, the flood response must be carried out effectively to minimise the number of casualties.

**Figure 3: Flood statistics in affected areas during the 2014 Malaysia floods (Malay Mail Online, 2014)**



Current technological advancement has granted the progressive growth in capabilities of today's flood DSSs, providing opportunities to improve decision-making processes for flood disaster management (Levy et al., 2005). Given that the main problem during flood events is the lack of coordination among authorities, disaster managers and victims, the development of an integrated DSS has been identified as a crucial non-structural measure in flood damage alleviation (Todini, 1999). Through the development of an integrated DSS, flood risk management in Malaysia could be enhanced by facilitating the process of decision-making during flood evacuations.

This study responds to the need of a more comprehensive approach towards flood management in Malaysia with the development of FEDSS aimed at resilience building among victims by bridging the information gap between them and the disaster managers. Having said that, the objective of this study is to develop a robust DSS for inundation risk evaluation and emergency management. Taking advantage of latest development in flood modelling techniques and advanced computer platforms, the FEDSS will inform the study with its following capabilities:

1. To provide the means of data mining and translation of raw technical data, as well as visualisation and display of results in a comprehensible manner;
2. To evaluate the hazard conditions on the basis of real-time analysis;
3. To compute and provide meaningful information such as locations at risk, closest flood evacuation centre and time-related information.

The discussion of this paper begins with the approach used in developing the FEDSS, which includes a description of the case study, the FEDSS structure and its development methodology. Next, the FEDSS development procedures and the capabilities of the prototype are presented in the form of a series of charts and demonstrations. At the end of this paper, the conclusion of the study and acknowledgements are given.

## 2. METHODOLOGY

This section outlines the research approach used in developing the FEDSS by informing the case study description, the overall workflow of the FEDSS and the development procedures.

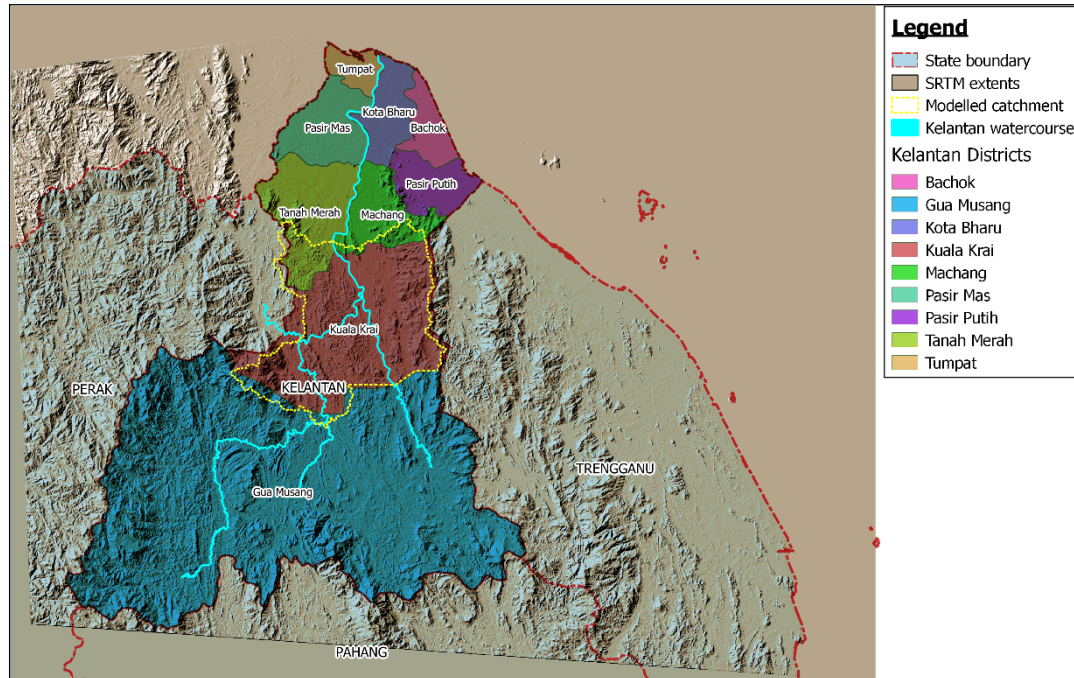
### CASE STUDY DESCRIPTION

Due of its geographical location, the Peninsular Malaysia experiences convectional rain storms from the monsoon seasons, which cause most of the extensive floods in the country. Approaching the end of the year, the northeast monsoons bring in severe rainfall coupled with the seasonal flooding, especially in the eastern states (D/iyaa, Gasim, Toriman, & Abdullahi, 2014). During the December 2014 – January 2015 flood crisis, the National Security Council of Malaysia confirmed that the state of Kelantan in the north east of Malaysia has the worst flooding in history, generating much concern and interest from all stakeholders (Azlee, 2015).

Therefore, the happening of the Malaysia flood crisis in 2014 – 2015 is adopted as a case study to acquire data and knowledge of the flood conditions for developing the FEDSS. The geographical scope is focused on a specific part of Kelantan, namely the district of Kuala Krai due to the wide availability of information in the area. It was also one of the few areas in Malaysia that was most badly hit by the 2014 floods.

Figure 4 shows the geographical extent of the case study area in the state of Kelantan.

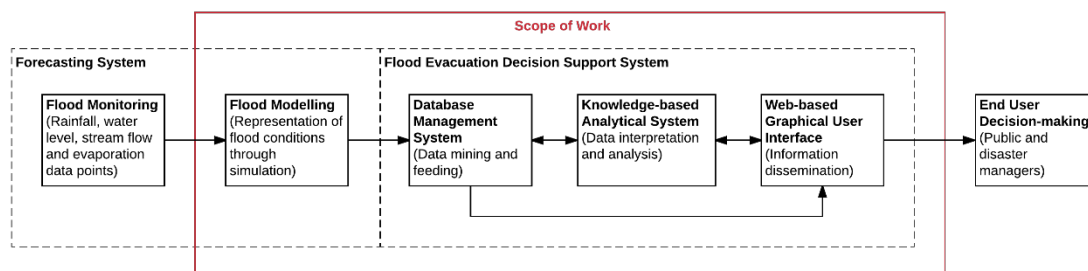
**Figure 4: Geographical extent of the case study area**



## STRUCTURE AND DEVELOPMENT OF THE FEDSS

The developed structure of the FEDSS is a simplified adaptation from the structure provided by Todini (1999). The FEDSS is essentially a computer-based integrated tool comprising of three separate modules: database management system, analytical system and user interface. Figure 5 presents the overall workflow of the FEDSS in a schematic diagram to illustrate the interaction between the internal components and external constituents. This study focuses on the development of the prototype, which capitalises on the flood representation data from real-time flood-forecasting systems (usually maintained by public agencies) to help users make informed and immediate decisions.

**Figure 5: Schematic structure of FEDSS**

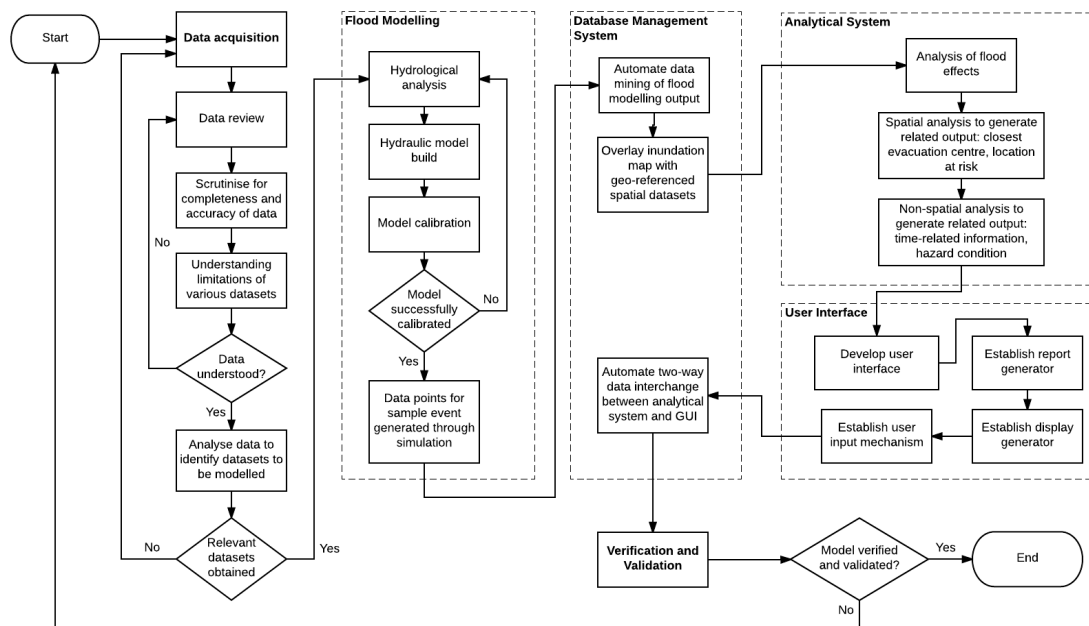


When fully-developed, all components of the FEDSS will form a well-integrated system. From beginning, the FEDSS links up with real-time flood-forecasting systems through data treatment procedures; to end, there is an easy-to-use interface which provides visualisations to users. As a result, the FEDSS facilitates the decision-making process by supplying data displays and analytical results in an organised manner to summarise critical flood information.

Figure 6 provides an overview of the research methodology in the form of a flowchart, which shows the step-by-step procedures in the development of the FEDSS.



Figure 6: Flowchart of research methodology



The sequential processes are closely-associated with each other, while individually comprising of its own objectives and requirements, which are described as such:

- *Data acquisition* from relevant authorities to obtain datasets required for building the FEDSS, such as historical monitoring gauge data and Digital Elevation Model (DEM);
- *Flood modelling of sample event* for the purpose of pilot testing and application, where the results of the simulation act as incoming data feed from real-time flood-forecasting systems. Hydrological analysis is carried out using the US SCS unit hydrograph method with Flood Modeller Pro (CH2M Hill, 2016); while 2D hydraulic modelling of surface runoff is carried out using TUFLOW (BMT Group Ltd., 2016);
- *Development of the FEDSS* which is made up of three parts, all of which are built using Microsoft Excel with Visual Basic for Applications. They are:
  - *Database management system* which has the functions of automated data mining, data treatment and data feeding to facilitate data transfer between components;
  - *Knowledge-based analytical system* which analyses raw datasets and translates them into meaningful information. Incoming data are fed through computational models comprising of mathematical procedures and multi-criterion analyses to provide the desired outputs;
  - *User interface* which provides visualisation of meaningful information to end users.

### 3. RESULTS AND DISCUSSION

This section highlights the procedures in the FEDSS development and the capacity of the prototype to integrate the flood hazard assessment and the user interface. The findings are presented in the form of a series of charts and demonstrations.

#### FLOOD MODELLING

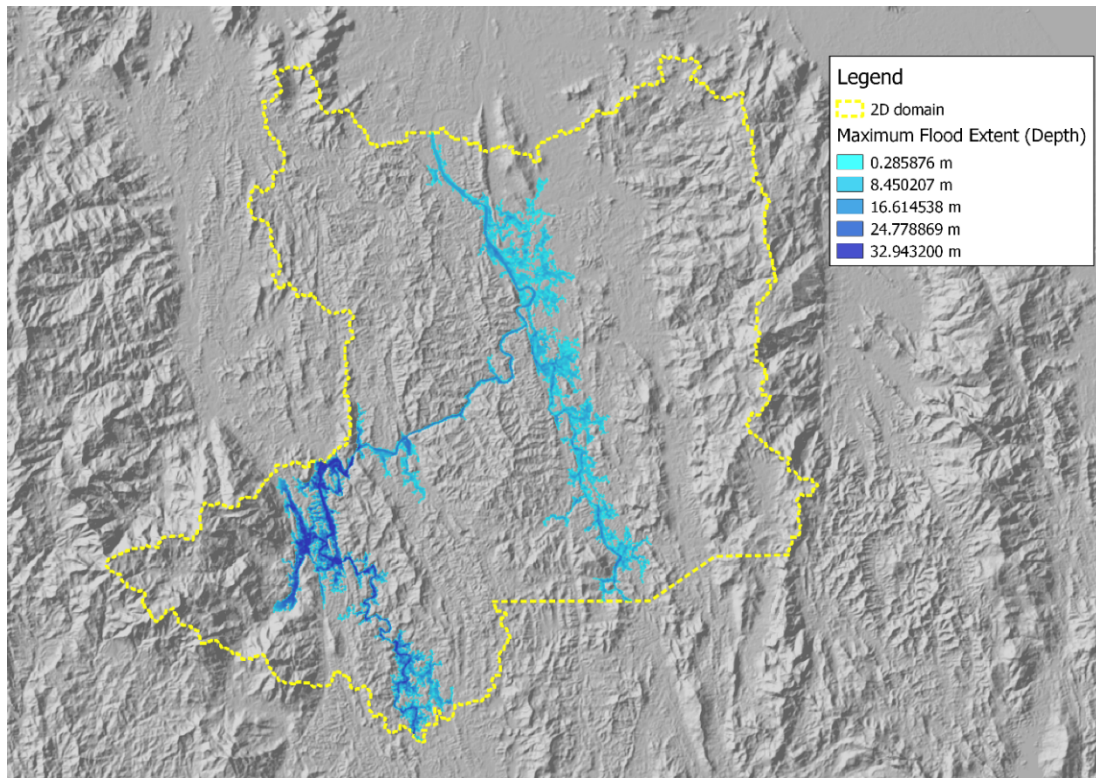
This sub-section presents the flood modelling approach and results obtained in this study. Upon obtaining an estimation of the precipitation intensity, a cascade of flood modelling activities has to be carried out to acquire a representation of the estimated flood conditions. The flood modelling of the sample event is based on two elements:

1. Hydrological model which evaluates the geo-morphological features and land-use of the upstream basin to estimate a peak flow and hydrograph shape at each sub-basin outlet using a rainfall-runoff model;
2. Two-dimensional hydraulic model simulation to identify the three parameters required to evaluate potential hazards, namely the maximum water level, the velocity of water, and the amount of time it remains in a given area (Todini, 1999).

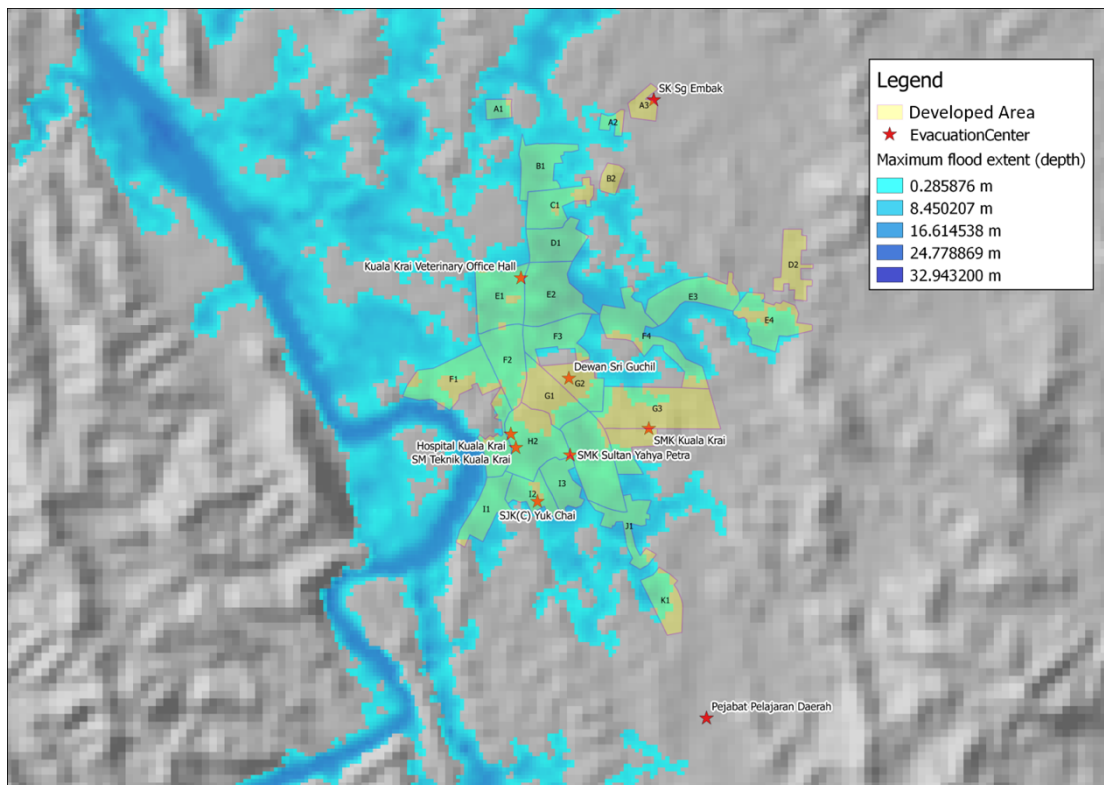
After simulation, the results can be displayed in a two-dimensional manner. The maximum flood extent obtained, in terms of water level, is illustrated in Figure 7. The flood pattern at the Kuala Krai township was investigated and deemed to be sufficiently representative in simulating the actual flood situation. With the production of the inundation map, it could then be intersected with the elements of concern such as vulnerable areas and evacuation centres.

Figure 8 illustrates the flood inundation map overlaying the delineated evacuation centres and developed areas in Kuala Krai.

**Figure 7: Maximum flood extent within modelled catchment**



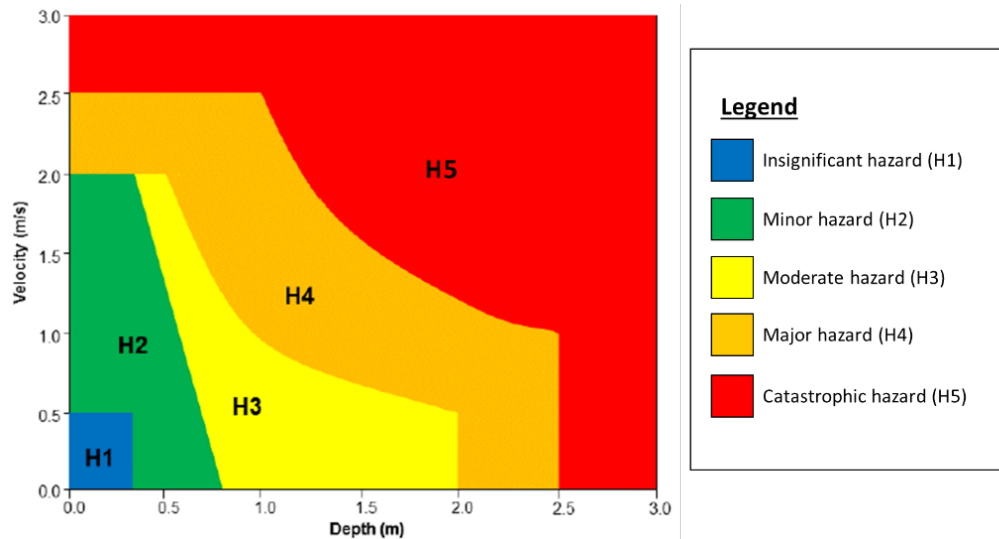
**Figure 8: Kuala Krai flood inundation map**



## FLOOD HAZARD ASSESSMENT

This section summarises the approach and assumptions used in the assessment of the flood hazard. The process of hazard definition is important to translate raw technical data into meaningful information for the end users. Flood modelling allows the severity of the predicted hazard to be visualised with the adoption of existing guidelines. In this study, the flood hydraulic hazard categorisation proposed by the Moreton Bay Regional Council (2016) has been used to facilitate this process. Figure 9 demonstrate the derivation of flood hazard categories, which depends on the depth and velocity of flood waters, while Table 1 describes the behaviour of the categories used.

**Figure 9: Flood hazard categories (Moreton Bay Regional Council, 2016)**



**Table 1: Flood hazard categories and their respective hydraulic behaviours (Moreton Bay Regional Council, 2016)**

<i>Low Risk to life and property</i>		<i>High Risk to life and property</i>		
<i>H1</i>	<i>H2</i>	<i>H3</i>	<i>H4</i>	<i>H5</i>
<i>Insignificant<sup>1</sup></i>	<i>Minor<sup>1</sup></i>	<i>Moderate<sup>1</sup></i>	<i>Major<sup>1</sup></i>	<i>Catastrophic<sup>1</sup></i>
No significant life risk Property risk only to items which come in direct contact with floodwaters such as building contents	Low life risk. Able bodied adults can walk safely. Cars can float and precautions must be followed to keep them out of floodwaters	Moderate life risk. Able bodied adults cannot safely walk Only large vehicles (trucks) can safely travel.	Major life risk Light frame buildings (e.g. houses) can fail structurally	Extreme life risk Majority of buildings could fail

Based on the product of flood depth and flood velocity, each grid cells consists of a score corresponding to the flood hazard category as shown in Figure 9. Hazard rating values on the grid cells are obtained within the delineated areas. A mean value is obtained for each development area by averaging all hazard rating values of the grid cells covered by these area blocks. Based on these fundamental principles in categorising flood hazards, a customised flood hazard assessment technique could be developed to suit the local requirements of the area.

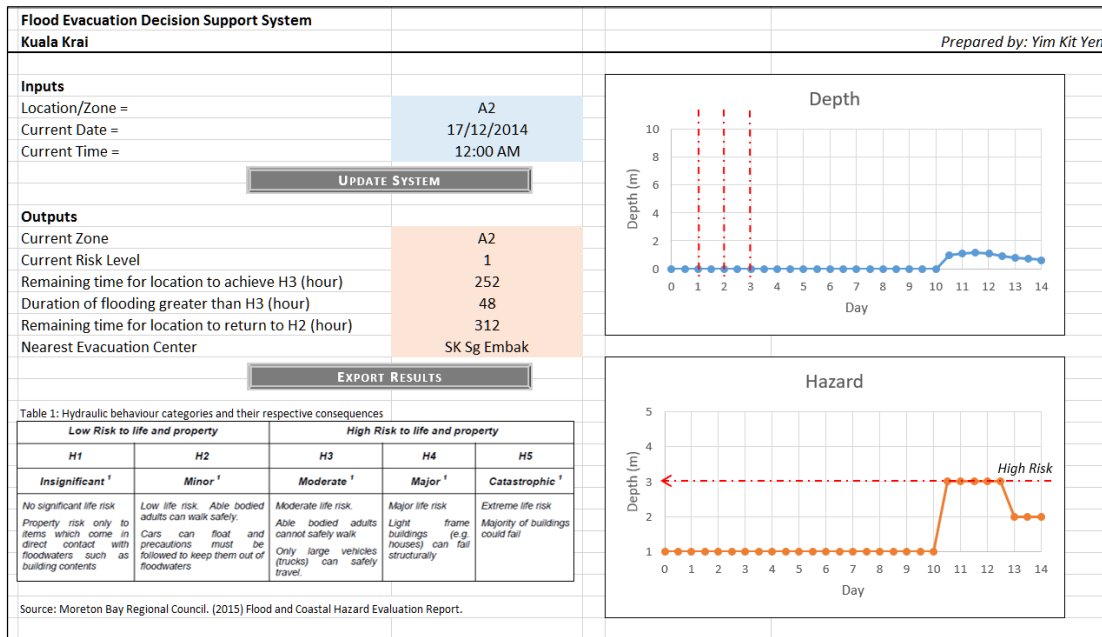
## USER INTERFACE

The FEDSS improves the existing decision-making process by providing a summary of critical flood information such as locations at risk, time-related information, suggestions of closest flood evacuation centre. loped user interfaces of FEDSS.

**Figure 10** and

**Figure 11** demonstrate the developed user interfaces of FEDSS.

**Figure 10: Screenshot of the developed FEDSS**



In contrast to the web-based support system developed by Katuk, Ku-Mahamud, Deris and Deris which supports flood response operation among disaster managers (2007), the FEDSS is developed mainly for public's usage. The FEDSS directly responds to the needs of public users during the process of evacuation with the capability of answering questions such as:

- Which areas should be avoided due to flooding?
- Which areas are tolerably safe to use during the process of evacuation?
- Where are the closest evacuation centres?
- What is the estimated time remaining before these areas are unsafe/inaccessible due to flooding?
- How long is the duration of the flood?

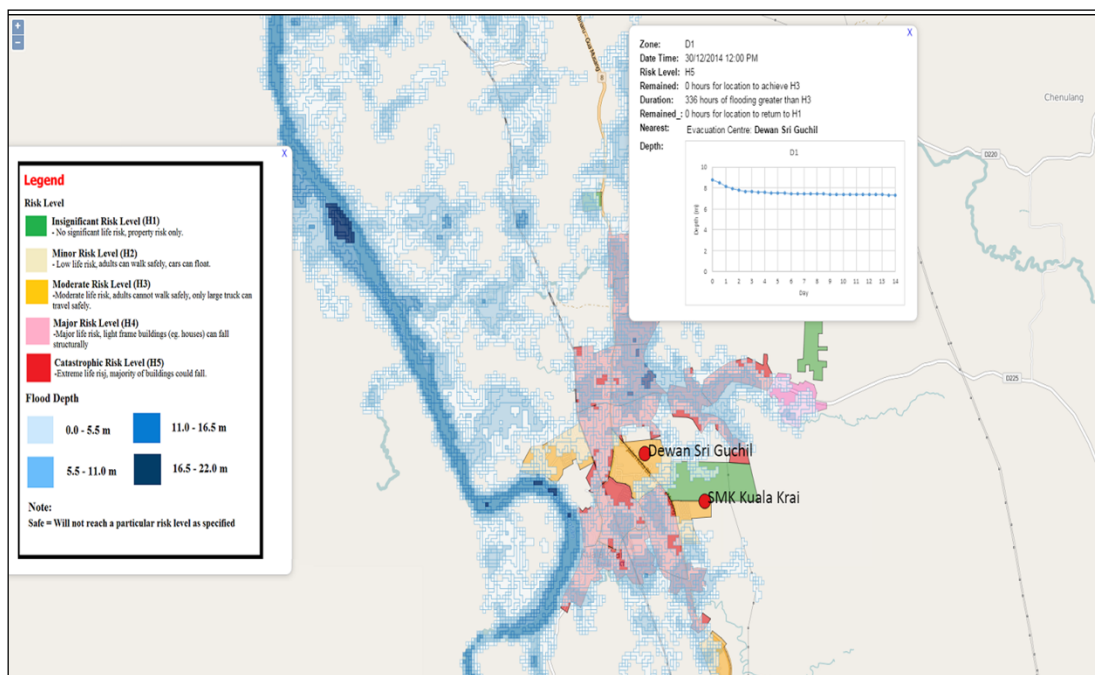
On the basis of the above-mentioned questions, the outputs generated are estimated water depth and hazard rating at the specified location, as well as time-related information. The inputs required by the user is straightforward, which are the current location and timestamp of the user.

The user interface must be tailored to the public audience. Hence, the user interface has to be easy to use, catering for the usage of a lay person. At the same time, the interface should pass on the processed information from the analytical system to end users in a clear and concise manner to effectively support interpretation of results. Although the FEDSS does not provide exact courses of action, it should provide a clear presentation of unambiguous predictions accompanied with the associated warnings, as suggested by Todini (1999).

**Figure 11** shows the graphical user interface which presents flood information in the form of an interactive map to help users better understand the flood situation during the flood.

**Figure 11: Screenshot of the graphical user interface**





Other parties benefited from this initiative include emergency managers and the relevant authorities who are responsible to make decision calls that potentially save many lives and properties from harms. Current flood hazard information within the whole township could be summarised into exportable reports with just a click of a button on the user interface.

#### 4. CONCLUSION

The development of FEDSS is essential to optimise real-time flood information delivery between flood forecasting systems and the end users. The development procedures presented in this paper could be utilised to provide automated flood information delivery in flood-prone areas. With the availability of the system, community's ability to respond to floods is improved by being able to make better informed decisions in times of need. This is achieved by an automated mechanism that reports the up-to-date information of the flood hazard. By translating raw technical data from flood forecasting systems to meaningful and organised information, public acceptance is improved, optimising up the process of evacuation.

As a final remark, it is the belief of the author that the availability of the system could improve flood hazard management policy making and processes. The systematic process in decision-making and transparency of information during crises could provide a deeper understanding of the issues at stake, potentially reducing the politicisation of relief efforts. This study also serves as a good base for other implementations and research in the areas related to flooding. Potential expansion of the study includes resource mobilisation, evacuation and rescue routing. Future development efforts could also be made towards public participation and emergency managers' input, such as implemented in the Philippines flood information portal where social media feeds are processed into their system.

The increase in potential damage of flooding over the years might be inevitable due to changing climatic patterns and rapid civil development. Therefore, the findings of this study will benefit the society by helping communities navigate resiliency challenges.

#### ACKNOWLEDGEMENT

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