RIVER MODELLING FOR FLOOD RISK MAP PREDICTION: CASE STUDY OF SUNGAI KAYU ARA

by

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TABLE OF CONTENTS

ACKNOWLEDGEMENTS ……..……..…..ii

TABLE OF CONTENTS …….……..……..……iii

LIST OF TABLES……..viii

LIST OF FIGURES…….……..…..……..…xi

LIST OF SYMBOLS……..……...……xxvi

LIST OF PUBLICATIONS……...……..……xxviii

ABSTRAK…….……xxx

ABSTRACT…….…..……...xxxii

CHAPTER 1: INTRODUCTION

1.1 Background and Motivation……....1

1.2 Objectives……..……..5

1.3 Structure of the Thesis……..……...6

CHAPTER 2: LITERATURE REVIEW

2.1 River Flood……..……8

2.2 Risk and Hazard……..……...11

2.3 River Flood Modelling……..…….13

2.4 River Flood Mapping……..……...16

2.5 Computer Models…….…….18

2.6 Integration of River Flood Hazard Modelling and GIS……..…20

2.6.1 Tight Coupling System…….....……..….28

2.7 River Flood Hazard Categorization Guidelines…….....32

2.7.1 CSIRO Flood Hazard Categorization Guideline…….....33

2.7.2 Strategic Flood Risk Assessment (SFRA) Guideline….....35

2.7.3 Guideline of Department of Environment, Food and Rural Affair (DEFRA)…….…..…36

2.7.4 NSW Flood Development Manual……..…40

2.8 St. Venant Equations……..……42

CHAPTER 3: METHODOLOGY

3.1 Introduction……..……..……47

3.1.1 Case Study…….....47

3.1.2 Methodology ……..52

3.1.2.a Hydrological Modelling…….…….....…….53

3.1.2.b Hydraulic Modelling……54

3.1.2.c River Flood Hazard Mapping…….…….57

3.1.2.d River Flood Risk Mapping …….57

CHAPTER 4: HYDROLOGICAL MODELLING

4.1 Introduction……..……..……60

4.2 HEC-HMS3.1.0…….……..……...…61

4.2.1 Loss Method…….……..……62

4.2.2 Transformation Method…….……..……64

4.2.3 Base-Flow Method……..……67

4.2.4 Routing Method……..…….70

4.3 HEC-GeoHMS1.1……..……75

4.4 Hydrological Model Input Data……..79

4.4.1 Data Collection……..……..…….……79

4.4.2 Events Selection……..……82

4.4.3 Mean Areal Rainfall……...……..…….....83

4.5 HEC-HMS Model Establishment for Sungai Kayu Ara.....85

4.5.1 Sensitivity Analysis for HEC-HMS3.1.0 Model…….....…89

4.5.2 Selection of Calibration and Validation Events……..……97

4.5.3 Calibration of HEC-HMS Model……..……..99

4.5.4 Validation of HEC-HMS3.1.0 Model……...108

4.6 Design Hydrograph for Sungai Kayu Ara River Basin…….....…113

4.6.1 Effect of Land-Use on River Basin Response…….….119

4.6.2 Hydrological Simulation……..…….122

CHAPTER 5: HYDRAULIC MODELLING

5.1 Introduction……..……130

5.2 HEC-RAS4.0…….…..…….130

5.3 The HEC-GeoRAS 3.1.1 Extension……..……..134

5.4 HEC-RAS Input Data……..……135

5.4.1 HEC-RAS Geometric Data……..…….136

5.4.1.a Spatial Data……..……..141

5.4.1.b Google Earth Images……..……144

5.4.2 HEC-RAS Steady Flow Data……..…….…145

5.5 Establishing HEC-RAS Model Credibility……..……148

5.5.1 Sensitivity Analysis of HEC-RAS Model……149

5.5.2 Calibration and Validation of HEC-RAS Model……..151

5.6 Simulation of HEC-RAS Model……..……163

5.7 MIKE11 Model……..……..…189

5.7.1 MIKE11 River Network File……..…..198

5.7.2 MIKE11 Cross-section File……..……200

5.7.3 MIKE11 Boundary File……..……..202

5.7.4 MIKE11 Hydrodynamic Parameter File……...…203

5.7.5 MIKE11 Simulation file……..…….204

5.8 MIKE View…….....205

5.9 The MIKE11GIS Extension…….....206

5.10 Establishing MIKE11 Model Credibility……..….208

5.11 Simulation of MIKE11 for Sungai Kayu Ara River Basin…….211

5.12 Comparison between MIKE11 and HEC-RAS4.0……..……..240

5.12.1 Credibility of the model……..……240

5.12.2 Available Outcomes……..……..250

5.12.3 Usability of the Models……..…….259

5.12.4 Availability of the Models……..……264

CHAPTER 6: RIVER FLOOD RISK MAP PREDICTION

6.1 River Flood Modelling……..…..……..265

6.2 River Flood Hazard Mapping…….…….……....266

6.2.1 River Flood Hazard Mapping Based on River Flood Depth Map…….....…….…….269

6.2.2 River Flood Hazard Mapping Based on River Flood Velocity Map……...…….…….278

6.2.3 River Flood Hazard Mapping with Combination of River Flood Depth and Velocity Maps…….……287

6.3 River Flood Risk Mapping……..…….....….305

CHAPTER 7: DISCUSSION AND CONCLUSIONS

7.1 Discussion…….…….…..……..…331

7.1.1 Hydrological Modelling……..……..……333

7.1.2 Hydraulic Modelling…….336

7.1.3 Comparison between HEC-RAS and MIKE11……341

7.1.4 River Flood Hazard Mapping……...…….....347

7.1.5 River Flood Risk Mapping…….....…….....…….349

7.2 Conclusions……..…….……...352

7.2.1 Hydrological Modelling Conclusions …….....…….352

7.2.2 Hydraulic Modelling Conclusions …….....…….353

7.2.3 River Flood Hazard Mapping Conclusions …….....354

7.2.4 River Flood Risk Mapping Conclusions …….....….355

7.3 Future Works……..….....……...……...356

REFERENCES……..…....……...……....357

LIST OF TABLES

Table 1.1 Study Scenarios……..……6

Table 2.1 Factors Contributing to River Flood……..…….....…….12

Table 2.2 Definition of Flood Risk Categories by CSIRO……..……34

Table 2.3 Flood Hazard Categories……...……..…36

Table 2.4 Description of Hazard categories……..……..39

Table 3.1 Area and Percentage of Coverage Types of Land-use in Sungai Kayu Ara……..…….51

Table 4.1 Characteristics of Sungai Kayu Ara Sub-River Basins……..….79

Table 4.2 Particulars of Rain Gauges and Water Level Station Included in the Research……...81

Table 4.3 Results of Thiessen Polygon Method…….….84

Table 4.4 Ranking of the Effectiveness of Sensitive Parameters on Runoff Volume and Runoff Peak Discharge……96

Table 4.5 Selected Rainfall Events for Hydrologic Model Calibration……..….98

Table 4.6 Selected Rainfall Events for Hydrologic Model Validation……....99

Table 4.7 Different Soils Characteristics……....100

Table 4.8 Result of the Simulation and Observed Runoff Peak and Volume……107

Table 4.9 Results of Calibration Process for Hydrologic Model……..….109

Table 4.10 Final Validated Parameters Value for of HEC-HMS Model for Sungai Kayu Ara River Basin.....113

Table 4.11 Coefficients of the Fitted IDF Equation for Kuala Lumpur…….....…..115

Table 4.12 Standard Durations for Urban Rainfall Water Drainage…….....116

Table 4.13 Design Rainfall Intensity and Depth for Sungai Kayu Ara ….....117

Table 4.14 Percentage of Imperviousness Area in Each Sub-river Basin for Each Development Condition in Sungai Kayu Ara River Basin……..…….……..…121

Table 4.15 Scenarios of Hydrological Modeling for Sungai Kayu Ara ……121

Table 4.16 Results of the HEC-HMS3.1.0 for the 36 Scenarios……..…..123

Table 5.1 Peak Discharges at the Upstream and the Chainage 4000m of Sungai Kayu Ara Study Reach……..…….…….……..…147

Table 5.2 Flood Events for Calibration of Hydraulic Model Sungai Kayu Ara .....…152

Table 5.3 Results of Calibration Process of HEC-RAS4.0 for Sungai Kayu Ara 153

Table 5.4 Flood Events for Hydraulic Model Validation in Sungai Kayu Ara .....…...158

Table 5.5 Results of Validation Process of HEC-RAS4.0 for Sungai Kayu Ara 160

Table 5.6 Percentage of Imperviousness Area in Different Development Conditions in Sungai Kayu Ara River Basin…….....……...….....164

Table 5.7 Area of Flood Extents Created by HEC-RAS in Sungai Kayu Ara …..……172

Table 5.8 Results of Calibration Process of MIKE11 for Sungai Kayu Ara ..…….....209

Table 5.9 Results of Validation Process of MIKE11 for Sungai Kayu Ara .……....210

Table 5.10 Calculated Water Level by MIKE11 at the Location of the Water Level Station at the Outlet of the Sungai Kayu Ara River Basin .....….....….225

Table 5.11 Computed Area of River Flood Extents by MIKE11 for Sungai Kayu Ara River Basin ……..…….....…….....……..….237

Table 5.12 Calculated Inundated Areas with Depth 0-100 cm for Sungai Kayu Ara River Basin……...…….……..239

Table 5.13 Simulation Results of Calibration Events Using MIKE11 and HEC-RAS4.0 Models for Kayu Ara River……...241

Table 5.14 Results of Simulation of Validation Events in MIKE11 and HEC-RAS4.0 for Kayu Ara River…….…….....243

Table 5.15 Simulation Results of HEC-RAS4.0 and MIKE11 for Existing Development Conditions…….……...246

Table 5.16 Simulation Results of HEC-RAS4.0 and MIKE11 for Intermediate Development Conditions……..…..…247

Table 5.17 Simulation Results of HEC-RAS4.0 and MIKE11 for Ultimate Development Conditions…….……..248

Table 5.18 Inundated Area Estimated by HEC-RAS4.0 and MIKE11 for Design Rainfall 60 minute Duration in Kayu Ara River Basin……....257

Table 6.1 Scenarios Used in River Flood Hazard Mapping……..……...……..266

Table 6.2 River Flood Hazard Categories based on Water Depth…….269

Table 6.3 Results of River Flood Hazard Map Based on Water Depth in Sungai Kayu Ara River Basin…….....…….…..……...275

Table 6.4 Statistics of River Flood Hazard Map Based on Water Depth in Sungai Kayu Ara River Basin…….…….……....277

Table 6.5 River Flood Hazard Categories based on Flow Velocity…….……...…279

Table 6.6 Results of River Flood Hazard Map Based on Flow Velocity in Sungai Kayu Ara river Basin…….…….…….284

Table 6.7 Statistics of River Flood Hazard Map Based on Flow Velocity in Sungai Kayu Ara river Basin…….....……..…….……287

Table 6.8 Extent of the River Flood Hazard Categories for Different Scenario in Sungai Kayu Ara River Basin ……...……..…….302

Table 6.9 Risk Value for River Flood Hazard in Sungai Kayu Ara River Basin……...309

Table 6.10 Risk Value for Main Road Accessibility in Sungai Kayu Ara.....……311

Table 6.11 Risk Value of Debris Flow in Sungai Kayu Ara……..…….……...313

Table 6.12 Area of River Flood Risk in Each Scenario for Sungai Kayu Ara.……..…327

LIST OF FIGURES

Figure 1.1 Flood in Jalan Sultan Ismail, Kuala Lumpur, June 2007……...……...1

Figure 1.2 Flood Damage in Golestan National Park, Iran, August 2001…….…..…2

Figure 1.3 Flood in Kuala Lumpur, Malaysia, March 2009.....3

Figure 1.4 Flood in Kuala Lumpur, Malaysia, January 2008…….……....4

Figure 2.1 Number of Great Natural Catastrophes from 1950 to 2001 (Munich, 2002)....9

Figure 2.2 Number of Disasters Attributed to Floods from 1975 to 2001 …....…..…..10

Figure 2.3 Number of People Killed in Floods from 1975 to 2001 ...……..……...10

Figure 2.4 Flood Hazard Mapping in Germany.....14

Figure 2.5 Flood Risk Map for Part of the London, England.....15

Figure 2.6 Application of GIS in Flood Mapping in United States…….....……22

Figure 2.7 Channel geometry incorporated into a digital terrain model ……...….....24

Figure 2.8 Flood visualization using AVRas and a TIN…….…..……25

Figure 2.9 TIN Surface Model…….....…….……...27

Figure 2.10 Tight Coupling System……..……...29

Figure 2.11 GUI for HEC-GeoRAS3.1.1, Pre- and Post-Processor Menus……..…..30

Figure 2.12 Definition of Flood Risk Categories by CSIRO ……..……34

Figure 2.13 River Flood Hazard Matrix…….……..……37

Figure 2.14 River Flood Hazard Categories……...…….….41

Figure 3.1 Location of Sungai Kayu Ara in Malaysia…….…..…….……..48

Figure 3.2 Base Map of Sungai Kayu Ara…….……..……49

Figure 3.3 Digital Elevation Model (DEM) of the Sungai Kayu Ara River Basin…..….49

Figure 3.4 Land-use Map of Sungai Kayu Ara……..……...…51

Figure 3.5 Methodology Flowchart…….52

Figure 4.1 Snyder's Unit Hydrograph……..……66

Figure 4.2 Initial Base-flow Recession……..……..68

Figure 4.3 Base-flow Model Illustration……..……69

Figure 4.4 Recession with Multiple Runoff Peaks……..……69

Figure 4.5 Simple Watershed with Kinematic-Wave Model Representation……..…72

Figure 4.6 HEC-GeoHMS 1.1 in ArcviewGIS version 3.1……..……...76

Figure 4.7 Characteristics for Sungai Kayu Ara River Basin ……..…..….78

Figure 4.8 Runoff Surface Flow Direction Map of the Sungai Kayu Ara ……..78

Figure 4.9 Rating Curve for the Sungai Kayu Ara River Basin …….….81

Figure 4.10 Location of Rainfall and Water Level Stations in Sungai Kayu Ara..... 82

Figure 4.11 Thiessen Map of Sungai Kayu Ara River Basin……..……84

Figure 4.12 Goodness of Fit for Model Results……..…….89

Figure 4.13 Sensitivity Analysis of HEC-HMS3.1.0 for Runoff Volume……...90

Figure 4.14 Sensitivity Analysis of HEC-HMS3.1.0 for Runoff Peak Discharge……...91

Figure 4.15 Observed Runoff Volume of the Selected Rainfall Events for Hydrologic Model Calibration……..…….……..98

Figure 4.16 Observed Runoff Peak of the Selected Rainfall Events for Hydrologic Model Validation……...……..99

Figure 4.17 Calibration Result for Rainfall Event 25/03/1996, R^2: 0.94……...…....102

Figure 4.18 Calibration Result for Rainfall Event 17/10/1996, R^2: 0.94……..…….102

Figure 4.19 Calibration Result for Rainfall Event 10/12/1996, R^2: 0.92……..….102

Figure 4.20 Calibration Result for Rainfall Event 15/03/1998, R^2: 0.95……..….102

Figure 4.21 Calibration Result for Rainfall Event 31/08/1998, R^2: 0.95…..……..…103

Figure 4.22 Calibration Result for Rainfall Event 15/03/1999, R^2: 0.92……..…....103

Figure 4.23 Calibration Result for Rainfall Event 24/05/2000, R^2: 0.90…….....…..103

Figure 4.24 Calibration Result for Rainfall Event 18/11/2000, R^2: 0.91……..…....103

Figure 4.25 Calibration Result for Rainfall Event 27/07/2001, R^2: 0.90…….....…104

Figure 4.26 Calibration Result for Rainfall Event 28/03/1996, R^2: 0.96……...104

Figure 4.27 Calibration Result for Rainfall Event 19/04/1996, R^2: 0.90……..……..…104

Figure 4.28 Calibration Result for Rainfall Event 02/07/1996, R^2: 0.94……..……..…104

Figure 4.29 Calibration Result for Rainfall Event 24/10/1997, R^2: 0.95……..……..…105

Figure 4.30 Calibration Result for Rainfall Event 20/02/1998, R^2: 0.98……..……..…105

Figure 4.31 Calibration Result for Rainfall Event 10/02/1999, R^2: 0.99……...…105

Figure 4.32 Calibration Result for Rainfall Event 10/03/1999, R^2: 0.97……..…....…105

Figure 4.33 Calibration Result for Rainfall Event 23/11/2000, R^2: 0.98……...…106

Figure 4.34 Calibration Result for Rainfall Event 22/07/2001, R^2: 0.90……..……..…106

Figure 4.35 Correlation of Observed and Simulated Peak Discharge in Calibration….106

Figure 4.36 Correlation of Observed and Simulated Runoff Volume in Calibration Process for HEC-HMS in Sungai Kayu Ara River Basin…….…….108

Figure 4.37 Evaluation of Calibrated Values Based on Average Parameter Values…..110

Figure 4.38 Evaluation of Calibrated Values Based on Median Parameter Values…...110

Figure 4.39 Evaluation of Calibrated Values Based on Mode Parameter Values……..110

Figure 4.40 Result of Simulation of HEC-HMS3.1.0 According to the Average, Median and Mode Parameter Values of Calibration Range…….……..…….111

Figure 4.41 Correlation of Observed and Simulated Runoff Peak Discharge in Validation Process ……..……..……..……112

Figure 4.42 Correlation of Observed and Simulated Volume in Validation Process..112

Figure 4.43 Rainfall Hydrograph for 20year ARI with 60 minutes and 120 minutes Duration.....117

Figure 4.44 Rainfall Hyetograph for 20year ARI with 180 minutes and 360 minutes Duration.....117

Figure 4.45 Rainfall Hyetograph for 50year ARI with 60 minutes and 120 minutes Duration.....118

Figure 4.46 Rainfall Hyetograph for 50year ARI with 180 minutes and 360 minutes Duration.....118

Figure 4.47 Rainfall Hyetograph for100 year ARI with 60 minutes and 120 minutes Duration.....118

Figure 4.48 Rainfall Hyetograph for 100 year ARI with 180 minutes and 360 minutes Duration.....119

Figure 4.49 Effect of Urbanization on Different Components of the Water Cycle…..120

Figure 4.50 Runoff Peak Discharge and Runoff Volume in Existing, Intermediate and Ultimate Development Conditions for 20 years ARI in Sungai Kayu Ara ….…..……124

Figure 4.51 Runoff Peak Discharge and Runoff Volume in Existing, Intermediate and Ultimate Development Conditions for 50 years ARI in Sungai Kayu Ara ……...…124

Figure 4.52 Runoff Peak Discharge and Runoff Volume in Existing, Intermediate and Ultimate Development Conditions for 100 years ARI in Sungai Kayu Ara….…..……124

Figure 4.53 Simulated Runoff Hydrograph for Rainfall Events with 60 minutes Duration in Existing, Intermediate and Ultimate Development Condition with 20 years ARI……..……...….126

Figure 4.54 Simulated Runoff Hydrograph for Rainfall Events with 120 minutes Duration in Existing, Intermediate and Ultimate Development Condition with 20 years ARI……..……...…126

Figure 4.55 Simulated Runoff Hydrograph for Rainfall Events with 180 minutes Duration in Existing, Intermediate and Ultimate Development Condition with 20 years ARI…….……..……..126

Figure 4.56 Simulated Runoff Hydrograph for Rainfall Events with 360 minutes Duration in Existing, Intermediate and Ultimate Development Condition with 20 years ARI…….…….……...127

Figure 4.57 Simulated Runoff Hydrograph for Rainfall Events with 60 minutes Duration in Existing, Intermediate and Ultimate Development Condition with 50 years ARI……..……...…127

Figure 4.58 Simulated Runoff Hydrograph for Rainfall Events with 120 minutes Duration in Existing, Intermediate and Ultimate Development Condition with 50 years ARI……..……..127

Figure 4.59 Simulated Runoff Hydrograph for Rainfall Events with 180 minutes Duration in Existing, Intermediate and Ultimate Development Condition with 50 years ARI…….……..……..128

Figure 4.60 Simulated Runoff Hydrograph for Rainfall Events with 360 minutes Duration in Existing, Intermediate and Ultimate Development Condition with 50 years ARI…….……..……..128

Figure 4.61 Simulated Runoff Hydrograph for Rainfall Events with 60 minutes Duration in Existing, Intermediate and Ultimate Development Condition with 100 years ARI……..……..128

Figure 4.62 Simulated Runoff Hydrograph for Rainfall Events with 120 minutes Duration in Existing, Intermediate and Ultimate Development Condition with 100 years ARI…….……...129

Figure 4.63 Simulated Runoff Hydrograph for Rainfall Events with 180 minutes Duration in Existing, Intermediate and Ultimate Development Condition with 100 years ARI…….…..……...…129

Figure 4.64 Simulated Runoff Hydrograph for Rainfall Events with 360 minutes Duration in Existing, Intermediate and Ultimate Development Condition with 100 years ARI…….…….……...129

Figure 5.1 Terms of the Energy Equation…….....…….……133

Figure 5.2 The Study Reach of Sungai Kayu Ara……...……...137

Figure 5.3 Longitudinal Section of the Study Reach ……....…….…..…….138

Figure 5.4 Generated Geometry Data by HEC-GeoRAS3.1.1 for Sungai Kayu Ara ...140

Figure 5.5 Cross Sections for Chainage from 3705m to 4098m of the Sungai Kayu Ara 140

Figure 5.6 Imported Geometry Data File in HEC-RAS4.0…….…..…..……142

Figure 5.7 Cross Section of Chainage 5070m of the Sungai Kayu Ara River in HEC-RAS Geometry Data File……....…….……..142

Figure 5.8 Digital Elevation Model (DEM) of Sungai Kayu Ara River Basin……..143

Figure 5.9 Correlation between Google Earth Images and Digital Maps in Sungai Kayu Ara River Basin…….....…….……...….145

Figure 5.10 Locations of Upstream and Mid-Stream (Internal) Flow Discharges and Downstream Rating Curve for Steady Flow in Sungai Kayu Ara River Basin…….....148

Figure 5.11 Flood Events for Calibration of Hydraulic Model in Sungai Kayu Ara….152

Figure 5.12 Water Surface Profiles of the Selected Calibration Rainfall Events in HEC-RAS for Sungai Kayu Ara River Basin…….…….....….....……157

Figure 5.13 Correlation between Observed and Simulated Water Level in Calibration Process of HEC-RAS4.0 in Sungai Kayu Ara River……...…….....…157

Figure 5.14 Flood Events for Model Validation in Sungai Kayu Ara River Basin……159

Figure 5.15 Water Surface Profiles of the Selected Validation Rainfall Events in HEC-RAS for Sungai Kayu Ara River Basin…….....……..……..…..161

Figure 5.16 Coefficient of Determination for the Observed and Simulated Water Level in Validation Process in Sungai Kayu Ara River……..…..……...162

Figure 5.17 Longitudinal Profile of HEC-RAS Simulation in Existing Development Condition with 20years ARI in Sungai Kayu Ara River Basin……..……..….165

Figure 5.18 Longitudinal Profile of HEC-RAS Simulation in Existing Development Condition with 50 years ARI in Sungai Kayu Ara River Basin……..……..165

Figure 5.19 Longitudinal Profile of HEC-RAS Simulation in Existing Development Condition with 100 years ARI in Sungai Kayu Ara River Basin…….....166

Figure 5.20 Longitudinal Profile of HEC-RAS Simulation in Intermediate Development Condition with 20years ARI in Sungai Kayu Ara River Basin……..…...166

Figure 5.21 Longitudinal Profile of HEC-RAS Simulation in Intermediate Development Condition with 50 years ARI in Sungai Kayu Ara River Basin……..…..…167

Figure 5.22 Longitudinal Profile of HEC-RAS Simulation in Intermediate Development Condition with 100 years ARI in Sungai Kayu Ara River Basin…….....….167

Figure 5.23 Longitudinal Profile of HEC-RAS Simulation in Ultimate Development Condition with 20years ARI in Sungai Kayu Ara River Basin…….....168

Figure 5.24 Longitudinal Profile of HEC-RAS Simulation in Ultimate Development Condition with 50 years ARI in Sungai Kayu Ara River Basin……...….168

Figure 5.25 Longitudinal Profile of HEC-RAS Simulation in Ultimate Development Condition with 100 years ARI in Sungai Kayu Ara River Basin……..…..…..169

Figure 5.26 Area of Flood Extents for Existing Development Condition Scenario in Sungai Kayu Ara River…….....….……..…..172

Figure 5.27 Area of Flood Extents for Intermediate Development Condition Scenario in Sungai Kayu Ara River…….…….……173

Figure 5.28 Area of Flood Extents for Ultimate Development Condition Scenario in Sungai Kayu Ara River……...……..……...….173

Figure 5.29 Flood Extent and Water Depth Distribution Generated by HEC-RAS for Events with 20 years ARI in Existing Development Condition in Sungai Kayu Ara River Basin…….……..……176

Figure 5.30 Flood Extent and Water Depth Distribution Generated by HEC-RAS for Events with 50 years ARI in Existing Development Condition in Sungai Kayu Ara River Basin…….……..……...….177

Figure 5.31 Flood Extent and Water Depth Distribution Generated by HEC-RAS for Events with 100 years ARI in Existing Development Condition in Sungai Kayu Ara River Basin……...……..178

Figure 5.32 Flood Extent and Water Depth Distribution Generated by HEC-RAS for Events with 20 years ARI in Intermediate Development Condition in Sungai Kayu Ara River Basin……...…….……179

Figure 5.33 Flood Extent and Water Depth Distribution Generated by HEC-RAS for Events with 50 years ARI in Intermediate Development Condition in Sungai Kayu Ara River Basin……..……..…..…...180

Figure 5.34 Flood Extent and Water Depth Distribution Generated by HEC-RAS for Events with 100 years ARI in Intermediate Development Condition in Sungai Kayu Ara River Basin……...……..……181

Figure 5.35 Flood Extent and Water Depth Distribution Generated by HEC-RAS for Events with 20 years ARI in Ultimate Development Condition in Sungai Kayu Ara River Basin……...……..……..…..….182

Figure 5.36 Flood Extent and Water Depth Distribution Generated by HEC-RAS for Events with 50 years ARI in Ultimate Development Condition in Sungai Kayu Ara River Basin…….....……..……....183

Figure 5.37 Flood Extent and Water Depth Distribution Generated by HEC-RAS for Events with 100 years ARI in Ultimate Development Condition in Sungai Kayu Ara River Basin…….....……...……...……184

Figure 5.38 Flow Velocity Distribution Generated by HEC-RAS for Event with 60 minutes Duration with 20 years ARI in Existing Development Condition in Sungai Kayu Ara River Basin …….....……...…….……..….185

Figure 5.39 Flow Velocity Distribution Generated by HEC-RAS for Event with 60 minutes Duration with 50 years ARI in Existing Development Condition in Sungai Kayu Ara River Basin …….....…….……..….185

Figure 5.40 Flow Velocity Distribution Generated by HEC-RAS for Event with 60 minutes Duration with 100 years ARI in Existing Development Condition in Sungai Kayu Ara River Basin …….....…….....…….……...….186

Figure 5.41 Flow Velocity Distribution Generated by HEC-RAS for Event with 60 minutes Duration with 20 years ARI in Intermediate Development Condition in Sungai Kayu Ara River Basin ……..….....186

Figure 5.42 Flow Velocity Distribution Generated by HEC-RAS for Event with 60 minutes Duration with 50 years ARI in Intermediate Development Condition in Sungai Kayu Ara River Basin …….....…….....187

Figure 5.43 Flow Velocity Distribution Generated by HEC-RAS for Event with 60 minutes Duration with 100 years ARI in Intermediate Development Condition in Sungai Kayu Ara River Basin ……187

Figure 5.44 Flow Velocity Distribution Generated by HEC-RAS for Event with 60 minutes Duration with 20 years ARI in Ultimate Development Condition in Sungai Kayu Ara River Basin ……..188

Figure 5.45 Flow Velocity Distribution Generated by HEC-RAS for Event with 60 minutes Duration with 50 years ARI in Ultimate Development Condition in Sungai Kayu Ara River Basin ……188

Figure 5.46 Flow Velocity Distribution Generated by HEC-RAS for Event with 60 minutes Duration with 100 years ARI in Ultimate Development Condition in Sungai Kayu Ara River Basin ……..189

Figure 5.47 Cross Section Divided into a Series of Rectangular Channels…….....192

Figure 5.48 Channel Section with Computational Grid…….……194

Figure 5.49 Centred 6-point Abbott Scheme……..…….194

Figure 5.50 Centring of Continuity Equation in 6-point Abbott Scheme……..……195

Figure 5.51 Digital Contours and Cross Sections of Sungai Kayu Ara ……..……199

Figure 5.52 River Network File of Sungai Kayu Ara River in MIKE11……..…200

Figure 5.53 Cross Section File of Chainage 951.88 of Sungai Kayu Ara in MIKE11..201

Figure 5.54 Location of Boundary Conditions in MIKE11 in Sungai Kayu Ara ….....210

Figure 5.55 Correlation between Observed and Simulated Water Level in Calibration Process of MIKE11 in Sungai Kayu Ara River ……..……..212

Figure 5.56 Correlation between Observed and Simulated Water Level in Validation Process of MIKE11 in Sungai Kayu Ara River ……..……..211

Figure 5.57 Longitudinal Profile for Existing Condition, ARI 20 and Duration 60 minutes……..……..……..212

Figure 5.58 Longitudinal Profile for Existing Condition, ARI 20and Duration 120 minutes……..……..…….212

Figure 5.59 Longitudinal Profile for Existing Condition, ARI 20 and Duration 180 minutes……..……..……..…213

Figure 5.60 Longitudinal Profile for Existing Condition, ARI 20 and Duration 360 minutes……..……..……..……..…….213

Figure 5.61 Longitudinal Profile for Existing Condition, ARI 40 and Duration 60 minutes……..……..…….……..213

Figure 5.62 Longitudinal Profile for Existing Condition, ARI 50and Duration 120 minutes……..……..……...……214

Figure 5.63 Longitudinal Profile for Existing Condition, ARI 50 and Duration 180 minutes……...……..……..…….……..214

Figure 5.64 Longitudinal Profile for Existing Condition, ARI 50 and Duration 360 minutes……..……..……...…214

Figure 5.65 Longitudinal Profile for Existing Condition, ARI 100 and Duration 60 minutes……..……..……...….215

Figure 5.66 Longitudinal Profile for Existing Condition, ARI 100 and Duration 120 minutes……..……..……..…….215

Figure 5.67 Longitudinal Profile for Existing Condition, ARI 100 and Duration 180 minutes……..……...……..……215

Figure 5.68 Longitudinal Profile for Existing Condition, ARI 100 and Duration 360 minutes……..……..……...…216

Figure 5.69 Longitudinal Profile for Intermediate Condition, ARI 20 and Duration 60 minutes……..……..…….…..216

Figure 5.70 Longitudinal Profile for Intermediate Condition, ARI 20 and Duration 120 minutes…….....……..……...….216

Figure 5.71 Longitudinal Profile for Intermediate Condition, ARI 20 and Duration 180 minutes……..……..…….…..217

Figure 5.72 Longitudinal Profile for Intermediate Condition, ARI 20 and Duration 360 minutes……..……..……...….217

Figure 5.73 Longitudinal Profile for Intermediate Condition, ARI 50 and Duration 60 minutes……..……..…….…..217

Figure 5.74 Longitudinal Profile for Intermediate Condition, ARI 50 and Duration 120 minutes……..……..……...218

Figure 5.75 Longitudinal Profile for Intermediate Condition, ARI 50 and Duration 180 minutes……..……..……...218

Figure 5.76 Longitudinal Profile for Intermediate Condition, ARI 50 and Duration 360 minutes……...……...…....218

Figure 5.77 Longitudinal Profile for Intermediate Condition, ARI 100 and Duration 60 minutes……..……..……...……219

Figure 5.78 Longitudinal Profile for Intermediate Condition, ARI 100 and Duration 120 minutes……..……..……..…….219

Figure 5.79 Longitudinal Profile for Intermediate Condition, ARI 100 and Duration 180 minutes ……...…….……..……219

Figure 5.80 Longitudinal Profile for Intermediate Condition, ARI 100 and Duration 360 minutes……..……....……220

Figure 5.81 Longitudinal Profile for Ultimate Condition, ARI 20 and Duration 60 minutes……..……..……...220

Figure 5.82 Longitudinal Profile for Ultimate Condition, ARI 20 and Duration 120 minutes……...……..…220

Figure 5.83 Longitudinal Profile for Ultimate Condition, ARI 20 and Duration 180 minutes……..……...….221

Figure 5.84 Longitudinal Profile for Ultimate Condition, ARI 20 and Duration 360 minutes……..……..……..…….221

Figure 5.85 Longitudinal Profile for Ultimate Condition, ARI 50 and Duration 60 minutes……..……..……..221

Figure 5.86 Longitudinal Profile for Ultimate Condition, ARI 50 and Duration 120 minutes……..……..……...222

Figure 5.87 Longitudinal Profile for Ultimate Condition, ARI 50, Duration 180 minutes……..……..……...…222

Figure 5.88 Longitudinal Profile for Ultimate Condition, ARI 50, Duration 360 minutes……..……..……..…….222

Figure 5.89 Longitudinal Profile for Ultimate Condition, ARI 100, Duration 60 minutes……...…...……....……..…….223

Figure 5.90 Longitudinal Profile for Ultimate Condition, ARI 100, Duration 120 minutes……..…...…….……..223

Figure 5.91 Longitudinal Profile for Ultimate Condition, ARI 100, Duration 180 minutes……..…...……...……223

Figure 5.92 Longitudinal Profile for Ultimate Condition, ARI 100, Duration 360 minutes……..……....…….……..224

Figure 5.93 Q- and H-points for Sungai Kayu Ara River from 2408m to 3254m in ArcviewGIS……...…..……..…….227

Figure 5.94 Flood Extent and Water Depth Distribution Generated by MIKE11 for Events with 20 years ARI in Existing Development Condition in Sungai Kayu Ara River Basin…….……..…….....……...…….228

Figure 5.95 Flood Extent and Water Depth Distribution Generated by MIKE11 for Events with 50 years ARI in Existing Development Condition in Sungai Kayu Ara River Basin…….……..……...…..229

Figure 5.96 Flood Extent and Water Depth Distribution Generated by MIKE11 for Events with 100 years ARI in Existing Development Condition in Sungai Kayu Ara River Basin……...……..……...……..230

Figure 5.97 Flood Extent and Water Depth Distribution Generated by MIKE11 for Events with 20 years ARI in Intermediate Development Condition in Sungai Kayu Ara River Basin……...……..….…....231

Figure 5.98 Flood Extent and Water Depth Distribution Generated by MIKE11 for Events with 50 years ARI in Intermediate Development Condition in Sungai Kayu Ara River Basin……..…….…..232

Figure 5.99 Flood Extent and Water Depth Distribution Generated by MIKE11 for Events with 100 years ARI in Intermediate Development Condition in Sungai Kayu Ara River Basin……...……..233

Figure 5.100 Flood Extent and Water Depth Distribution Generated by MIKE11 for Events with 20 years ARI in Ultimate Development Condition in Sungai Kayu Ara River Basin……...…….……..…..234

Figure 5.101 Flood Extent and Water Depth Distribution Generated by MIKE11 for Events with 50 years ARI in Ultimate Development Condition in Sungai Kayu Ara River Basin……...……..……...….235

Figure 5.102 Flood Extent and Water Depth Distribution Generated by MIKE11 for Events with 100 years ARI in Ultimate Development Condition in Sungai Kayu Ara River Basin……...……..……...…236

Figure 5.103 Correlation between Observed and Simulated Water Level during Calibration of HEC-RAS4.0 for Kayu Ara River……..……....242

Figure 5.104 Correlation between Observed and Simulated Water Level during Calibration of MIKE11 for Kayu Ara River…….…….…....242

Figure 5.105 Correlation between Observed and Simulated Water Level during Validation of HEC-RAS4.0 for Kayu Ara River……..……..…244

Figure 5.106 Correlation between Observed and Simulated Water Level during Validation of MIKE11 for Kayu Ara River…….....…..244

Figure 5.107 Simulation Results of HEC-RAS4.0 and MIKE11 for Existing Development Conditions ……..…...……...…….246

Figure 5.108 Simulation Results of HEC-RAS4.0 and MIKE11 for Intermediate Development Conditions…….…….…..……...……..247

Figure 5.109 Simulation Results of HEC-RAS4.0 and MIKE11 for Ultimate Development Conditions…….……..…….248

Figure 5.110 Correlation between HEC-RAS4.0 and MIKE11 Simulated Water Levels for the 36 Scenarios in Kayu Ara River Basin……..……..…250

Figure 5.111 MIKE 11 GIS Outputs Flood Maps and Topographical Data……..…...252

Figure 5.112 Process Flow Diagram for Using HEC-GeoRAS…….…...…..254

Figure 5.113 Flood Extends Boundaries in HEC-RAS4.0 and MIKE11 in Ultimate Development Condition, ARI100 for Duration 60 minute in Kayu Ara ……...255

Figure 5.114 Flood Extends Boundaries in HEC-RAS4.0 and MIKE11 in Ultimate Development Condition, ARI100 for Duration 60 minute in Kayu Ara ……...255

Figure 5.115 Flood Extends Boundaries in HEC-RAS4.0 and MIKE11 in Ultimate Development Condition, ARI100 for Duration 60 minute in Kayu Ara ……...256

Figure 5.116 Flood Extends Boundaries in HEC-RAS4.0 and MIKE11 in Ultimate Development Condition, ARI100 for Duration 60 minute in Kayu Ara ……...256

Figure 5.117 Inundated Area Estimated by HEC-RAS4.0 and MIKE11 for Design Rainfall with 60 minute Duration in Kayu Ara …..……...258

Figure 5.118 Comparison of Chainage and River Station Network Referencing in HEC-RAS4.0 and MIKE11…….…….……..262

Figure 5.119 Grid-Based Terrain Model Created in MIKE11GIS…….....263

Figure 5.120 TIN-based Terrain Model Created in HEC-GeoRAS……...……263

Figure 6.1 Flowchart of River Flood Hazard Mapping…….……..……...268

Figure 6.2 River Flood Hazard Map (Depth) for Design Rainfall Event with 20 years ARI in Existing Development Condition in Sungai Kayu Ara …….....……...……270

Figure 6.3 River Flood Hazard Map (Depth) for Design Rainfall Event with 50 years ARI in Existing Development Condition in Sungai Kayu Ara .....……..…….270

Figure 6.4 River Flood Hazard Map (Depth) for Design Rainfall Event with 100 years ARI in Existing Development Condition in Sungai Kayu Ara .....……..…..271

Figure 6.5 River Flood Hazard Map (Depth) for Design Rainfall Event with 20 years ARI in Intermediate Development Condition in Sungai Kayu Ara ...……...……271

Figure 6.6 River Flood Hazard Map (Depth) for Design Rainfall Event with 50 years ARI in Intermediate Development Condition in Sungai Kayu Ara ...……...…....272

Figure 6.7 River Flood Hazard Map (Depth) for Design Rainfall Event with 100 years ARI in Intermediate Development Condition in Sungai Kayu Ara .…….....272

Figure 6.8 River Flood Hazard Map (Depth) for Design Rainfall Event with 20 year ARI in Ultimate Development Condition in Sungai Kayu Ara .....…….273

Figure 6.9 River Flood Hazard Map (Depth) for Design Rainfall Event with 50 years ARI in Ultimate Development Condition in Sungai Kayu Ara .…….....…273

Figure 6.10 River Flood Hazard Map (Depth) for Design Rainfall Event with 100 years ARI in Ultimate Development Condition in Sungai Kayu Ara ....……..…...274

Figure 6.11 Results of River Flood Hazard Map Based on Water Depth in Sungai Kayu Ara ....…….……275

Figure 6.12 River Flood Hazard Map (Velocity) for Design Rainfall Event with 20 years ARI in Existing Development Condition in Sungai Kayu Ara .....…….……..…279

Figure 6.13 River Flood Hazard Map (Velocity) for Design Rainfall Event with 50 years ARI in Existing Development Condition in Sungai Kayu Ara .....……..……280

Figure 6.14 River Flood Hazard Map (Velocity) for Design Rainfall Event with 100 years ARI in Existing Development Condition in Sungai Kayu Ara .....……..……280

Figure 6.15 River Flood Hazard Map (Velocity) for Design Rainfall Event with 20 years ARI in Intermediate Development Condition in Sungai Kayu Ara ...……..….281

Figure 6.16 River Flood Hazard Map (Velocity) for Design Rainfall Event with 50 years ARI in Intermediate Development Condition in Sungai Kayu Ara ...…….…..….281

Figure 6.17 River Flood Hazard Map (Velocity) for Design Rainfall Event with 100 years ARI in Intermediate Development Condition in Sungai Kayu Ara .....……..….282

Figure 6.18 River Flood Hazard Map (Velocity) for Design Rainfall Event with 20 year ARI in Ultimate Development Condition in Sungai Kayu Ara ...…….....282

Figure 6.19 River Flood Hazard Map (Velocity) for Design Rainfall Event with 50 years ARI in Ultimate Development Condition in Sungai Kayu Ara ....…….....283

Figure 6.20 River Flood Hazard Map (Velocity) for Design Rainfall Event with 100 years ARI in Ultimate Development Condition in Sungai Kayu Ara 283

Figure 6.21 Results of River Flood Hazard Map Based on Flow Velocity in Sungai Kayu Ara 285

Figure 6.22 Formulas of the Lines between Low, Medium and High Hazard Categories.....288

Figure 6.23 Representation of Two Raster Layers.....290

Figure 6.24 Representation of Combination of Two Raster Layers.....291

Figure 6.25 River Flood Hazard Map for Design Rainfall Event with 20 year ARI in Existing Development Condition in Sungai Kayu Ara 293

Figure 6.26 River Flood Hazard Map for Design Rainfall Event with 50 year ARI in Existing Development Condition in Sungai Kayu Ara 294

Figure 6.27 River Flood Hazard Map for Design Rainfall Event with 100 year ARI in Existing Development Condition in Sungai Kayu Ara 295

Figure 6.28 River Flood Hazard Map for Design Rainfall Event with 20 year ARI in Intermediate Development Condition in Sungai Kayu Ara 296

Figure 6.29 River Flood Hazard Map for Design Rainfall Event with 50 year ARI in Intermediate Development Condition in Sungai Kayu Ara 297

Figure 6.30 River Flood Hazard Map for Design Rainfall Event with 100 year ARI in Intermediate Development Condition in Sungai Kayu Ara 298

Figure 6.31 River Flood Hazard Map for Design Rainfall Event with 20 year ARI in Ultimate Development Condition in Sungai Kayu Ara 299

Figure 6.32 River Flood Hazard Map for Design Rainfall Event with 50 year ARI in Ultimate Development Condition in Sungai Kayu Ara 300

Figure 6.33 River Flood Hazard Map for Design Rainfall Event with 100 year ARI in Ultimate Development Condition in Sungai Kayu Ara 301

Figure 6.34 Extent of the River Flood Hazard Categories for Existing Development Condition Scenario in Sungai Kayu Ara 303

Figure 6.35 Extent of the River Flood Hazard Categories for Intermediate Development Condition Scenario in Sungai Kayu Ara 303

Figure 6.36 Extent of the River Flood Hazard Categories for Ultimate Development Condition Scenario in Sungai Kayu Ara 303

Figure 6.37 River Flood Risk Definition (APFM, 2006)……..…..……307

Figure 6.38 Diagram of the River Flood Risk Procedure…….....……..……308

Figure 6.39 Classified Land-use Map for Sungai Kayu Ara……...……...……310

Figure 6.40 Risk Value for Main Road Accessibility……...….....….312

Figure 6.41 Risk Value of Debris Flow in Sungai Kayu Ara…….…..……..……314

Figure 6.42 Method of Combination of Maps for River Flood Risk Map…….…..…...317

Figure 6.43 River Flood Risk Map for Design Rainfall Event with 20 year ARI in Existing Development Condition in Sungai Kayu Ara .....……318

Figure 6.44 River Flood Risk Map for Design Rainfall Event with 50 year ARI in Existing Development Condition in Sungai Kayu Ara .....……319

Figure 6.45 River Flood Risk Map for Design Rainfall Event with 100 year ARI in Existing Development Condition in Sungai Kayu Ara .……....320

Figure 6.46 River Flood Risk Map for Design Rainfall Event with 20 year ARI in Intermediate Development Condition in Sungai Kayu Ara .....……..….321

Figure 6.47 River Flood Risk Map for Design Rainfall Event with 50 year ARI in Intermediate Development Condition in Sungai Kayu Ara .....……..……..…322

Figure 6.48 River Flood Risk Map for Design Rainfall Event with 100 year ARI in Intermediate Development Condition in Sungai Kayu Ara .....……..……..…323

Figure 6.49 River Flood Risk Map for Design Rainfall Event with 20 year ARI in Ultimate Development Condition in Sungai Kayu Ara .…….……...324

Figure 6.50 River Flood Risk Map for Design Rainfall Event with 50 year ARI in Ultimate Development Condition in Sungai Kayu Ara …….…….…...325

Figure 6.51 River Flood Risk Map for Design Rainfall Event with 100 year ARI in Ultimate Development Condition in Sungai Kayu Ara …….…….……...326

Figure 6.52 Area of River Flood Risk in Each Scenario for Sungai Kayu Ara 327

LIST OF SYMBOLS

${}^{R}I_t$	Average rainfall intensity (mm/hr) for ARI R and duration t
R	Average recurrent interval (years)
HR	River Flood Hazard Rating
V	Velocity (m/s)
D	Depth (m)
DF	Debris factor
f_t	Loss during period t
K	Saturated hydraulic conductivity
S_f	Wetting front suction
F_t	Cumulative loss at time t
t_r	Rainfall duration
t_p	River basin lag-time
A	Watershed drainage area
C_p	UH peaking coefficient
C	Conversion constant
Cp	Peak flow coefficient,
Q_0	Initial base-flow (at time zero)
K	an exponential decay constant
S_f	Energy gradient
S_0	Bottom slope
V	Velocity
y	Hydraulic depth
x	Distance along the flow path
t	Time (Duration)

g	Acceleration due to gravity
Q	Flow discharge
R	Hydraulic radius
A	Cross-sectional area
B	Water surface width
q	Lateral inflow per unit length of channel
F	Goodness-of-fit
q_i	Observed value i
r_i	Concurrent simulated value i
n	Number of data pairs
Y	Depth of water at the cross section
Z	Elevation of the main channel inverts
V,	Average velocities, respectively
h_e	Energy head loss
L_{lob}	Cross section reach length specified for flow in the left overbank
L_{ch}	Cross section reach length specified for flow in the main channel
L_{rob}	Cross section reach length specified for flow in the right overbank

LIST OF PUBLICATION BASED ON THIS THESIS

1. **Sina Alaghmand**, Rozi bin Abdullah and Ismail Abustan. "Assessment of Effect of Rianfall Event Duration on River Basin Hydrological Response (A Case Study on Sungai Kayu Ara River Basin, Malaysia)". March 2009, Kuala Lumpur, Malaysia. The 1st Regional Conference on Geo-Disaster Mitigation and Waste Management. (Paper Accepted).

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4. **Sina Alaghmand** and Rozi bin Abdullah. "Effect of Development Condition on River Basin Response (A Case Study on Kayu Ara River Basin, Malaysia)", December 2008, Johor Bahru, Malaysia, International Graduate Conference on Engineering and Conference (IGCES08).

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6. **Sina Alaghmand** and Rozi bin Abdullah. "Assessment of Effect of Average Recurrence Interval (ARI) of Rainfall Events on River Basin Response (A Case Study on Kayu Ara River Basin, Malaysia)", November 2008, Sarawak, Malaysia, Curtin University of Technology Science and Engineering International Conference (CUTSE 2008).

7. **Sina Alaghmand**, Rozi bin Abdullah, Ismail Abustan and Mohammadi, A. "A Literature Review of Applications of Geography Information System (GIS) in River Hydraulic Modelling", June 2008, Kuala Lumpur, Malaysia, International Conference on Construction and Building Technology (ICCBT08).

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10. **Sina Alaghmand** and Mohammadi, A. "Available Issues from Hydraulic Computer Models for Preparation of River Flood Hazard Map (A case study on Sungai Kayu Ara River Basin, Malaysia) ", April 2008, Austria, European Geosciences Union (EGU).

PERMODELAN SUNGAI UNTUK RAMALAN PETA RISIKO BANJIR: KAJIAN KES SUNGAI KAYU ARA

ABSTRAK

Penyelidikan ini memberikan tumpuan terhadap kepentingan kebanjiran sungai di kawasan bandar yang menyebabkan kehilangan nyawa dan kerosakan harta benda. Pengetahuan tindak balas tadahan sungai terhadap kejadian hujan yang menghasilkan airlarian ribut adalah kritikal di dalam praktis kejuruteraan untuk perancangan dan pembangunan di kawasan bandar. Pemetaan bahaya kebanjiran sungai merupakan gandingan permodelan hidrologik, permodelan hidraulik dan paparan melalui GIS. Sungai Kayu Ara yang terletak di Damansara dijadikan kajian kes di dalam penyelidikan ini. Kesan magnitud hujan (20 tahun, 50 tahun dan 100 tahun ARI) dan tempoh (60, 120, 180 dan 360 minit) untuk keadaan pembagunan sedia ada, pertengahan dan puncak dinilai menggunakan 36 senario yang telah dikenal pasti. Keputusan dari simulasi model hidrologik menunjukan peningkatan magnitud hujan bolih menghasilkan pertambahan isipadu dan puncak kadaralir airlarian ribut, manakala peningkatan tempoh peristiwa hujan menyebabkan pertambahan isipadu airlarian ribut tetapi penurunan puncak kadaralir. Isipadu dan puncak kadaralir yang tinggi dihasilkan oleh keadaan pembangunan puncak (90% kawasan tidak telap air) jika dibandingkan dengan keadaan pembangunan sedia ada dan pertengahan. Penjanaan peta bahaya kebanjiran sungai adalah berdasarkan pada kedalaman air, halaju aliran, dan gandingan kedalaman air dan halaju aliran. Peta tersebut menunjukan impak kedalaman air adalah lebih tinggi jika dibandingkan dengan halaju aliran semasa kejadian kebanjiran sungai. Sehubungan dengan itu, bahaya yang disebabkan oleh kedalaman air adalah lebih signifikan dari halaju aliran. Peta bahaya kebanjiran merupakan asas untuk ramalan risiko kebanjiran.

Peta risiko kebanjiran merupakan fungsi kepada bahaya kebanjiran sungai, kebolehtahan dan pendedahan. Di dalam kes ini, jenis guna tanah, akses laluan jalan dan aliran debris digunakan untuk mewakili elemen kebolehtahan dan pendedahan di dalam ramalan risiko peta banjir. Kesemua empat elemen tersebut dibangunkan melalui GIS sebagai lapisan raster di mana setiap pixel memberikan nilai untuk setiap elemen. Penjanaan peta risiko banjir adalah hasil gandingan empat element, bahaya kebanjiran sungai, jenis guna tanah, akses laluan jalan utama dan aliran debris. Kaedah yang dicadangkan untuk ramalan peta risiko kebanjiran sungai mengesyorkan empat kelas tahap kebanjiran sungai iaitu, rendah, sederhana, tinggi dan ekstrim. Peta risiko kebanjiran sungai yang telah dibangunkan menunjukan bahaya kebanjiran sungai, bahaya aliran debris, jenis guna tanah dan akses laluan jalan utama mempunyai impak yang signifikan dan berupaya membantu di dalam perancangan dan pengurusan kebanjiran sungai di kawasan bandar. Perubahan dan corak yang ditunjukan oleh peta ramalan risiko kebanjiran sungai merupakan fungsi terhadap bahaya kebanjiran sungai dan bahaya aliran debris; dimana taburan bahaya yang ditunjukan oleh jenis guna tanah dan akses laluan jalan utama adalah seragam.

RIVER MODELLING FOR FLOOD RISK MAP PREDICTION: CASE STUDY OF SUNGAI KAYU ARA

ABSTRACT

The research illustrates an importance of river flood in urban areas which cause lost of lives and properties damages. Knowledge on the river basin response to rainfall events of runoff is vital in engineering practices for urban planning and development. Flood hazard map prediction is a combination of hydrological modelling, hydraulic modelling and river flood visualization using GIS. The case study of this research is Sungai Kayu Ara located in Damansara, Kuala Lumpur. A total of 36 scenarios are identified in order to assess the effects of rainfall magnitude (20 year, 50 year and 100 year ARI) and duration (60, 120, 180 and 360 minutes) for existing, intermediate and ultimate development conditions. The results of hydrological model simulation indicated that, an increase in the rainfall magnitude leads to increase of runoff volume and peak discharge while increase of rainfall event duration increases the runoff volume but decreases the runoff peak discharge. Furthermore, an ultimate river basin development conditions (90% imperviousness) generate higher runoff volume and peak discharge in comparison with existing and intermediate development conditions. The river flood hazard maps are generated based on water depth, flow velocity and combination of water depth and flow velocity. These maps showed that the impact of water depth is more considerable than flow velocity during river flood. Hence, hazard attributed to water depth is more significant in comparison with flow velocity. River flood hazard maps are the base of the river flood risk prediction. River flood risk maps are considered as the function of river flood hazard, vulnerability and exposure. In this case, land-use type, main road accessibility and debris flow are involved to reflect the terms

vulnerability and exposure in river flood risk map prediction. These four elements are provided as GIS raster layers in which all pixels indicate the severity value of each element. The generated river flood risk map is the result of combination of four main elements, river flood hazard, land-use type, main road accessibility and debris flow. The suggested method for river flood risk map prediction recommends four classes of severity for river flood consists of, low, medium, high and extreme. The established flood risk prediction map has shown that the river flood hazard, debris flow hazard, land-use type and main road accessibility have significant impact and able to facilitate the planning and management of river flooding in urban areas. The variation of predicted river flood risk pattern is a function of river flood hazard and debris flow hazard patterns; as the distribution of hazards produced by land-use type and main road accessibility is uniform.

CHAPTER 1
INTRODUCTION

1.1 Background and Motivation

In recent years there have been a number of significant riverine floods in the rest of the world, which resulted in tragic loss of life and in enormous material damage (Figures 1.1 and 1.2). In the past decades, thousands of lives have been lost, directly or indirectly, by flooding. In fact, of all natural risks, floods pose the most widely distributed natural risk to life today. River flood risk management is the process under which different bodies try to reduce the current and the future vulnerability of human society to natural risks. Flood risk management measures can be structural where the risk is modified for example dam and reservoir construction, channel improvements, by-pass channels and artificial levees. Non-structural where the flood damage and disruption is modified for example setting up flood plain management regulations such as zoning, building codes and measures where both the methods are applied. It is clear that no protection work can offer a hundred percent security against floods. There is always the possibility that a threshold is surpassed and that floodwater will enter into areas where it should not go, e.g. by overtopping or breaching of dikes.

Figure 1.1 Flood in Jalan Sultan Ismail, Kuala Lumpur, June 2007

Figure 1.2 Flood Damage in Golestan National Park, Iran, August 2001

Starting in the year 2000s, extreme rainfall events with high intensity are not longer a new issue in Malaysian urban cities, especially in the West Coast area (Figures 1.3 and 1.4). This phenomenon is formed mostly through convection process (Embi et. al., 2004). The main motivation of this research is an importance of river flood events in urban areas which cause in large number lost of lives and properties damages. Knowledge on the river basin response to rainfall events which is in the form of runoff is vital in engineering practices for urban planning and management. River flood modelling is a combination of hydrological modelling, hydraulic modelling and river flood visualization using GIS.

Flooding is one of the major natural hazards affecting communities across Malaysia and has caused damages worth millions of dollars every year. The required allocation for flood mitigation projects has increased almost 600% (RM 6000 million) for the 8th Malaysian Plan compared to RM 1000 million during the 7th Malaysian Plan (Abdullah, 2000).

Figure 1.3 Flood in Kuala Lumpur, Malaysia, March 2009

Floods are recurring phenomena, which form a necessary and enduring feature of all river basin and lowland coastal system. Major floods are the largest cause of economic losses from natural disasters mainly in more developed countries. And they are also a major cause of disaster-related deaths, mainly in the less developed countries. Despite recent adventures in the understanding of the relevant climatologically, fluvial and marine mechanisms, and a greater investment in flood reduction measures, floods take a larger number of lives and damage more properties each year, mainly, because of unwise land management practices and growing human vulnerability (Smith and Ward, 1998).

Knowing the fact that the floods are part of human being life and that this natural phenomena can’t be fully controlled, it’s important to focus and improve knowledge about the prevention. In order to achieve this issue it is crucial that, more specific and scientific work must be developed to a better understanding of the flooding phenomena

and their related geographical, hydrological and geomorphologic causes. Vaz (2000) and Jaarsma et. al. (2001) emphasized, respectively, the need to define a strategy that includes a judicious combination of structural and none structural measures, based on a careful analysis of the past floods and improvements in floods forecasting.

The main objectives of flood mapping can be sorted as follows: to prevent loss of life, to minimize property damage, to minimize social disruption and to encourage coordinated approach for land/water use. The role of flood mapping in river engineering is an important feature in planning and management: basis for managing flood plains, engineering & planning tool, first step in flood plain management, part of legislation for regulating development and basis for pursuing structural and non-structural measures.

Figure 1.4 Flood in Kuala Lumpur, Malaysia, January 2008

1.2 Objectives

This research involves the integration of three models:

1. The HEC Hydrologic Modelling System (HEC-HMS3.1) as a hydrologic model to simulate rainfall-runoff process.

2. The HEC River Analysis System (HEC-RAS4.0) as a hydraulic model to route the runoff through stream channels to determine water surface profiles at specific locations along the stream network.

3. MIKE11 as a hydraulic model to develop a model for floodplain determination and representation.

Furthermore, Geography Information System (GIS) is widely used as a powerful tool toward reaching to the study objectives. For instance, in order to link the HEC-HMS, HEC-RAS and MIKE11 to GIS environment, HEC-GeoHMS, HEC-GeoRAS and MIKE11GIS are applied. The objectives of this research have been set as follows:

i. To develop rainfall-runoff modelling using HEC-GeoHMS and HEC-HMS3.1 as hydrological model for Sungai Kayu Ara river basin.

ii. To develop hydraulic modelling applying MIKE11GIS, MIKE11, HEC-GeoRAS and HEC-RAS4.0 based on the results of HEC-HMS 3.1 for Sungai Kayu Ara river basin.

iii. To compare two hydraulic models, MIKE11 and HEC-RAS4.0, in terms associated with river flood risk mapping.

iv. To establish river flood hazard mapping in Sungai Kayu Ara river basin.

v. To predict river flood risk map in Sungai Kayu Ara river basin.

Note that, hydrological modelling, hydraulic modelling, river flood mapping and river flood risk mapping will be conducted for the 20 years, 50 years and 100 years ARI flood events in existing, intermediate and ultimate river basin development conditions using rainfall events with four different durations (60 minutes, 120 minutes, 180 minutes and 360 minutes). Table 1.1 indicates the thirty six study scenarios for Sungai Kayu Ara river basin.

Table 1.1 Study Scenarios

	Design Rainfall		
Development Conditions	20 year ARI	50 year ARI	100 year ARI
Existing	60, 120, 180 and 360 minutes	60, 120, 180 and 360 minutes	60, 120, 180 and 360 minutes
Intermediate	60, 120, 180 and 360 minutes	60, 120, 180 and 360 minutes	60, 120, 180 and 360 minutes
Ultimate	60, 120, 180 and 360 minutes	60, 120, 180 and 360 minutes	60, 120, 180 and 360 minutes

1.3 Structure of the Thesis

This thesis is divided into seven chapters. Chapter 1 includes a brief introduction, problem statement and objectives of the research. The methods for river flood risk mapping and analysis and related theories are reviewed in Chapter 2. The case study of this research will be described in Chapter 3. This chapter also gives a general methodology of the research. The detailed description of hydrological and hydraulic

models is presented in Chapters 4 and 5. Chapters 4 and 5 discuss on the introduction, methodology and development of HEC-HMS3.1 hydrologic model and HEC-RAS4.0 and MIKE11 hydraulic models for Sungai Kayu Ara river basin, respectively. Chapter 6 discusses and illustrates the generated river flood hazard mapping and river flood risk mapping for Sungai Kayu Ara river basin. Finally, chapter 7 presents the findings of the research, problems, a brief research outlook for the future and conclusions.

CHAPTER 2
LITERATURE REVIEW

2.1 River Flood

Water is a basic requirement for sustaining life and development of society. Proper management, protection and development of the water resources are challenges imposed by population growth, increasing pressure on the water and land resources by competing usage, and degradation of scarce water resources in many parts of the world.

River flood is defined as a high flow that exceeds or over-tops the capacity either the natural or the artificial banks of a stream (Hoyt and Langbein, 1958; Walesh, 1989; Knight and Shiono, 1996; Omen, et. al. 1997; Smith and Ward, 1998). Flooding results from excessive rain on the land, streams overflowing channels or unusual high tides or waves in coastal areas. Some of the most important factors that determine the features of floods are rainfall event characteristics, depth of the flood, the velocity of the flow, and duration of the rainfall event (Smith, 1996). Most floods are caused by intense precipitation combined with other factors such as: snow melt, inadequate drainage, water-saturated ground or unusually high tides or waves. As mentioned in Figure 2.1, floods are the most damaging phenomena that effect to the social and economic of the population (Smith and Ward, 1998). There are many different types of flooding. The most common types are: river floods, flash floods, coastal floods, urban floods and ice jams.

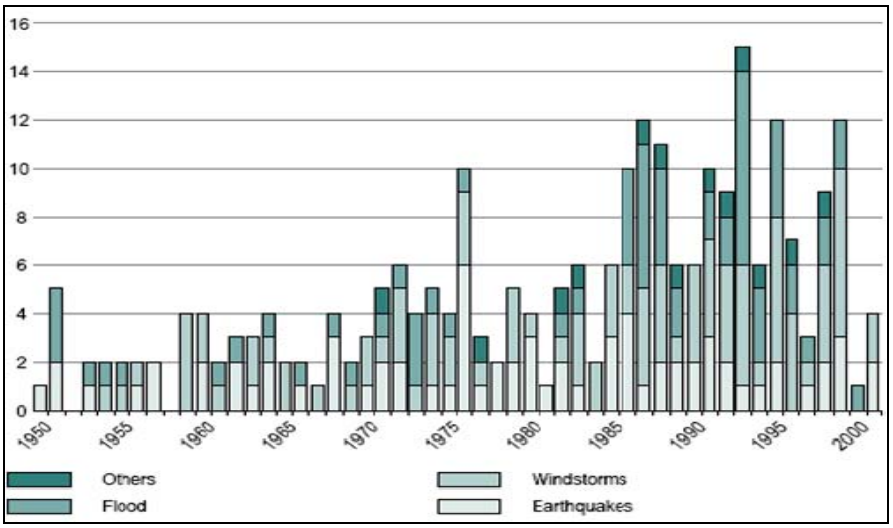

Figure 2.1 Number of Great Natural Catastrophes from 1950 to 2001 (Munich, 2002)

Every year, floods claim many lives and adversely affect around 75 million of people worldwide (Figures 2.2 and 2.3). The reason lies in the widespread geographical distribution of river floodplains and low-lying coasts, together with their long-standing attractions for human settlement (Ologunorisa and Abawua, 2005). Many factors cause floods. In general, the reasons for increasing flooding in many parts of the world are climatologically, changes in land-use and increasing population and land subsidence (Smith and Ward, 1998). Problems related to flooding and vulnerability of the population have greatly increased in recent decades due to several factors including changes in land-use in the hinterlands, urbanization of flood-prone sites, squatter settlements and sub-standard constructions, and increased household density (Munich, 2002; Pelling, 2003).

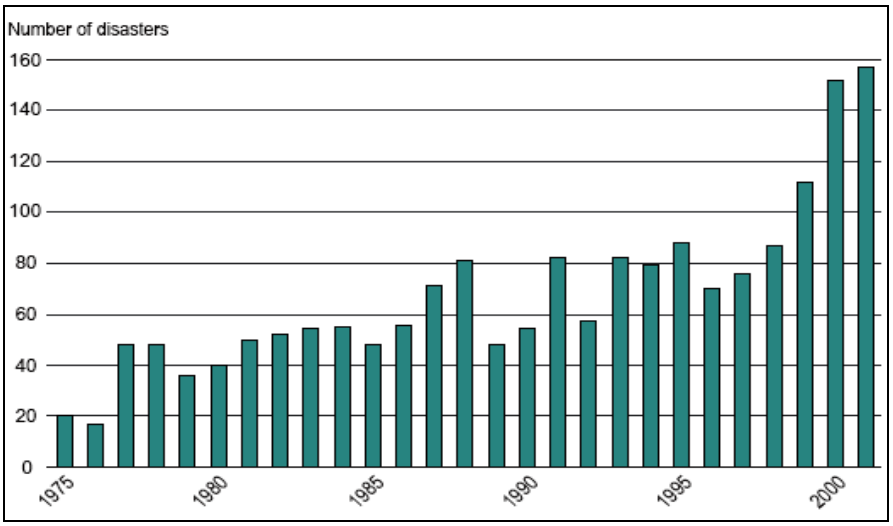

Figure 2.2 Number of Disasters Attributed to Floods from 1975 to 2001 (Source: EM-DAT, CRED, University of Louvain, Belgium)

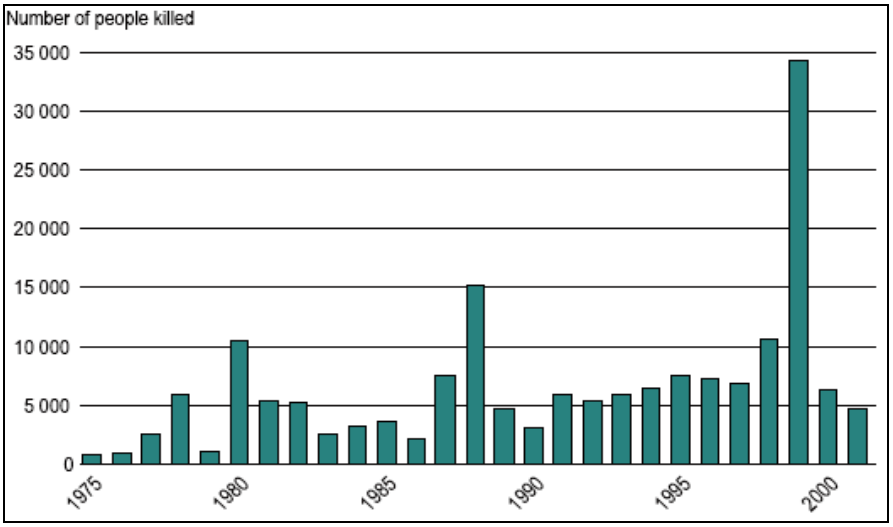

Figure 2.3 Number of People Killed in Floods from 1975 to 2001 (Source: EM-DAT, CRED, University of Louvain, Belgium)

There is a relationship between urbanization and hydrological characteristics, such as decrease of infiltration, increase of overland flow, increase in frequency and height of flood peak, increase in range of discharge (variability) and decrease lag time. The dangers of floodwaters are associated with a number of different characteristics of

the flood such as depth of water, duration, velocity, sediment load, rate of rise and frequency of occurrence (Kingma, 2002).

Floods result from a combination of meteorological and hydrological extremes as indicated in the Table 2.1. In most cases, floods are additionally influenced by human factors. Although these influences are very diverse, they generally tend to aggravate flood hazards by accentuating river flood peaks. Thus river flood hazards in built environments have to be seen as the consequence of natural and man-made factors. The factors contributing to river flood can be categorized into three classes; meteorological factors, hydrological factors and human factors. Table 2.1 shows the factors contributing to river flood.

2.2 Risk and Hazard

Risk is widely recognized as precisely what it implies as a possibility and often referred in term of probability (ACS, 1998). Risk also can be defined as the probability of harmful consequences or expected loss (of lives, people injured, property, livelihoods, economic activity disrupted or environment damaged) resulting from interactions between natural or human-induced hazards and vulnerable conditions. Risk is an integral part of life. It is impossible to live in a risk-free environment. Risk is sometimes taken as synonymous with hazard but risk has additional implication of the chance and probability a particular hazard actually occurring (Omen et al., 1997).

Table 2.1 Factors Contributing to River Flood

Meteorological Factors	Hydrological factors	Human factors
▪ Rainfall ▪ Cyclonic storms ▪ Small-scale storms ▪ Temperature ▪ Snowfall and snowmelt	▪ Soil moisture level ▪ Groundwater level prior to storm ▪ Natural surface infiltration rate ▪ Presence of impervious cover ▪ Channel cross-sectional shape and roughness ▪ Presence or absence of over bank flow, channel network ▪ Synchronization of run-offs from various parts of watershed ▪ High tide impeding drainage	▪ surface sealing due to urbanization, deforestation) increase run-off and may be sedimentation ▪ Occupation of the flood plain obstructing flows ▪ Inefficiency or non-maintenance of infrastructure ▪ Too efficient drainage of upstream areas increases flood peaks ▪ Climate change affects magnitude and frequency of precipitations and floods ▪ Urban microclimate may enforce precipitation events

Hazard is defined as threatening event, or the probability of occurrence of a potentially damaging phenomenon within a given time period and area, while risk is expected losses (of lives, persons injured, property damaged, and economic activity disrupted) due to a particular hazard for a given area and reference period. In other words, risk is the actual exposure of something of human value to hazard and often regarded as the combination of probability and loss (Chow, 1958). Hazard refers to the probability of a potentially dangerous phenomenon occurring in a given location within

a specified period of time (Alexander, 1993). Risk does not exist if exposure to a harmful situation does not or will not occur (Omen et al., 1997). Thus, it can be defined that hazard (or cause) as a potential threat to humans and their welfare and risk (or consequence) as the probability of the specific hazard occurrence (Smith, 1996; Sinnakaudan et al., 2003).

Hazards include geophysical events, hydro-meteorological phenomena, and technological circumstances that relate to accidents or failures in industrial, military and energy generation activities. While some hazards can be considered to be exclusively natural in origin, the spatial and temporal patterns of hazard occurrence are increasingly correlated with patterns of human behaviour and relationship with their natural environment. Human practices such as the alteration of natural drainage, the creation of landfills, or the destruction of the natural environments and increased groundwater extraction may radically alter the pattern of the hazard behaviour (Otieno, 2004). Results of human habitation such as unplanned rapid urban development, uncontrolled logging of natural forests or major changes in land-use can influence the spatial and temporal pattern of the hazards. In this research, river flood is considered as a natural hazard and river flood mapping is conducted for river flood risk map prediction.

2.3 River Flood Modelling

River flood extent mapping is the process of determining inundation extents and depth by comparing river water levels with ground surface elevation. The process requires the understanding of flow dynamics over the flood plain, topographic

relationships and the sound judgments of the modeller (Noman et al., 2001; Sinnakaudan et al., 2003). Flood hazard maps produced may include water depth, flood extent, flow velocity and flood duration. This is a basic and important indicator for the flood plain land use development planning and regulations (Walesh, 1989).

Flood hazard mapping was first initiated in 1988 in the United States by the Hydrologic Engineering Centre (HEC) of the U.S. Army Corps of Engineers (Smith, 1996; Feldman & Owen. 1997). The purpose of the study is mainly to produce flood hazard maps for the National Insurance Program (NFIP) due to the reluctance of private insurance industry in providing insurance policies as a result of catastrophic losses (Smith, 1996).

Flood mapping uses a map to predict the probable extent of flooding; flood hazard maps can be based on known, recorded, or prehistoric events. Floodplain Mapping Process (FMP) includes gathering required data, hydrologic analysis, hydraulic analysis and floodplain mapping using output data sets and base maps. Figures 2.4 and 2.5 show river flood hazard mapping in Germany and England, respectively.

Figure 2.4 Flood Hazard Mapping in Germany (Adapted from: http://flood-risk-assessment.com/insurance-solutions.html/ accessed on 22/11/2007, 10.40 a.m.)

The boundary of a hazard area may vary according to the frequency of the flooding event, such as the 10-year, the 100-year or the 500-year flood. River flood hazard mapping is an inherently complicated process, full of uncertainties due to complexities in the hydrological/hydraulic models used, the availability and quality of data, and the subjectivity of human judgment in the process (Jones et al., 1998). Some example of vital data required for flood hazard mapping are past and previous discharge records, channel hydraulic structure, flood plain geometry and roughness, historic flood stage or area of inundation (from ground photos, aerial photos/remote sensing data and scattered discrete ground observation). The results will be more credible if they have been calibrated and compared to the actual data (Walesh, 1989).

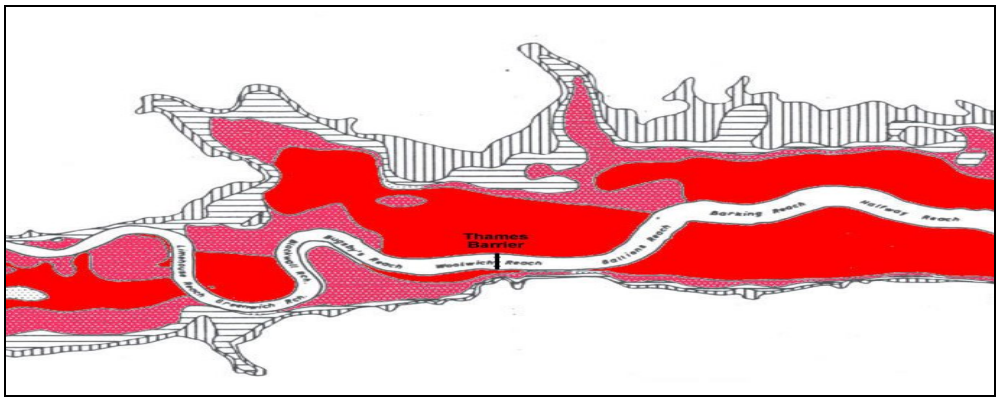

Figure 2.5 Flood Risk Map for Part of the London, England (Adopted from: http://www.floodlondon.com/floodlt.htm/ accessed on 22/11/2007, 10.40 a.m.)

The first step in flood risk analysis is to find out what are the problems. After this has been done, the risk management is implemented through flood protection measures. Once a potential risk has been identified, it is important to know its characteristics. The knowledge about the characteristics of the flood is the base of the flood risk

managements. The assessment of these characteristics requires historical data, but as a matter of fact, in most rivers sufficient observations are not available. Therefore, to determine these values recourse must be made to some sort of predictive model. The reliable prediction of the hydrodynamics of flooding events forms an indispensable basis to fulfil risk characteristics (Stelling et al, 1998).

There are four different strategies in regarding to the reduction of flood damages. The first approach, “Keep the flood away from people”, has an objective to reduce flood effect by implementing structural and non-structural measures such as constructing dams and bunds along river and applying river basin management programs. The second approach, “Keep the people away from flood “, has an objective avoiding the use of flood prone areas. The third approach, “Accept floods and clean up afterwards” is based on the acceptance of flooding conditions as natural phenomenon and continue live in the risky areas. The final approach is the combination of the three approaches, which could be implemented based on the site-specific requirements (Petry, 2002).

2.4 River Flood Mapping

All the existing methods for flood plain mapping can be grouped into the following three major categories (Smith & Ward, 1998) namely the analytical method, the historical method and the physiographic method. All these three methods share two common steps for flood plain mapping; determination of water surface profiles and transfer of water elevation from profiles to maps. Essentially these three methods use the same procedure to delineate flood plain boundaries by determining the flood elevation at

each river cross section. The boundaries are then interpolated between the cross section. The three methods differ only in their way of determining the water surface profile. The analytical method determines a T-years surface profile by obtaining solutions to the dynamic equation to a T-year flood. The historical method involves the adjustment of water surface profiles according to historic flood. This method requires detailed historical flooding information. Predicted flood hazard zones are largely based on mathematical or statistical theory and use the historical record of the past events to estimate the future probability or recurrence of similar events. The results are expressed in terms of average probability. There are no precise indications of when any particular event may occur (Smith, 1996). The physiographic method derives a T-year water surface profile by a depth-frequency relationship and uses projection of depth as elevations on a map (Sinnakaudan et al., 2003).

Historical and physiographic approaches which are similar to DID´s modified method, may be used to get the basic idea about the river flood hazard for planning purposes, but are inadequate for detailed design and floodplain mapping for insurance rating. However there is no evidence on the provision of flood insurance schemes in Malaysia although it is considered as a possible alternative or complementary components of the overall flood proofing designs (DID, 2000). Only the analytical approach can meet the requirement of the Urban Storm-water Management Manual for Malaysia (USMM), as specified in Volume 4, Chapter 11 which requires that any new development proposals should include base flood elevation (BFE) information (DID, 2000). These three methods are labour-intensive, involving the manual interpretation of aerial photos and contour maps and full of uncertainties during the entire mapping

process. Because of the high cost incurred, flood plain maps are very difficult to update using these traditional manual methods (Sinnakaudan et al., 2003).

2.5 Computer Models

Models are required where the characteristics and, accuracy of the boundary conditions and the input data determine the outcome of the computations. Such models show the effects of different boundary conditions or input data on the results. Hence in river flood modelling by looking at different inputs (hydrological data), the behaviour (hydraulic characteristics) of the river flood risk at given instances of a period of time can be determined and investigated. The computer model simulations lead into better decision making in the management of the risks and disasters.

Nowadays, scientists and engineers take advantages from computer modelling techniques in determining river flood modelling. Computer models for the determination of river flood generally consists of four parts (Snead, 2000), these are:

i. The hydrologic model which develops rainfall-runoff from a design rainfall or historic rainfall event.

ii. The hydraulic model which routes the runoff through stream channels to determine water surface profiles (including depth and velocity) at specific locations along the stream network.

iii. The extraction of geospatial data for use in the hydrological and hydraulic models

iv. A tool for floodplain mapping and visualization.

Combination of the hydraulic series data within a spatial interface, such as a Geographical Information System (GIS) and Remote Sensing (RS), are the key to graphical visualizations on the hydraulic modelling. The increasing availability of very high performance GIS software packages such as ArcviewGIS offers new opportunities for engineers to perform flood inundation analysis in conjunction with hydraulic models with interactive visualization within immerse decision support environments (Tate, 1999; Ab. Ghani et al., 1999; ESRI, 1992, 1996, 1997 & 2001; Sinnakaudan et al., 2003.). The GIS technology has the ability to capture, store, manipulate, analyze, and visualize the diverse sets of geo-referenced data (Burrough, 1986; Aronoff, 1989; Goodchild, 1993; Sinnakaudan, 1999). On the other hand, hydraulic is inherently spatial and hydraulic models have large spatially distributed data requirements (USFEMA, 1997; Graf, 1998; Jones et al., 1998; Noman et al., 2001; Horrit & Bates, 2002). The integration of hydraulic model and GIS is therefore quite natural. The GIS allows modulation and simulation of different scenarios and the graphic representation of the different alternatives.

Nowadays the integration between GIS software and hydrological modelling software has been developed for various purposes. One of them is HEC-GeoHMS, which is an ArcviewGIS extension specially designed to process geospatial data for use with the Hydrological Engineering Center- Hydrological Modelling System (HEC-HMS). The other one is MIKE11GIS which is the linking extension between ArcviewGIS and MIKE11 hydraulic model.

2.6 Integration of River Flood Hazard Modelling and GIS

Integrating the hydraulic model outputs into a GIS environment has improved flood analysis in recent years. Numerous modelling techniques have been studied in an attempt to find an optimum combination of various methods. In an attempt to link the model outputs to a spatial interface, Djokic et. al. (1994) developed an interface between the Hydrologic Engineer Centre's HEC-2 1-D, steady-state hydraulic model and the Arc/info spatial GIS. The interface, Known as ARC/HEC2, exports the terrain data from Arc/info into HEC-2. The ARC/HEC2 interface converts HEC-2 water surface elevations into GIS coverage in Arc/info.

In recent years, efforts have been made to integrate hydraulic models and GIS to facilitate the manipulation of the model output which led to the establishment of a new branch of hydraulics and hydrology, namely, hydro-informatics (Karimi & Houston, 1996; Yang et al., 2002). Hydro-informatics encompasses the use of advanced information technology procedures to improve the level of technology in predicting the governing processes of water science and engineering (Abbott, 1999). Traditional computational hydraulic tools which use the FORTRAN programming language running under the MS-DOS system can now be presented in more usable forms. The introduction of framework based system integrating the object-oriented methodologies in creating modelling tools using Windows Graphical User Interfaces (GUIs) may provide an understandable and highly visualized output for both the hydraulic experts and non-specialist users (Lam et al., 1996; Karimi & Houston, 1996; Pullar & Springer, 2000; Yang, et al., 2002; Huang & Jiang 2002). This concept has also alleviated the desired modularity and re-use of the existing modules in software developments (Ye et al., 1996;

Sinnakaudan et al., 1998; Tucker et al., 1999; Alfredsen & Sather, 2000; USACE, 2000; Sinnakaudan et al., 2001; Yang et al., 2002; USEPA, 2003).

A hydraulic model, like any other model, is intended to be a realistic representation of the physical processes over time in a river channel or flood plain and gives decision makers an indication of the outcome for different options (Pullar & Springer, 2000). The hydraulic model usually has the capacity to analyze, to predict and to solve engineering problems without taking into consideration the geographical prospective (McKinney & Cai, 2002). Under these circumstances, GIS becomes a valuable tool (Pullar & Springer, 2000; McKinney & Cai, 2002). Zerger (2002) notes that there are strong grounds for believing that GIS has an important function to play because natural hazards are multi-dimensional phenomena which has a spatial component.

Further more, for the past two decades many GIS integrated modelling applications have capitalized on using the GIS as a database manager and visualization tools (Westervelt & Shapiro, 2000; Karimi & Houston, 1996). Data requirements, search method, governing algorithms, flood inundation extent and depth are the main area where these procedures might need to be modified and differ from the manual flood hazard map delineation processes (Noman et al., 2001). These techniques depend on the spatial capabilities of GIS, produce consistent modelling inputs as well as continual quality control (before, during and after the modelling process) where the benefits are nearly impossible to be obtained using the spreadsheets or other non-graphic methods of data organization. Moreover, once data is available in the GIS, they can be extracted, combined with other data, reformatted as needed for various modelling processes and

even used to generate other inputs needed by the models (Robbins & Phipps, 1996). Figure 2.6 represents an application of GIS in flood mapping in United States.

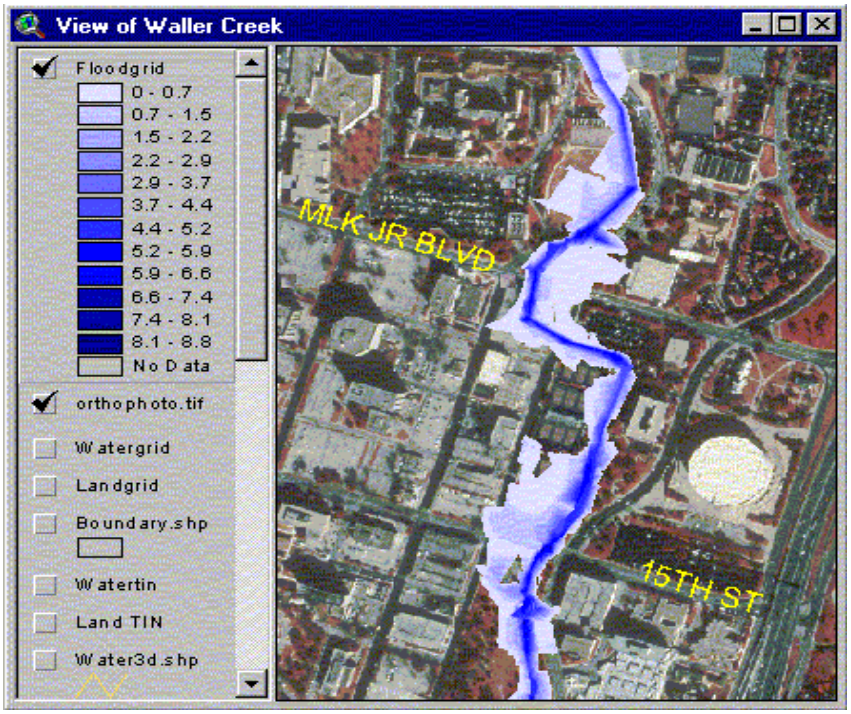

Figure 2.6 Application of GIS in Flood Mapping in United States

The incorporation of river basin models into GIS involves three major components: (1) spatial data construction; (2) integration of spatial model layers and; (3) GIS and model interface. The integration of GIS has improved matters by streamlining data input, assist in visualization, design, calibration, modification/comparison and providing better interpretation of model outputs. There are a number of methods to integrate GIS and analytical models which will be reviewed in the next section. The link between GIS and a tailor made hydraulic model should be close enough to allow automatic data transfer, but at the same time should be loose enough to let the user replace the hydraulic model with an alternative (Noman al et., 2001). Numerous

modelling techniques for integrating environmental models with GIS have been discussed and analyzed by many researchers to find an optimum combination of various methods (Burrough, 1986; Goodchild, 1993; Karimi & Houston, 1996; McDonnell, 1996; Abbott, 1999; Alfredsen & Sather, 2000; Huang & Jiang, 2002).

Evans (1998) developed a data exchange format to transfer physical element descriptions between hydrologic and hydraulic software packages and GIS software. The package studied was HEC-RAS, with the ability to import cross-section locations as XYZ coordinates from terrain models to develop channel and reach geometry. Upon completion of the hydraulic calculations, HEC-RAS exports the data back to a GIS for comparison with the terrain model. In 1998, ESRI translated and improved Evans' code and added some utilities to facilitate its use. The result was an ArcviewGIS extension called *AVRas*.

Tate (1999) further investigated how to improve upon the HEC-RAS model's accuracy by incorporating field surveyed, stream geometry and control structures into a GIS-based terrain model (Figure 2.7). The research led to the development of *Avenue* scripts for ArcviewGIS that integrate such data. The terrain model Tate used for his study was based on very accurate digital orthography. Andrysiak (2000) applied Tate's Avenue scripts to a larger study area using a digital elevation model (DEM) with 30-meter accuracy of the terrain model. When studying both cases, one can deduce that terrain model refinement is limited to the accuracy of the data. In addition, accuracy of the geo-referencing of the surveyed cross-sections and control structures is imperative in the development of an optimum terrain model.

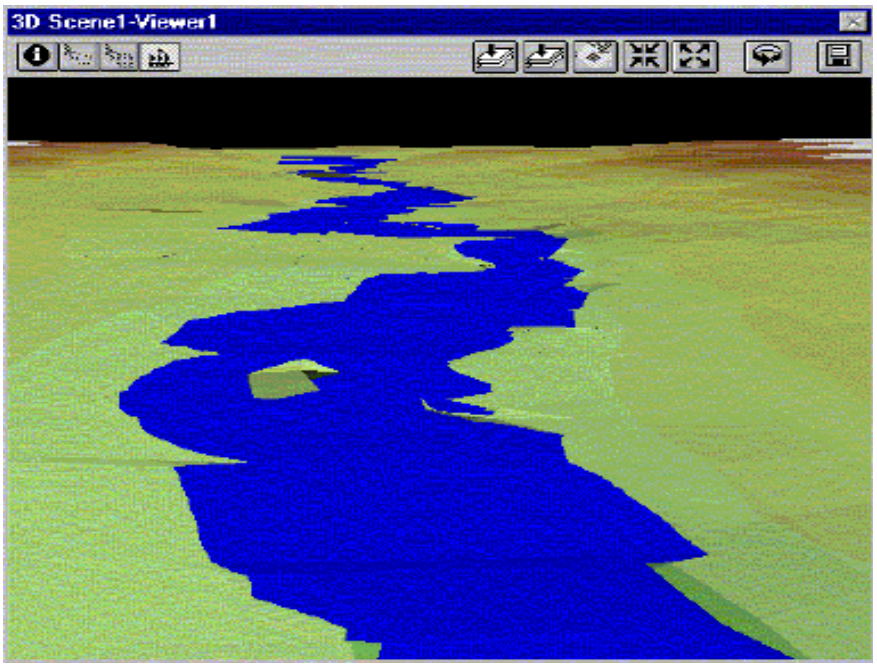

Figure 2.7 Channel geometry incorporated into a digital terrain model (Tate 1999)

Azagra-Camino (1999) focused on a smaller study area using more precise terrain data from the development of a Triangulated Irregular Network (TIN) in ArcviewGIS (Figure 2.8). The TIN was created from aerial photography, which resulted in a highly accurate terrain depiction of the study area. Using the AVRas extension, Azagra-Camino (1999) extracted topographic information from the TIN and imported it as channel and stream geometry for use in the HEC-RAS model. The flood visualization results provided highly accurate 2D and 3D flood maps. Azagra and Camino's method was limited to one output in time for each run from the steady state HEC-RAS model, making the process of developing flood animations tedious. The created animations required multiple runs of the HEC-RAS model and importing the data into the TIN. Additionally, Azagra-Camino (1999) extracted the cross-section data directly from the terrain model. Since the terrain data were based on aerial photography, the cross section