Validating flood inundation map for hydrodynamic modelling of an ungauged catchment

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ABSTRACT
Flood mapping for an ungauged catchment is an extremely difficult task due to the lack of information and hydrological data of which the map can be produced from. More often than not, many flood-prone urban catchments in Malaysia still remained ungauged. Advances in digital photography in recent years have enabled photographs to be used for capturing important information of flood. These photographs can be used to establish information that describes the variation of flood through time and space. This study will attempt to produce reliable flood inundation map for the town of Tanah Merah, Kelantan, which is affected by tropical monsoon flood. A small ungauged catchment, i.e. Sungai Maka was used as the subject of study. 1D hydrodynamic model (InfoWorks) coupled with high resolution Digital Elevation Model (DEM) from Light Detection and Ranging (LiDAR) was used. First, a simple calibration was carried out by adjusting modelling parameters to suit estimated flood depth at various points along the river from flood photographs. The flood extent will then be verified by comparing against satellite image. At the same time, flood records would be retrieved and used as the final verification of the model's accuracy. Preliminary calibration showed that the method used could accurately represent the fluctuation of flood level to an accurate of R2 = 0.98. It is hoped that further results from the study could successfully demonstrate that flood photographs, records and satellite images are highly informative and valuable tools for calibrate and validate flood inundation maps for the many ungauged catchment in Malaysia.

Keywords: Ungauged catchment; flood inundation map; hydrodynamic model; calibration; InfoWorks CS.

1 Introduction

Generally, Malaysia experiences floods frequently due to our tropical monsoon climate. 9% of the total country land areas are flood prone and 75% of Malaysia population inhabits these areas. Floods not only inflict damage to properties and lives, this natural phenomenon also halts and interrupts economic and physical development of the country. Flooding becomes an ever present issue in Malaysia that in the Ninth Malaysian Plan (2005-2010) alone, over 70% of the RM5.3 billion budget granted for Department of Irrigation and Drainage (DID) was allocated exclusively for flood mitigation works (DID, 2009a). Therefore, managing floods is one of the key factors for driving the nation forward towards Vision 2020.

Ungauged catchments refer to catchments which are not monitored in terms of hydrological processes such as stream flow or water level. In Malaysia, only major rivers (and some critical smaller ones in ultra urban areas) are gauged by the authorities. Gauged catchment provides historical flow or water level data which is very critical in calibrating and verifying hydrodynamic models. Urbonas (2007) stated that uncalibrated and blind use of 'default' engineering parameters in hydrodynamic models can result in 250% difference in the results, thus affecting engineering judgment to be taken afterwards.

Due to the lack of observed data or historical records, it is hard to verify if a computer model (using the estimated modelling parameters) is sufficiently accurate to describe the hydrologic and hydraulic behaviours of the catchment (Jones and Kay, 2007). In large scale modelling, regionalisation can often provide good flood estimation (Merz and Bloschl, 2004; Parajka et al., 2005; Gotzinger and Bardossy, 2006; Bardossy, 2007; and Kay et al, 2007). Unfortunately, regionalisation requires pooling from at least several gauged catchments, which would seem impractical or not feasible under typical flood mitigation consultancy or design works. It is therefore not uncommon to find uncalibrated models being used for simulating ungauged catchment. While DID (2009b) acknowledged that ungauged catchment can be common and difficult to model, the use of uncalibrated models can only be used for relative comparisons (assessing impact of land use change or climate change), but not for design purposes, which will require definitive values for hydrological and hydraulic properties.

In response to data scarcity, modellers have adapted to data scarce condition by utilising all available information to produce more reliable hydrodynamic models. The advances of electronic gadgets in recent years have seen the development of digital photography into a reliable recording media of time, scene, and location. Average photographs, taken from decent digital cameras or mobile phones promptly record the exact time the photos were taken. In more advanced gadgets, photos can be directly geo-referenced too. A series of flood photographs taken at different locations and time could therefore be used to establish the propagation of flood through time and space. Fixed structure such as signboards and houses could act as 'stead gauge' whereby flood level can be estimated before or after flood events. DID (2010) validated their hydrodynamic model by comparing flood depths predicted by the model to that indicated by photograph records in selected areas for two flood events. The use of photograph records (provided by flood victims or local authorities) proved to be a great source of flood information when no official flood records were available. Leow et al (2009) also applied flood photographs to validate their model for Sungai Berop in Perak.

Recent development in remote sensing industry has seen the rise of another interesting approach to calibrate or validate hydrodynamic models of ungauged catchment. Modellers have generally shifted attention to indirect source of flood information, i.e. the utilisation of satellite image or remote sensing technology, as proposed by Horritt (2006). The approach was successfully applied by Di Baldassarre et al (2009) in the UK. This study will expand the scope of research by DID (2010) and will utilise a hybrid calibration technique of utilising flood photographs and satellite images to produce flood inundation map for an ungauged catchment. It is hoped that the study could successfully demonstrate the use of remotely sensed data and secondary flood information (flood photographs) in improving the accuracy and reliability of flood prediction in ungauged catchment.

2 Study area

The study area, Sungai Maka (Figure 1), which is situated in Tanah Merah, Kelantan, on the east coast of Peninsular Malaysia, suffers from flood almost every year. The area experiences heavy monsoon rainfall during the southwest monsoon from October to January each year. Flooding in Sungai Maka (which covers almost 70% of Tanah Merah Town) is serious as the damages are of substantial sum and even worse, it is reoccurring annually, prohibiting economic growth and physical development. Flood water can rise above 2m in some parts of the town, submerging residential houses and cut off access roads.

Figure 1 Location map for the study area

3 Data collection

Data for Hydrodynamic Modelling and Flood Mapping
Terrain information obtained from LiDAR and ground river survey was used to built a hydrodynamic model for Sungai Maka. The alignment and cross section details of the river and incoming urban drains were obtained from engineering survey. Catchment delineation was based on terrain information obtained from LiDAR. 10m-resolution LiDAR DEM was used to generate flood level and extent in the integrated InfoWorks CS environment.

A rainfall station situated nearby to the study area was used as the primary stormwater input in this study. Records of the flooding period in 2007 (1st to 31st December 2007) were retrieved and used in the calibration process. Further records of flooding period in 2009 and 2011 will be used in the validation simulations. Downstream boundary conditions of the study area, i.e. Sungai Kelantan were generated based on linear interpolation between Guillemard Bridge and Tambatan Diraja hydrological stations.

3.1 Data for Calibration and Validation

For the calibration process, flood photographs of the 2007 monsoon flood within Sungai Maka were being gathered from various sources including the Department of Irrigation and Drainage, and flood victims. These photos are screened to ensure floods are captured together with a fix structure (of which flood level can be estimated from). Exact locations of the photos were identified through Assisted Global Positioning System (A-GPS) with an accuracy of 5m. Elevations were then traced from engineering survey or LiDAR DEM, while flood depths were estimated visually based on the photographs. Finally photos are grouped according to locations, where 4 locations were established for this catchment. 9 photos at various times were used as the calibration information. Examples of these photos used to establish the chronology of flood at Point 2 is given in Figure 2 below.

Figure 2 Establishing Flood Chronology using Photographs

For validation of the calibrated model, satellite image during flooding period will be acquired. Presently, satellite image (SPOT-4 multispectral 2.5m resolution) for flood in January 2009 was found fit to be used in this validation exercise due to low cloud covers (< 50%). This data will be used to validate the flood extent mapped by the model as compared to the flood extent in the satellite image. In order to further confirm the credibility of the model, a water level gauged will be installed in Point 2 for continuous monitoring of water level during the 2011 monsoon period.

4 Methodology

4.1 Model Setup

The study started off with hydrodynamic model building. InfoWorks Collection System (CS) model by MWH Soft Ltd was used in this study. Figure 3 shows the model with LiDAR DEM in InfoWorks CS environment. The LiDAR DEM was used to calculate hydrologic parameters required by the InfoWorks CS model including subcatchment slope and length in GIS environment. These physical properties are assumed valid and fixed throughout the calibration and validation processes. Existing land use was manually digitized from a SPOT 5 satellite image. Proper Curve Numbers were assigned to each land use type. The InfoWorks treats each subcatchment as the basic hydrological unit and hence weighted CN was used in runoff volume computation.

Overland Kinematic Wave routing was selected to route runoff to catchment outlet, i.e. into hydraulic engine. Subsequently, the model will mathematically solve the St Vennant's Equation to compute hydraulic properties for each node and link in the model. Flood in a 1D model used in this study is represented by flood cones or imaginary storage zone. Excess runoff volumes are converted into water levels before the water levels are mapped on the provided DEM.

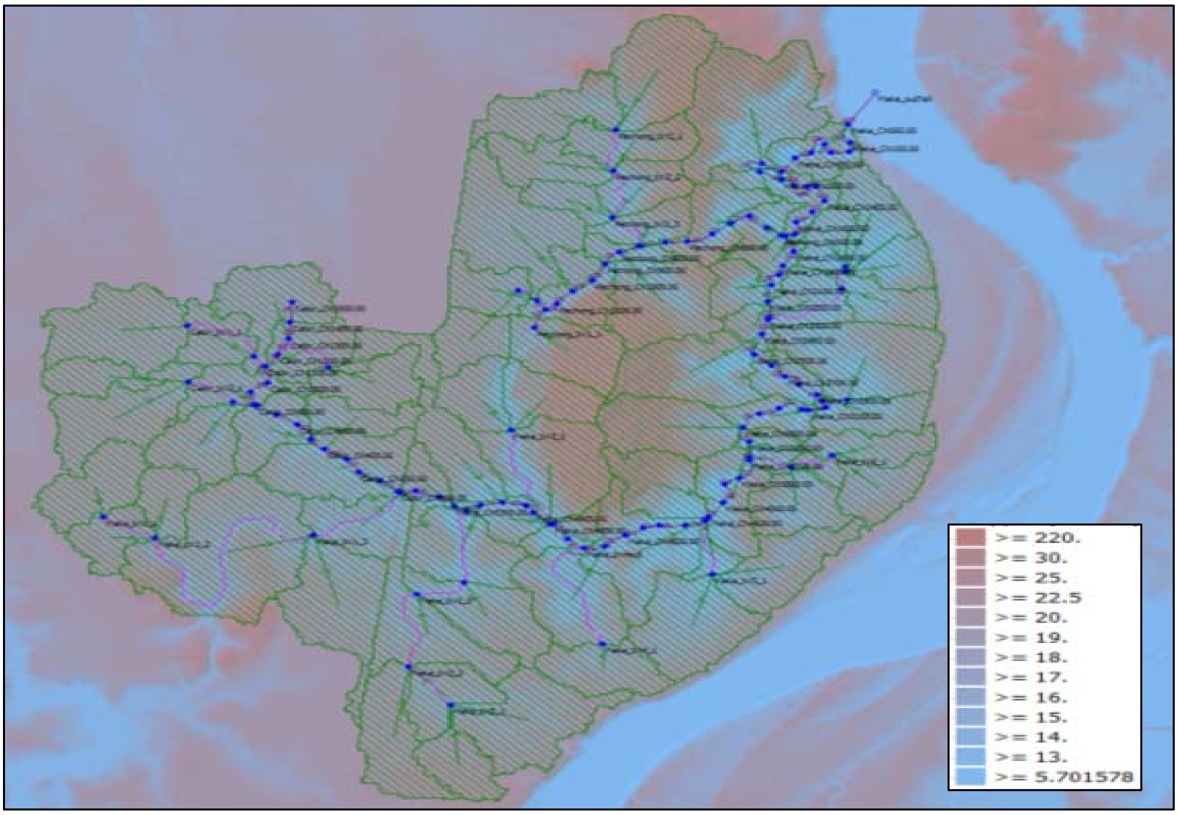

Figure 3 Sungai Maka Hydrodynamic Model in InfoWorks CS Environment

4.2 Hydrodynamic model calibration

A spatially homogenous rainfall record of 1st to 31st December 2007 was used for the calibration process. Simulated water levels were compared against records derived from flood photo. Manual calibration was carried out in systematically on hydrologic (CN Number) and hydraulic (manning's n) parameters. Water levels derived from the photos were used as calibration points where the modelling parameters were adjusted so that the simulation results resemble the observed as close as possible.

4.3 Flood Extent Validation:

In an exercise to determine if the calibrated model is able to sufficiently produce flood inundation map that portray the exact flooding conditions; the modelled flood map was compared to the flood extent from a satellite image. In this case, the satellite image for January 2009 flood from the SPOT-4 satellite will be used. A method of flood extent validation proposed by Horritt (2006) (shown in Equation 1) would be used in this study.

$$F = \frac{A-B}{A+B+C} \quad (1)$$

where F is the goodness-of-fit, A is the wet area correctly predicted by simulation, B is the wet area wrongly predicted as dry by simulation (over prediction), C is the dry area wrongly predicted as wet by simulation (under-prediction). An F value of near to 1 indicates model flood extent prediction is close to the observed. Should the comparison show great difference in both flood extent, the hydrodynamic model would have to be recalibrated using a different values of modelling parameters.

4.4 Flood Depth Validation:

As a further confirmation, a water level records from the monsoon period of 2011 would be used to validate the efficacy of the model. The water levels throughout the simulated period will be compared to the observed water levels at point 2. Goodness-of-fit indicators, i.e. coefficient of determination (R2) and root mean square area (RSME) would be used to gauge the performance of the model.

4.5 Flood Inundation Maps

After a succession of validations to prove the reliability of the model, it can then be used to generate flood inundation maps for the study area. Probabilistic flood maps would be generated from simulations using 10-, 50-, and 100-year Average Recurrence Intervals (ARI) design rainfall. These maps can be used for flood management and urban development planning purposes.

5 Expected results

At the time of writing, the model set up and calibration of the model had already been completed. Calibration was carried out using sets of flood photos. Validation using satellite image is currently underway while a water level gauge is currently being installed at point 2 to monitor the upcoming monsoon in 2011. Table 1 shows the comparison of water levels during the 2007 flood. After calibration, the flood trend was found to be sufficiently in agreement with the observed flood levels derived from flood photographs, as given in the time series plot of Figure 4. The best fit from 9 observed-simulated pairs of water level generated an R2 of 0.98 (Figure 5), indicating good agreement between both. of Subsequently, the 2007 flood was successfully mapped, as presented in Figure 6.

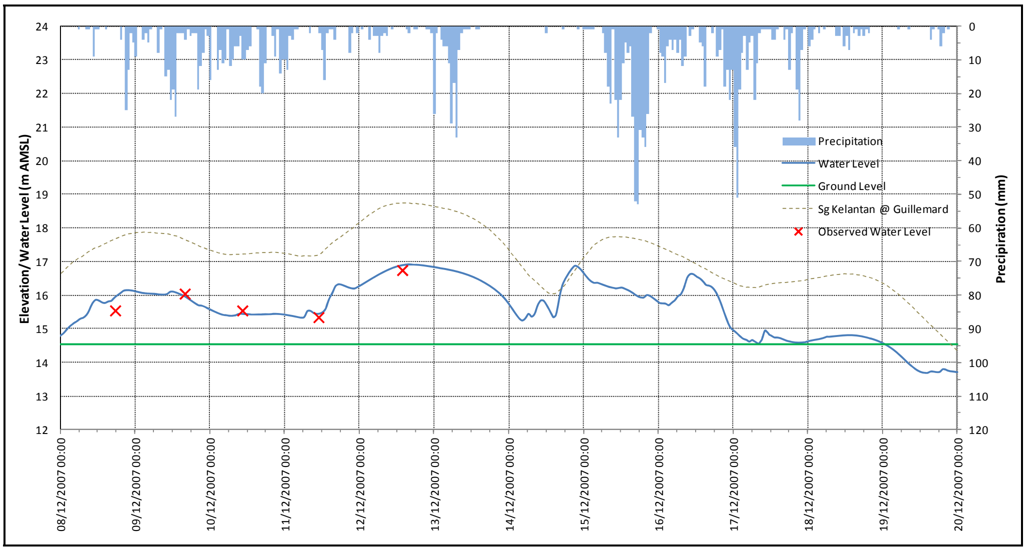

Figure 4 Time Series Plot of Simulated and Observed Flood Level

Table 1 Comparison of Observed and Simulated Flood Level at 4 Calibration Points

Location	Elevation (m AMSL)	Time & Date of Photograph	Water Depth from Photograph (m)	Simulated Water Level (Water Depth) (m)	Percentage of Difference (%)
Point 1	17.136	10-Dec 12.09PM	-1.5	15.428 (-1.71)	13.9
		12-Dec 02.02PM	-0.3	16.881 (-0.26)	-15.0
Point 2	14.532	08-Dec 05.49PM	0.9	15.498 (0.97)	-3.0
		09-Dec 04.10PM	1.5	15.934 (1.40)	-6.7
		10-Dec 10.36AM	1.0	15.433 (0.90)	-10.0
		11-Dec 11.06AM	0.8	15.437 (0.91)	13.8
		12-Dec 01.58PM	2.2	16.881 (2.35)	6.8
Point 3	14.268	10-Dec 10.49AM	1.5	15.431 (1.16)	-22.7
Point 4	15.732	11-Dec 11.55AM	1.0	16.907 (1.18)	18.0

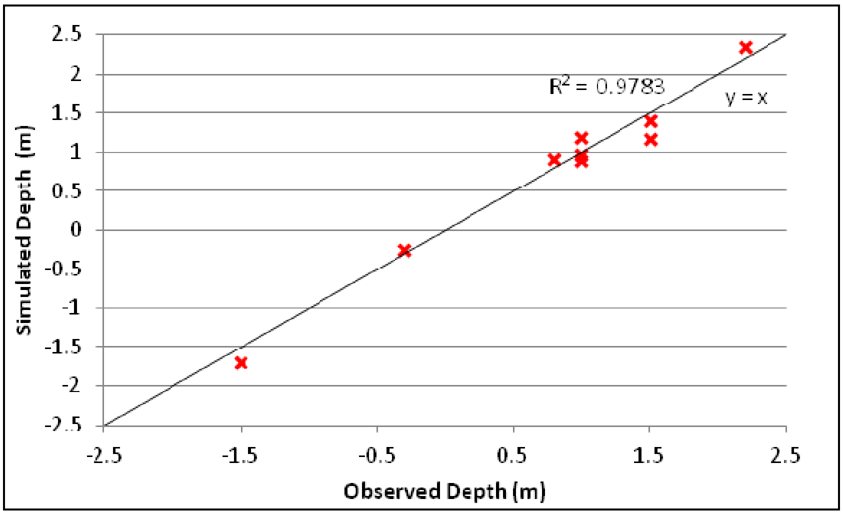

Figure 5 Simulated versus Observed Flood Level Plot.

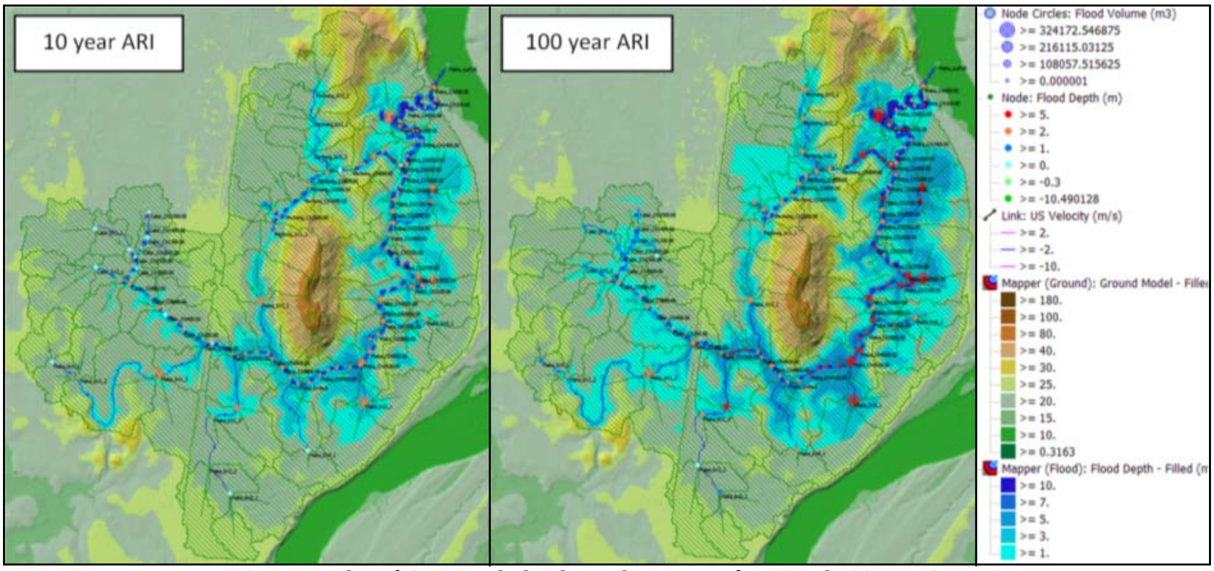

Figure 6 Examples of Generated Flood Inundation Map for 10 and 100 year ARI events.

6 Discussion

The proposed calibration technique by utilising flood photographs has been successfully tested at the study area to 'reproduce' the chronology of December 2007 monsoon flood. A final verdict to confirm the applicability of this technique is currently being carried out. Nevertheless, the derivation of important flood temporal and spatial information from flood photos proved to be a reasonable and practical alternative, especially for ungauged catchment where there is little or no hydrological data to rely on. This method could potentially improve reliability of flood modelling in ungauged catchment, which in turn could affect decision making and planning for flood management and mitigation works.

However, the technique is not without uncertainties or limitations. First of all, the mechanism to translate captured flood photo into flood depth requires improvement. Presently, the elevation of the selected calibration points are being extracted from DEM, which might not be the actual elevation, considering the resolution of the DEM as well as error in the A-GPS used for location identification. Secondly, the estimation method of flood depth from flood photo also requires refinement. The current 'visual' estimation would probably provide good and fast estimation but will induce additional uncertainties into the model.

Having said that, almost all hydrodynamic models contain certain amount of uncertainties. This is due to simplification of the natural environment and behaviour as a consequence of technological or computational limitation in hydrodynamic models. It is however the task and responsibility of the modeller to minimise and manage these uncertainties to enable the correct interpretation of the simulated results. Some improvements over the proposed method of calibration would include:

Predetermine the observation points - Elevation and location of the fixed structures shall be predetermined. This would avoid the need to manually estimate this information during the derivation of flood levels from photographs.

More frequent photo capturing - During a flood event, more photos of the same observation points should be taken. This would help to capture the fluctuation of flood levels as well as establishing the temporal trends of flood propagation.

Markings on observation points - Ideally, the use of stick gauge is preferable, but most cases it is sufficient to use other pole structure such as traffic signage, lamp posts, and bridge piers as observation points. Depth markings can be put on these structures to facilitate flood level estimation.

Trained Photographer - While recording floods is a routine task for most DID personnel, it requires the knowledge of right technique and composition to produce good flood photographs of which valuable information can be extracted. Trained personnel could vastly improve the flood recording mechanism.

8 Conclusion

This study explores an alternative calibration technique utilising flood temporal and spatial information extracted from flood photographs in ungauged catchment flood modelling. Under data scarce condition, flood mapping can be difficult task. Ironically, most urban catchments affected by floods are ungauged. Recent advances in electronic gadgets have propelled digital photography into an effective tool to capture the scene, time and location of flood. After proper sorting, flood photographs can roughly present the chronology and extent of flood event, a piece of very valuable information for an ungauged catchment. The study applied this calibration technique on a small urban ungauged catchment of Sungai Maka in Tanah Merah, Kelantan, which is affected by annual monsoon flood. Flood photographs were used to derive water levels at 4 locations within the catchment, with each location containing few records at different time. A 1D hydrodynamic model was built and calibrated using the flood level derived from the photographs for December 2007 monsoon flood. This study managed to calibrate the model to reproduce a flood map of the said flood event with good agreement of water levels at the observation points. In the next phase, the study will validate the performance of the model by comparing the calibrated model with satellite image of flood event and water level records from a gauging station. It is hoped that the validation could confirm the feasibility of this technique, which will significantly improve reliability of flood mapping in ungauged catchment.

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