HYDRO-METEOROLOGICAL FLOOD SIMULATION INTEGRATING RADAR RAINFALL WITH INFOWORKS RS™ AND GIS ANALYSIS

RESEARCH MANAGEMENT INSTITUTE (RMI)
UNIVERSITI TEKNOLOGI MARA
40450 SHAH ALAM, SELANGOR
MALAYSIA

BY :

ZAIZATUL ZAFFLINA MOHD ZAKI
ASSOC. PROF. DR WARDAH TAHIR
ZURAISAH DOLLAH

MAY 2011

HYDRO-METEOROLOGICAL FLOOD SIMULATION INTEGRATING RADAR RAINFALL WITH INFOWORKS RS™ AND GIS ANALYSIS

BY :

ZAIZATUL ZAFFLINA MOHD ZAKI
ASSOC. PROF. DR WARDAH TAHIR
ZURAISAH DOLLAH

MAY 2011

Contents

1. Letter of Report Submission

Tarikh : 3 Mei 2011

Prof. Dr. Abu Bakar Abdul Majeed
Penolong naib Canselor (Penyelidikan)
Institut Pengurusan Penyelidikan
Universiti Teknologi MARA
Shah Alam, Selangor

Prof.,

PER:LAPORAN AKHIR PENYELIDIKAN

Perkara di atas adalah dengan segala hormatnya dirujuk.

Saya Zaizatul Zafflina Binti Mohd Zaki (241827), ketua bagi projek yg bertajuk 'Hydro-Meteorological Flood Simulation Integrating Radar Rainfall with Infoworks™ RS and GIS Analysis' dengan rujukan 600-RMI/ST/DANA 5/3Dst (30/2009) ingin memaklumkan bahawa projek seperti yang tersebut telah selesai dengan jayanya.

Terima kasih kepada pihak Institut Pengurusan Penyelidikan diatas tajaan (dana kecemerlangan) yang diberikan untuk menyiapkan projek ini sehingga selesai. Semoga kerjasama yang baik ini dapat diteruskan untuk projek-projek lain pada masa akan datang.

Sekian terima kasih.

Yang benar,

ZAIZATUL ZAFFLINA BINTI MOHD ZAKI
(Ketua Projek)

PROF.MADYA DR WARDAH TAHIR

ZURAISAH DOLLAH
(Ahli Projek)

2. Letter of Offer (Research Grant)

Surat Kami : 600-RMI/ST/DANA 5/3/Dst (30/2009)
Tarikh : 13 Mac 2009

Zaizatul Zafflina binti Mohd Zaki
Ketua Projek
Fakulti Kejuruteraan Awam
40450 UiTM Shah Alam
SELANGOR

Prof Madya Dr Wardah Tahir
Ahli Projek
Fakulti Kejuruteraan Awam
40450 UiTM Shah Alam
SELANGOR

Zuraisah binti Dollah
Fakulti Kejuruteraan Awam
40450 UiTM Shah Alam
SELANGOR

Tuan/Puan,

TAJUK PROJEK PENYELIDIKAN DANA KECEMERLANGAN: DEVELOPMENT OF A-HYDRO-METEOROLOGICAL FLOOD MONITORING SYSTEM BY INTEGRATING WEATHER-RADAR BASED RAINFALL ESTIMATION WITH GIS-INFOWORKS

Dengan hormatnya perkara di atas adalah dirujuk.

Sukacita dimaklumkan Institut Pengurusan Penyelidikan (RMI) telah meluluskan cadangan penyelidikan yang telah dikemukakan oleh tuan/puan bertajuk di atas dengan syarat-syarat seperti berikut:

i. Tempoh projek penyelidikan ini ialah 1 tahun, iaitu bermula **15 Mac 2009** hingga **15 Mac 2010.**

ii. Tuan/Puan dinasihatkan untuk membuat pembetulan proposal penyelidikan seperti yang dicadangkan oleh panel penilai (sila lihat lampiran penilai yang disertakan*)*

iii. Kos yang diluluskan ialah sebanyak **RM4,600.00 sahaja dalam *(Kategori C).*** Tuan/Puan diminta mengemukakan proposal beserta bajet yang baru mengikut kos yang diluluskan sebelum tuan/puan memulakan projek penyelidikan tuan/puan.

iv. Pembelian peralatan komputer/printer/PDA/alat multimedia adalah tidak dibenarkan.

v. Semua pembelian bahan/peralatan adalah diminta agar tuan/puan mematuhi prosedur perbendaharaan di mana pembelian melebihi RM500.00 hendaklah mengemukakan sebutharga dan borang analisa harga.

vii Pihak tuan/puan dikehendaki mengemukakan laporan prestasi secara ringkas pada setiap enam (6) bulan sepanjang tempoh penyelidikan tuan/puan berjalan.

viii. Tuan/Puan perlu menandatangani Borang Perjanjian Penyelidikan dengan kadar segera kerana penggunaan geran hanya akan dibenarkan setelah perjanjian ditandatangani.

viiii. **LAPORAN AKHIR** perlu dihantar sebaik sahaja projek penyelidikan **TAMAT** dan format menulis laporan akhir boleh diperolehi di laman web RMI, UiTM Shah Alam. (http://www.rmi.uitm.edu.my)

Sekian, harap maklum. Terima kasih.

'SELAMAT MENJALANKAN PENYELIDIKAN'

Yang benar,

PROF. DR. AZNI ZAIN AHMED
Penolong Naib Canselor (Penyelidikan)

s.k. 1. Dekan
Fakulti Kejuruteraan Elektrik
40450 UiTM Shah Alam
SELANGOR

2. Prof. Madya Dr. Ismail Musirin
Timbalan Dekan (Penyelidikan & Jaringan Industri)
Fakulti Kejuruteraan Elektrik
40450 UiTM Shah Alam
SELANGOR

3. Prof Madya Dr Mohd Hanafiah Abidin
Ketua Penyelidikan (Sains & Teknologi)
Institut Pengurusan Penyelidikan (RMI)

4. Puan Rosnani Abdul Razak
Penolong Bendahari
Unit Kewangan Zon 17 (Penyelidikan)
(untuk makluman dan tindakan)

3. Acknowledgements

Alhamdulillah, all praises be to Allah the Almighty, the Merciful and Gracious, Lord of the Universe. Thank to Allah for giving us the spirits and strength to complete this research entitled HYDRO-METEOROLOGICAL FLOOD SIMULATION INTEGRATING RADAR RAINFALL WITH INFOWORKS RS™ AND GIS ANALYSIS

Special thanks to:

Research Management Institute UiTM (RMI)
Malaysian Meteorological Department (MMD)
Jabatan Ukur dan Pemetaan Malaysia (JUPEM)
Jabatan Pengairan dan Saliran Malaysia (JPS)
Faculty of Civil Engineering UiTM Shah Alam
Mr. Fadhil from WIRA KERJAYA SDN BHD

and

to those who contributes, give ideas and advices to complete this research.

4. Enhanced Research Title and Objectives

Original Title as Proposed:

Development of A-Hydro-Meteorological Flood Monitoring System by Integrating Weather Radar Based Rainfall Estimation with GIS-Infoworks

Improved/Enhanced Title:

Hydro-Meteorological Flood Simulation Integrating Radar Rainfall with Infoworks RS™ and GIS Analysis

Original Objectives as Proposed:

-To develop the model of case study river by using Infoworks River Simulation and GIS.
-To identify the flood prone area based on different water levels by performing flood simulation on the river model.
-To develop an integrated hydro-meteorological flood monitoring by coupling the model above with weather radar based rainfall estimates.

Improved/Enhanced Objectives:

-To model the river system by integrating with weather radar-based rainfall estimates.
-To perform a flood simulation of the river model using Infoworks RS.
-To identify the flood inundation areas by using GIS.

5. Report

5.1 Proposed Executive Summary

Thunderstorms and incessant monsoon rainfalls are the cause of many natural disasters including floods in Malaysia. The damages and losses due to floods are so immense that billions of ringgit has been spent for salvages and recoveries. Even though the government has provided various flood mitigation measures but flooding still occur frequently especially if the systems related are not designed properly. A non structural measure strategy is proposed to help to reduce these damages. Identification of flood prone areas would assist the relevant agencies in issuing a timely warning to victims in the affecting areas. In addition, for an integrated flood monitoring measure, the use of alternative rainfall measurement system such as weather radar is considered crucial to complement areas inaccessible to rain-gauges. In addition, by using develop model flood occurrence can be monitored more closely.

5.2 Enhanced Executive Summary

(Abstract of the research)

There are many types of natural hazard occuring in the world and one of it is flood. The main cause of flooding is heavy rainfall and the conditions worsened with the release of water from dam and the tidal effects. In October 2003, the rising of flood waters that had reached danger levels in several areas in Northern Peninsular Malaysia had caused the evacuation of about 17,000 people and was claimed to be the worst compared to the previous event. The focus of this study is to model and simulate the river system by integrating with radar rainfall estimates using Infoworks RS and based on the increasing water level resulted from the model and simulation, inundation areas can be generated using GIS and area or villages that are likely to be inundated in the event of rise of water level can be known. Muda River cross section, and weather rainfall data were used for flood simulation using Infoworks RS while, aerial photo, topography map and water level of Pinang River were used in the development of digital elevation model (DEM) and flood analysis using ArcGIS 9.3 software. Results from the developed model have shown either the water in the river will overflow or not due to the event occured and the inundated area also can be identified. The simulated flood inundation areas would facilitate the relevant agencies to make predictions on the degree of severity of flood damages in the affected areas.

5.3 Introduction

5.3.1 Background of Study

Floods are one of the greatest challenges to the weather prediction and the most frequently happened among all kinds of natural hazards in the world. Flash floods are commonly occurring due to rapid development or urbanization combined with the changes of hydrological, inadequate drainage system and siltation. As development keep changing the face of the area, existing infrastructure came regularly under pressure to service demand beyond their design limits. Meanwhile the urbanization of the catchments around and near the area has resulted in flood runoff which exceeds the capacity of the river system. These also results in siltation of the dam and hence reduce the capacity of the dam as flood control (Sanyal and Lu, 2003).

In the past years, Malaysia which is located in the equatorial region had suffered seasonal and flash flooding in the flood prone areas. As reported by Hamzah (2005), the annual average rainfall is in the range of 2500 mm to 3500 mm and Malaysia experiences major flood event since 1926 until now. Apart from that,the government had spent a lot of money for flood mitigation measures. In the Department of Drainage and Irrigation Malaysia, flood mitigation project has become very important and to be monitored especially in term of effectiveness of project to deal with the flooding problem hence minimizing the impact of flood event the public. The financial involvement of flood mitigation project is increased year by year. From the year 1970 until 1990, the government had spent about RM 500 million, RM 700 million (1991-1995), RM 940 million (1996 – 2000) and RM 1.6 billion (2001-2005) (DID, 2008).

In view of the above problem, a study is proposed to assist the authorities to find alternative approach to eliminate flood damages in the future. Computer modeling has become an attractive technique or tools for flood forecasting. Infoworks River Simulation (Infowork RS) is being used as a tool to predict the flood and simulate the river condition during flooding by integrating data of river cross section, rainfall, contour and etc. The application of Geographic Information Sytem (GIS) by using ArcGIS software can give prediction on flood inundation area with the increasing of river water level.

5.3.2 Problem Statement

In October 2003, the rising of flood waters that had reached danger levels in several areas in Kedah, Penang and Perak had caused the evacuation of about 17,000 people where 10,258 people were evacuated in Kedah, 5,800 in Seberang Prai and 829 in northern Perak and was claimed to be the worst compared to the previous event in 1988, 1995 and 1998 (DID, 2010). It is important to know when a flood will occur, how bad it will be, and how long it will last. In this study the application of computer software, Infoworks River Simulation (Infoworks RS) and Arc GIS is being used to model the river system and hence simulate the river condition during flooding besides the expected of flood inundation area can be identified. In addition, for an integrated flood monitoring measure, the use of alternative rainfall measurement system such as weather radar is considered crucial to complement areas inaccessible to rain-gauges, thus further study need to be conducted on radar rainfall input.

5.3.3 Objectives of Study

The objectives of this study are:

a) To model the river system by using infoworks RS.
b) To perform a flood simulation of the river model using infoworks RS integrating with weather radar-based rainfall estimates.
c) To identify the flood inundation areas by using GIS.

5.3.4 Scope of Study

This study involves modeling of river system and Integrating Weather Radar using Infoworks River Simulation (Infoworks RS) and Geographic Information System (GIS). The Infoworks will simulate the river condition during flooding while ArcGIS 9.3 software is used for Digital Elevation Model (DEM) generation and analysis of the flood inundation area resulted from the increasing of river water level. The study areas involved in this work are Muda River (downstream) for Infoworks simulation and Pinang River (downstream) for flood inundation area prediction. For this study weather radar rainfall was obtained from Malaysian Meteorological Department (MMD) and used as the rainfall input in the Infowoks RS. The data of river cross section and water level are obtained from the Drainage and Irrigation Department (DID) while the catchment characteristics such topographic map and aerial photo are acquired from the Malaysian Mapping Department (JUPEM).

5.3.5 Significance of Study

By using the developed model, the potential flooding area can be predicted easily. This will help authorities to make prediction on the river condition and action can be taken to alert the public on the possibility of the risk of flooding. The authority and public will make important decisions regarding evacuation, moving property or other mitigation effort. Indirectly, this simulation also will minimize the flood loss and damage.

5.4 Brief Literature Review

5.4.1 Flood Mitigation

Flood mitigation measure is a method to reduce the effect of floods to overcome flooding. It can be categorized into structural measures or non structural measures. According to Abdullah (2004), structural measures or curatives measures are engineering methods that are used to solve the flooding problems. The river capacity can be increased to accommodate the surplus runoff through channel improvement, construction of levees and embankments, flood bypasses, river diversions, and construction of flood storage dams and flood attenuation ponds. All of these measures can be constructed either singly or in combination.

While, non-structural measures on the other hand are proposed where engineering measures are not applicable or viable or where supplemental measures are required. It is more for preventing floods from occurring and with the aim of minimising losses due to flooding. These measures are broadly aimed at reducing the flood magnitude through the management of catchment conditions as well as reducing the flood damage. They include Integrated River Basin Management (IRBM), Rainfall Harvesting, Infiltration/Gravel Drains, Previous Pavement, Guideline and Design Standard, Flood Hazard Mapping and Flood Forecasting and Warning System (Abdullah, 2004).

5.4.2 River Modeling

According to the Arlen *et. al* (1982), HEC 1 has a capability to simulate rainfall and snowmelt runoff from sub-basins and flow through a stream network, simulation of flows in urban areas and economic calculation for flood mitigation.

Paper presented by Chihhao *et. al*, (2009) show that HEC-RAS-assisted Qual2K simulations to produce water quality according to the river monitoring data by taking tidal effect into consideration. They studied the effectiveness of combining Qual2K model with the HEC-RAS model to assess the water quality of a tidal river in northern Taiwan. The contaminant loadings of biochemical oxygen demand (BOD), ammonia nitrogen (NH_3-N), total phosphorus (TP), and sediment oxygen demand (SOD) are utilized in the Qual2K simulation while HEC-RAS model is used to: (i) estimate the hydraulic constants for atmospheric re-aeration constant calculation; and (ii) calculate the water level profile variation to account for concentration changes as a result of tidal effect.

5.4.3 Infoworks River Simulation

Statistical analysis of historical rainfall patterns is used to determine design rainstorms of specific return periods. These design rainstorms are used as inputs to the model, hydrological and hydraulic analysis is undertaken to determine the resultant flows and levels, and finally the flood mapping results are calculated. By following this process, the model can be used to investigate the likely outcomes of specific design rainfall events. Rainfall data is used as an input to the model and it must be geographically specific, covering the whole basin. The data used usually from specific storms or extended rainfall events (Hassan, 2007).

InfoWorks RS combined advanced 1D hydrological, flow routing and fully hydrodynamic and 2D flow simulation engines, geographical analysis and a relational database within a single environment. It comprises full solution modeling of open channels, flood-prone area, embankments and hydraulic structures. Using InfoWorks RS modellers and engines can progress seamlessly from raw survey and time-series data to detailed, calibrated hydrological models. The results from InfoWorks RS enable planners and engineers to carry out fast and accurate modeling of the key elements of river and channel systems to support planning, design and operational management activities (Wallingford, 2003).

5.4.4 Geographic Information System (GIS) Applications

Geographic Information System (GIS) can be defined as a system that consist of tools, procedure and software which are designed to manage, manipulate, analysis and modeling the geographical data. The data and information are normally come in form of map(topographic or thematic map), model and also statistic. The use of GIS in varies engineering application such as town planning, highway engineering, environment, hydrology and water resources have been reported by Hirol and Mohd Yunus (2002).

According to the Liyanarachchi and Gunasena (2006), GIS provides tool for determining the flood inundated areas. It also can be used for future flood prediction where the possible increase in water level in the river in the form of digital elevation model (DEM) can be stored in GIS. Xihua and Bengt (2002) stated that GIS can be used as a tool for flood prediction and flood information for emergency planning as well as evaluation of the degree of risk.

Holger *et.al* (2007) represents a new approach using geographic information systems (GIS) with two extensions ArcView and ArcGIS to calculate flow accumulation. It considers the trap-efficiencies of dams and their specific operation time based on the well-known D8 single-flow algorithm. Vairavamoorthy *et.al* (2007) in their paper represents the development of a new software using GIS-based namely IRA-WDS. It is to predict the risks associated with contaminated water entering water distribution systems from surrounding foul water bodies such as sewers, drains and ditches.

5.5 Methodology

The study was divided into three (3) phases as illustrated in Figure 1. Phase 1 involves the selection of study area and data collection. Phase 2 is data processing stages which include the creation of DEM and also development of hydrodynamic model by using ArcGIS and Infoworks RS. Phase 3 covers flood simulation and results analysis.

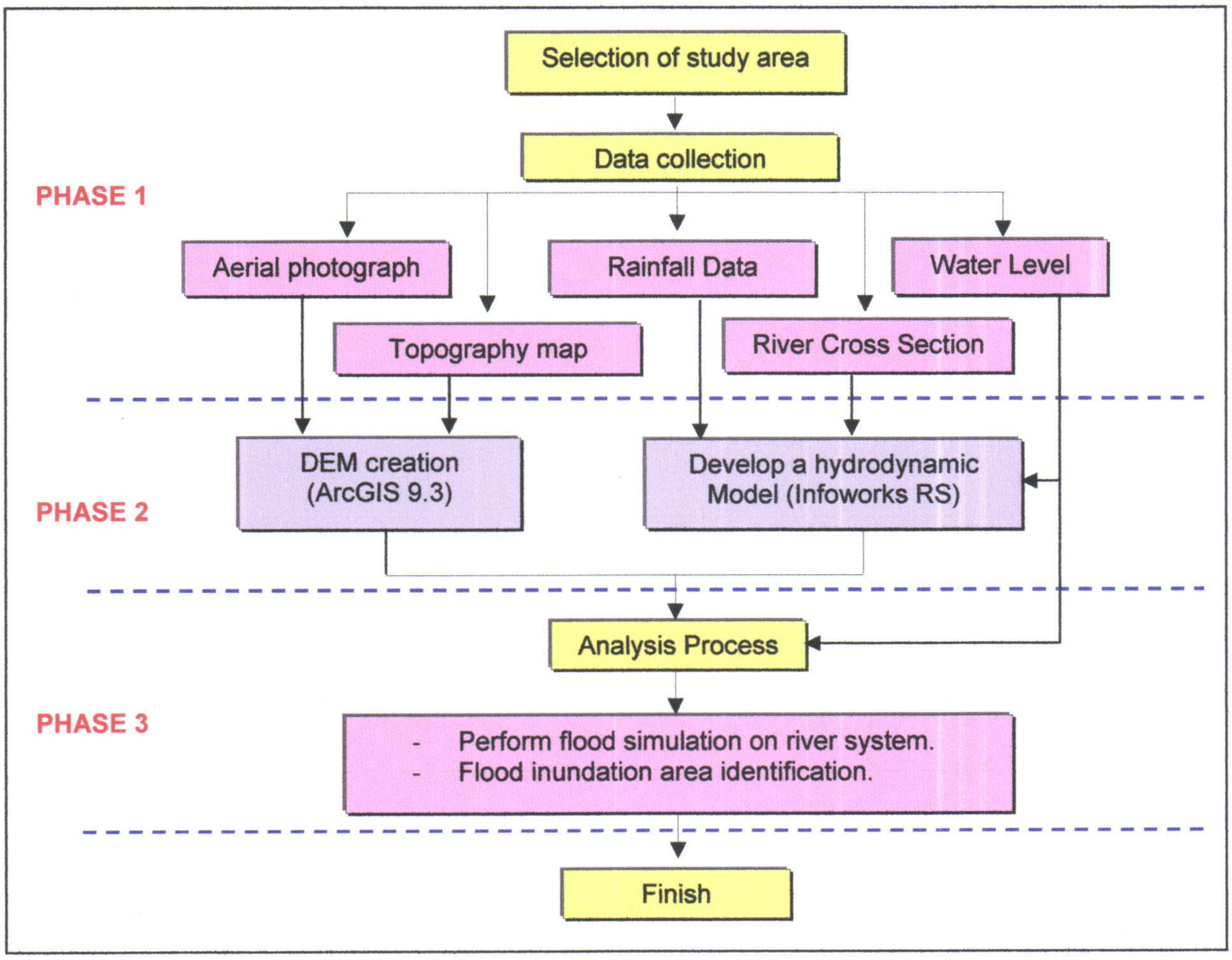


Figure 1: Research framework of the study

5.5.1 Study Area

Sg. Muda downstream and Sg. Pinang downstream river basins were chosen as the study areas. Both of these river basins are located in Northern Peninsular Malaysia which had experienced flooding during the north-east monsoon season period between November to January. The length of the Sg. Muda river is 180 km and Sg. Pinang river is 3.1 km approximately with catchment area of 4210 km^2 and 50.97 km^2 respectively. Figure 2 and Figure 3 show the study area.

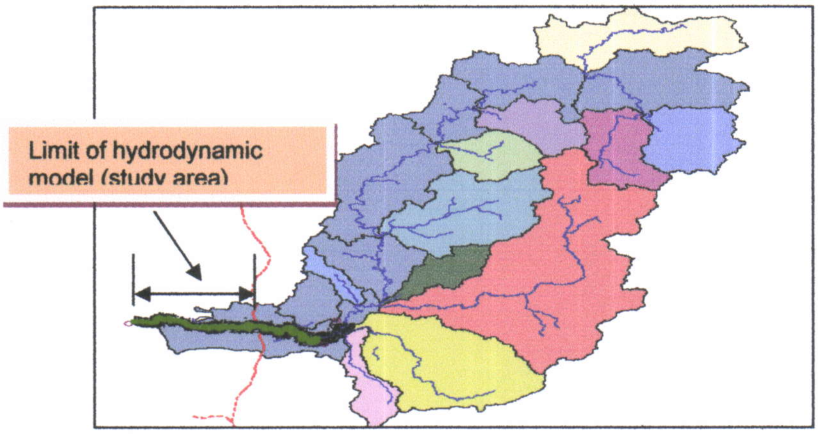


Figure 2: Study area for Sg.Muda river (downstream) (Nahrim, 2008)

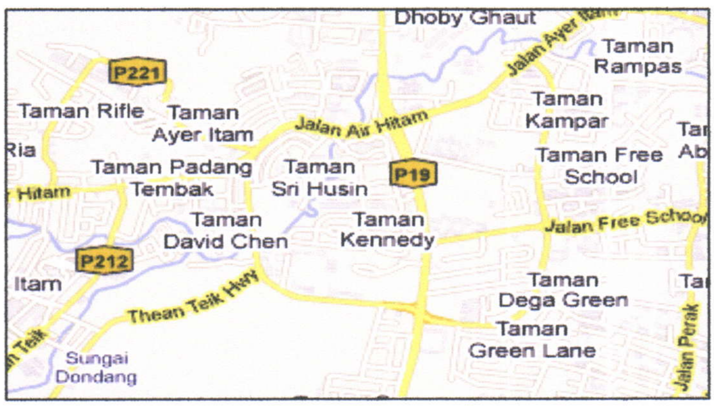


Figure 3: Study area for Sg. Pinang river (downstream) (Google earth, 2010)

5.5.2 Data Collection

Data such as river cross section, river discharge and water level were used to build a hydrodynamic model for Sg. Muda River were obtained from the Department Drainage and Irrigation while radar rainfall data were obtained from the Malaysian Meteorological Department. Figure 4 shows the example of river cross section at CH 12.64.

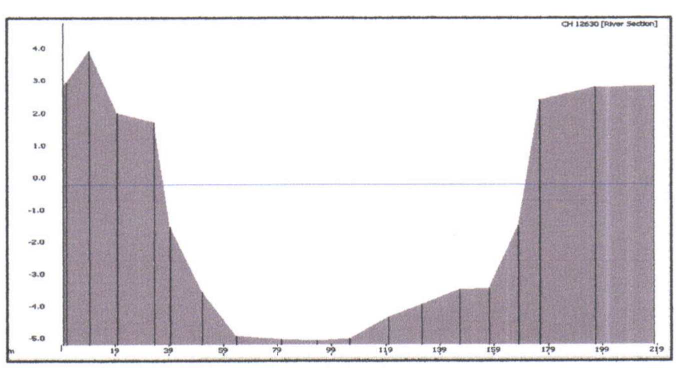


Figure 4: Example of Cross Section at CH 12.64

In Peninsular Malaysia, there are six radar stations available that are belong to Malaysian Meteorological Department (MMD). The MMD provides maps of radar rainfall estimated from S-Band conventional pulse radar station using 3D-Rapic program. The one hour Digital Precipitation Array (DPA), an accumulation in the 1.1 nm x 10 polar form converted to a 2.2 x 2.2 nm rectangular grid, was used for this study. Figure 5 shows an example of radar display dated 4/10/2003 at 0900 UTC. The radar image is being converted into rainfall intensity based on classical Marshall and Palmer relationship ($Z=200R^{1.6}$) . The colour code is defined in Figure 6 which shows the reflectivity palette provided by the Malaysian Meteorological Department (MMD).

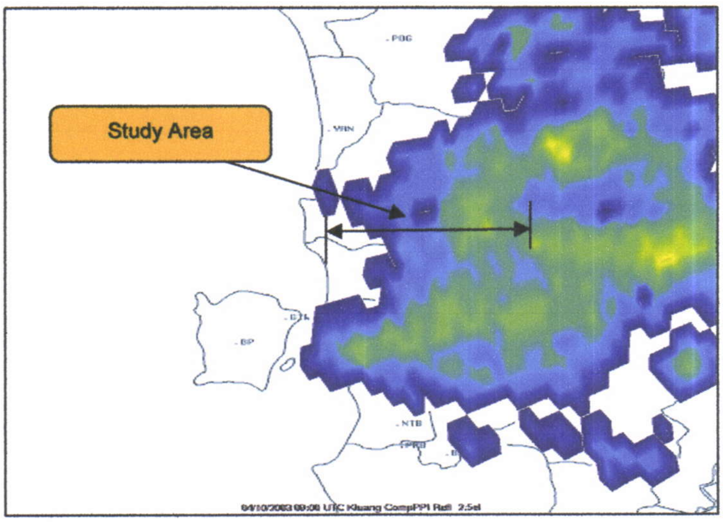


Figure 5: An example of radar display used in the study (MMD,2003)

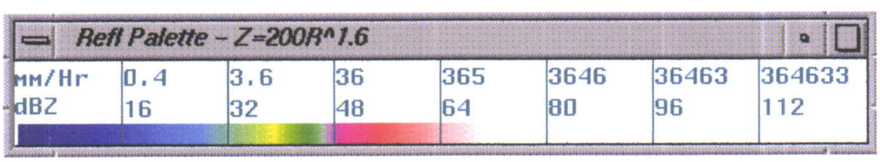


Figure 6: Weather radar precipitation color palettes (MMD,2003)

The aerial photo and topography map for Sg Pinang was obtained from the Jabatan Ukur dan Pemetaan Malaysia (JUPEM) for Sg. Pinang River. Figure 7 shows the topographic map of Sg. Pinang (downstream). The land use data that have been used was obtained from the Department of Agriculture and it was assumed that there is not much change in land use had occurred during the flood event represented in this study.

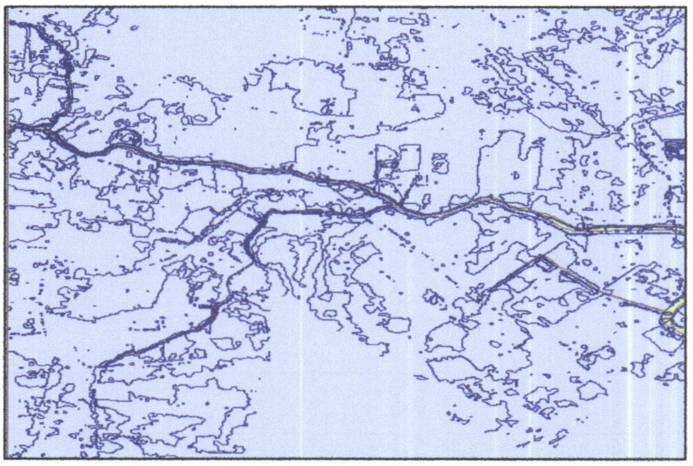


Figure 7: Topographic Map for Sg. Pinang (JUPEM, 2009)

5.5.3 Data Processing

For this study, Infoworks River Simulation (RS) was used to carry out the flood simulation and hydrodynamic model of Sg. Muda. The river cross section were updated and manipulated in such a way that they were connected by lines in Geoplan View. The cross section will link together to form a continuous river bed feature. ArcGIS 9.3 was used to identify the flood inundation area for Sg. Pinang. The process started by digital elevation model creation, digitizing and editing road, building and river.

5.5.4 Data Analysis

In this study, two processes analysis were performed involving Infoworks RS (River Simulation) for flood simulation and ArcGIS 9.3 for flood inundation area generation. By using Infoworks RS a steady run type were chosen for the 1D hydrodynamic simulation, and the result from this simulation was used as an input for unsteady run type simulation. The Infoworks RS computed the flow depths and also discharges. From the discharge values, water level of the river can be known and used as an input to ArcGIS 9.3 for flood inundation area identification.

5.6 Results and Discussion

5.6.1 Modeling a Hydrodynamic Model (Rainfall Input –Intergrated from Weather-Radar)

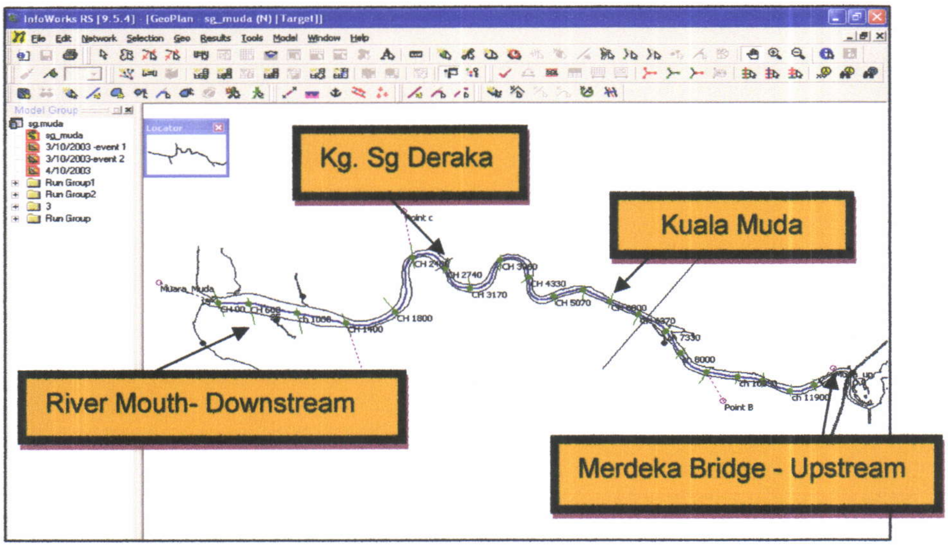


Figure 8: Muda River Hydrodynamic Model for Input from Weather Radar

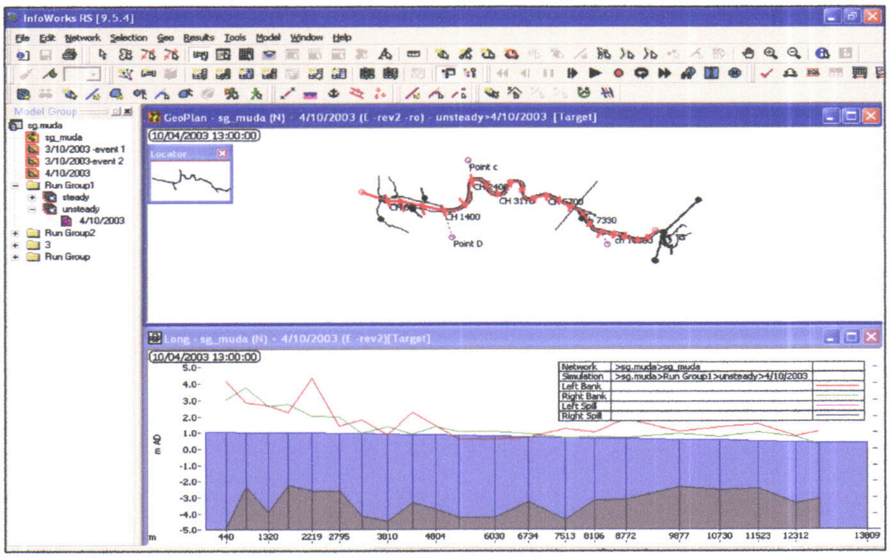


Figure 9: Longitudinal section of Muda River for Input from Weather Radar

Figure 8 shows the hydrodynamic model of Sg. Muda from weather radar rainfall as the input. The SCS boundary that is applied at Merdeka Bridge as upstream inflow hydrograph requires sets of data consisting of rainfall profiles and catchments characteristics. Stage-time boundary is used on river mouth as the downstream end of the network. A stage time boundary specifies a set of data consisting of water level above datum and time. Figure 9 shows one longitudinal section of Sg. Muda after unsteady flow simulation dated 3rd October 2003 using weather rainfall data as an input.

5.6.2 Flow Analysis Result (Rainfall Input – Integrated from Weather Radar)

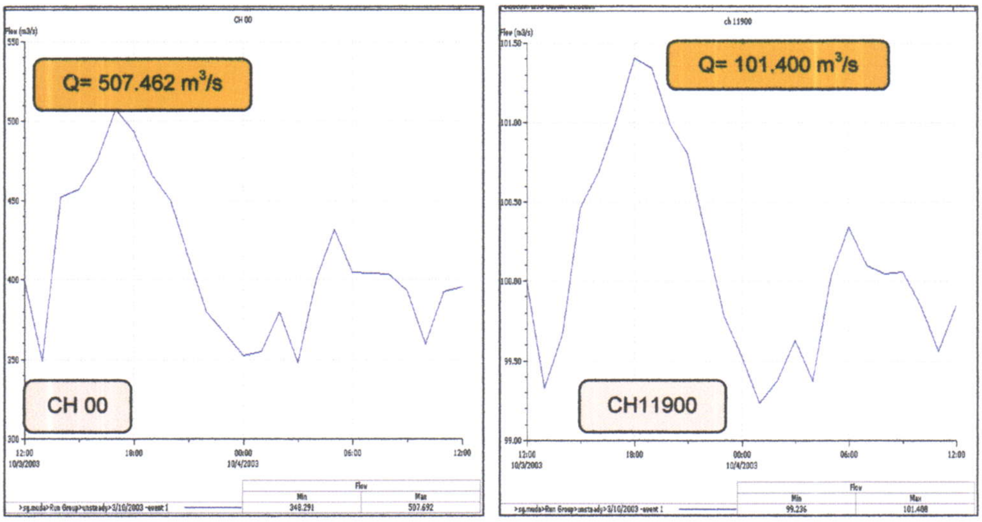


Figure 10: Flow Hydrograph at CH 00 and CH 11900

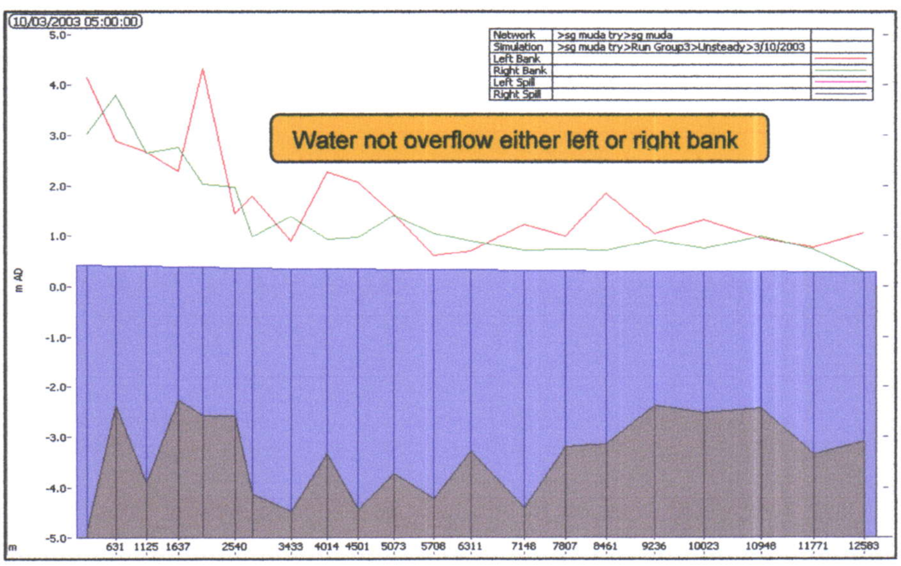
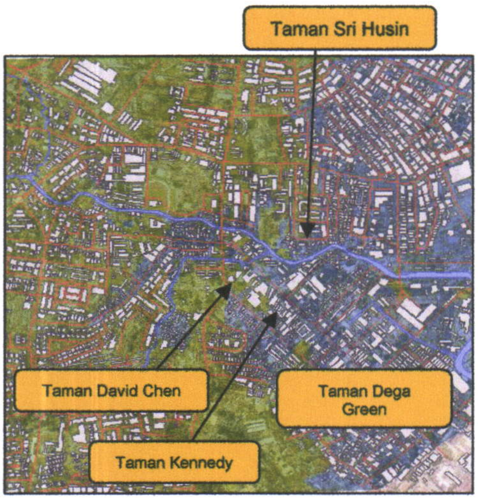


Figure 11: Longitudinal Cross Sections (3rd October 2003 event)

Figure 10 show the results of flow hydrograph for two locations that are obtained from the simulation of unsteady flow. It is found that the highest flow is 507.426 m^3/s at CH 00 followed by the 101.400 m^3/s at CH 11900. Figure 11 shows the longitudinal section for the event occurred on the 3rd October 2003. From the simulation it can be seen that the bank is not overflowed. Since the average rainfall received was less than 10 mm, it is logical because the quantity of rainfall received on the particular day is not classified as heavy rainfall.

5.6.3 Flood Inundation Area Identification using GIS

Based on the value of discharge obtained from Infoworks RS simulation, water level of the river had been known. But, due to data constraint, water level at Sg. Pinang River was obtained from the Department of Irrigation and Drainage and used for flood inundation area identification by using ArcGIS 9.3.



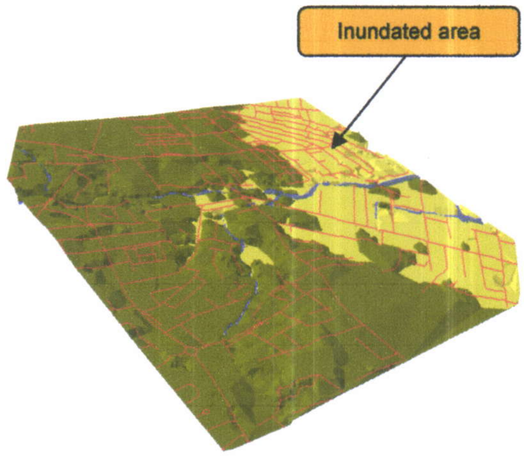


Figure 12: 2D and 3D flood simulation for 3.0 m above sea level

Figure 12 shows the flood inundation areas when river water level rises to 3.0 meter above sea level. In 2D flood simulation, blue color represents the inundated areas while in 3D flood simulation yellow colour represents the inundated areas for that study area. The areas affected are; Taman David Chen, Taman Kennedy, Taman Dega Green, Taman Sri Husin, Jalan Perak, Jalan Air Hitam and most of the downstream areas. The value of contour level indicated that the location is low land area so if water level raise only about 0.5 meter from normal water level, the small areas near to the downstream will be inundated. The high land with high ground level elevation will be saved and from this inundation mapping, the public and authorities can safe their live and properties by moving to the high land area.

5.7 Conclusion and Recommendation

5.7.1 Conclusion

The use of weather radar based rainfall as input to river modeling has been presented. It can be concluded that it is a potential technique of rainfall estimation and useful alternatives for areas without the rain gauges. The flood simulation of Sg. Muda by using Infoworks RS had been successfully achieved and the discharges of the river can be predicted. This study also has achieved the objective to identify the flood inundation areas by using ArcGIS 9.3 application as a disaster preparedness measure. By this approach, losses due to life and properties can be minimized.

5.7.2 Recommendation

For further improvement, it is highly recommended that all the data needed for integrated analysis be obtained so that the complete comprehensive analysis can be done and the result will be more accurate and applicable.