UNIVERSITI PUTRA MALAYSIA

CALIBRATION AND EVALUATION OF A FLOOD FORECASTING MODEL (MODIFIED TANK MODEL) FOR KELANTAN RIVER BASIN

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UPM

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By

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Thesis Submitted in Fulfilment of the Requirement for the Degree of Master of Science in the Faculty of Engineering Universiti Putra Malaysia

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Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

CALIBRATION AND EVALUATION OF A FLOOD FORECASTING MODEL (MODIFIED TANK MODEL) FOR KELANTAN RIVER BASIN

By

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Faculty: Engineering

A distributed lumped conceptual flood forecasting model, namely Modified Tank Model was calibrated in this study for the Kelantan River Basin (12056 km^2). Six hours rainfall and flood level data were collected from DID Data Bank and compiled as an input to Modified Tank Model. Autoregressive corrections were implemented to improve the simulated flood level at Guillemard Bridge (forecasting station). Statistical method and objective functions were applied to evaluate the simulation and forecasting capability of the Modified Tank Model.

Four years of flood data (1990, 1991, 1992 and 1994) were used to calibrate the Modified Tank Model and the performance of the model was verified by using 1998 data. A set of tank coefficients that suit tank configuration selected for Kelantan River Basin were determined by trial and error calibrations. Flood levels at Guillemard Bridge were simulated with actual measured catchment rainfall and the Mean Absolute Error (MAE) was found to be 0.59 m (7.8%) and $R^2 > 0.81$. The Modified Tank Model was found to be able to simulate and forecast the rising limb of flood hydrograph as well as the runoff

peak for 6hr, 12hr, 18hr and 24hr lead time forecasts. Good correlation ($R^2 > 0.97$) and average absolute error of 0.16 m were found for the 6hr lead time forecast (with error adjustment module). While average absolute errors of 0.2 m (2.6%), 0.24 m (3.1%) and 0.28 m (3.8%) were obtained for the 12hr, 18hr and 24hr forecasts with their R^2 within the range of 0.96 and 0.97.

The accuracy of water level forecast depends on the accuracy of the future rainfall forecast. In this study, two assumptions on rainfall quantities were made in order to evaluate the forecasting capability of the Modified Tank Model in actual forecasting operation. First assumption (Case A), assuming similar rainfall persists for the next 24 hours gives a range of errors from 0.26 m - 0.36 m, 0.36 m – 0.49 m and 0.45 m – 0.59 m with respect to 12hr, 18hr and 24hr lead time forecast while errors of the second assumption (Case B), assuming no rainfall for the next 24 hours were found in the range of 0.23 m – 0.35 m, 0.36 m – 0.56 m and 0.49 m – 0.76 m. Both cases show good correlation ($R^2 > 0.92$) established for 12hr lead time forecast. Meanwhile, R^2 were found in the range of 0.86 – 0.88 (18hr lead time forecast) and 0.73 – 0.84 (24hr lead time forecast) for both cases.

Verification (using 1998 flood data) results indicated that, 0.51 m, 0.12 m, 0.16 m, 0.2 m, 0.23 m were found as the simulation error, 6hr, 12hr, 18hr and 24hr lead time forecast errors, respectively. Good correlation with R^2 greater than 0.840, 0.983, 0.981, 0.975 and 0.967 were obtained with respect to the simulation, 6hr, 12hr, 18hr and 24hr forecasts. The flood hydrograph analysis (approximately 3 weeks of analysis period) showed that all errors increased slightly as compared to the overall simulation and forecast (approximately 2 months). Catchment water balance of the Modified Tank Model has been assessed with satisfactory results.

Abstrak tesis dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

UJIAN DAN PENILAIAN KE ATAS MODEL RAMALAN BANJIR (MODEL TANGKI UBAHSUAI) BAGI KAWASAN TADAHAN SUNGAI KELANTAN

By

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Julai 2001

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Satu model ramalan banjir, bernama Model Tangki Ubahsuai telah diuji untuk kawasan tadahan Sungai Kelantan (12056 km^2). Data-data paras air sungai dan hujan bagi tempoh 6 jam telah dikumpulkan dari Bank Data, DID dan dijadikan data input kepada Model Tangki Ubahsuai. Pembetulan regresi telah digunakan untuk memperbaiki pwnyelakuan paras air sungai di Jambatan Guillemard (stesen ramalan). Kaedah statistik dan fungsi objektif telah digunakan untuk menilai keupayaan tangki model untuk meramal dan penyelakuan..

Data-data musim banjir sepanjang 4 tahun (1990, 1991, 1992 dan 1994) telah digunakan dalam penyelakuan manakala data bagi tahun 1998 pula telah digunakan untuk mengesahkan prestasi Model Tangki Ubahsuai. Satu set pekali tangki yang sesuai dengan tatarajah tangki yang dipilih bagi tadahan Sungai Kelantan telah diperolehi dengan kaedah cuba ralat. Paras air sungai di Jambatan Guillemard berjaya selaku dengan purata kesilapan sebanyak 0.59 m (7.8%) dan $R^2 > 0.81$. Model Tangki Ubahsuai didapati mampu menyelaku dan meramal 'rising limb' hidrograf serta air larian puncak bagi ramalan 6 jam, 12 jam dan 24 jam. Korelasi yang baik ($R^2 > 0.97$) dan ralat sebanyak

0.16 m telah diperolehi bagi ramalan 6 jam. Sementara itu, purata kesilapan sebanyak 0.2 m (2.6%), 0.24 m (3.1%) dan 0.28 m (3.8%) dan R^2 dalam lingkungan 0.96 dan 0.97 telah diperolehi bagi ramalan 12 jam, 18 jam dan 24 jam masing-masing.

Ramalan paras air sungai yang tepat amat bergantung kepada ketepatan ramalan hujan masa depan. Dalam kajian ini, dua andaian kuantiti hujan telah dibuat untuk menilai keupayaan ramalan Model Tangki Ubahsuai dalam operasi ramalan sebenar. Andaian pertama (anggapkan kuantiti hujan yang sama berlaku bagi 24 jam seterusnya) telah memberikan kesilapan dalam lingkungan 0.26 m – 0.36 m, 0.36 m – 0.49 m dan 0.45 m – 0.59 m bagi ramalan 12 jam, 18 jam dan 24 jam masing-masing manakala ralat bagi andaian kedua (Anggapkan tiada hujan berlaku) didapati jatuh dalam lingkungan 0.23 m – 0.35 m, 0.36 m – 0.56 m dan 0.49 m – 0.76 m. Kedua-dua andaian memberikan korelasi yang baik iaitu $R^2 > 0.92$ untuk ramalan 12 jam. R^2 didapati antara 0.86 – 0.88 bagi ramalan 18 jam dan antara 0.73 – 0.84 bagi ramalan 24 jam untuk kedua-dua kes.

Keputusan pengesahan (menggunakan data banjir 1998) Model Tangki Ubahsuai menunjukkan kesilapan sebanyak 0.51 m, 0.12 m, 0.16m, 0.2 m dan 0.23 m masing-masing diperolehi bagi penyerupaan, ramalan 6 jam, 12 jam, 18 jam dan 24 jam. Korelasi yang tinggi iaitu R^2 lebih daripada 0.840, 0.983, 0.981, 0.975 dan 0.967 telah dicapai bagi penyeruaan, ramalan 6 jam, 12 jam, 18 jam dan 24 jam masing-masing. Analisis hidrograf banjir ($\approx$ 3 minggu jangka masa analisis) telah menunjukan kesemua ralat telah bertambah sedikit jika dibandingkan dengan penyerupaan dan ramalan keseluruhan ($\approx$ 2 bulan). Pengimbangan air tadahan bagi Model Tangki Ubahsuai juga telah ditaksirkan dan keputusan yang memuaskan diperolehi.

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TABLE OF CONTENTS

ABSTRACT ii
ABSTRAK iv
ACKNOWLEDGEMENTS vi
APPROVAL SHEET vii
DECLARATION FORM ix
LIST OF TABLES xii
LIST OF FIGURES xiii
LIST OF ABBREVIATIONS xvii

CHAPTER

I INTRODUCTION 1
Definitions of flood 3
Types of Flood 4
River Floods 4
Coastal Floods 4
Factors Affecting Floods 5
Flooding-Producing Mechanisms 5
Flood Hazard 7
Historical Flood in Kelantan 7
Flood Damage 8
Statement of Problem 9
Objectives 10
Scope and Limitations of the Study 11

II LITERATURE REVIEW 12

Flood Forecasting and Warning System 13
Flood Forecasting and Warning System in Malaysia 14
Flood Forecasting Model 20
Tank Model 25
Hydrological Concept of Tank Model 26
Runoff Mechanism of Tank Model 26
Catchment Runoff Computation 29

III APPLIED MODEL AND METHODOLOGY 34
Topography of Study Area 34
Meteorological Characteristic 37
Availability of Meteorological Data 37
Initial Data Screening 38
Catchment Areal Rainfall 42
Double Mass Analysis 42
Modified Tank Model 44
Modified Tank Model Calibration 51
Autoregressive Analysis 58
Model evaluation and Testing by Statistical Method 61

IV RESULTS 64
Simulated Flood Level 64
Autoregressive Analysis for Error Adjustment 73
Evaluations of Modified Tank Model Forecast Capability 84
Adjusted-6hr Forecast 84
Adjusted-12hr, 18hr and 24hr Forecast 90
Evaluations of Actual Forecasting Operation 102
Forecast Result According to Case A 104
Forecast Result According to Case B 109
Model Verification 115
Flood Hydrograph Analysis 122
Water Balance Analysis 126

V SUMMARY AND CONCLUSION 128
Summary 128
Conclusions 131
Scope and Limitations of the Modified Tank Model 132
Recommendations 132

REFERENCES 133

APPENDICES

A Sample of Available Flood Level and Discharge Data for the Study Period 138
B Sample of Collected Rainfall Data and Areal Rainfall Calculated for the Five Years Study Periods 152
C Double Mass Analysis 157
D Evaporation Analysis 159
E Lag Time Calculation 163
F Catchment Runoff Calculations 164
G Correlation Figures 167

BIODATA OF THE AUTHOR 192

LIST OF TABLES

Table		Page
1.1	Summary of Flood Damage in Kelantan.....	9
2.1	Flood Forecasting Models in Malaysia.....	19
3.1	Theissen Weight Calculation for Each Catchment Rainfall Station.....	42
3.2	Rating Curves of Guillemard Bridge (1995), Dabong and Tualang (1996)..	52
3.3	Calculation of Autoregressive Coefficients and Forecast Flood Level	59
4.1	Sample Results Calculated by Modified Tank Model Software for the Year of 1994.....	69
4.2	Sensivity of Tank Coefficients in the Calibration Process	70
4.3	Simulation Errors with respect to Different Objective Functions for The Calibration Period.....	71
4.4	Average Autoregressive Coefficients Obtained from Five Years Study Periods.....	84
4.5	Errors of Adjusted-6hr Flood Level with respect to Different Objective Functions for the Calibration Periods.....	89
4.6	Errors of Adjusted-12hr, 18hr and 24hr Flood Level with respect to Different Objective Functions for the Calibration Periods	91
4.7	Errors of Adjusted-12hr, 18hr and 24hr Flood Level with respect to Different Objective Functions for the Calibration Periods (Case A).....	109
4.8	Errors of Adjusted-12hr, 18hr and 24hr Flood Level with respect to Different Objective Functions for the Calibration Periods (Case B).....	114
4.9	Errors Summary of Adjusted-6hr, 12hr, 18hr and 24hr Forecast for 1998..	116
4.10	Errors Summary of Simulation, Adjusted-6hr, 12hr, 18hr and 24hr Forecast Flood Level for the Five Years Flood Peak Analysis.....	123
4.11	Errors of Simulated, 6hr, 12hr, 18hr and 24hr Forecast Flood Peak Level with respect to the Observed Flood Peak Level.....	125
4.12	Water Balance Calculation at Guillemard Bridge during Flooding Period...	127

LIST OF FIGURES

Figure		Page
1.1	Flood Prone Area of Peninsular Malaysia	2
1.2a	All Rainfall (P) Infiltrates Into the Soil Surface in the Early Stage of A Rainfall Event	6
1.2b	The Generation of Flood Flow during A Rainfall Event	6
1.3	The Formation of Overland Flow in Areas of Low Infiltration Capacity.	7
2.1	Typical Siren Station	17
2.2	Typical Flood Warning Board	18
2.3	Flood Runoff Process	27
2.4	Time Distribution of Three Runoff Components in a Hydrograph	28
2.5	Schematic Diagram of Tank Model Runoff Mechanism	28
2.6	Typical Tank Model for Flood Runoff Computation	30
2.7	Tank Configuration of Kelantan Flood Forecasting Model, 1984	33
3.1	Topography Map of Study Area, Kelantan River Basin	35
3.2	Location of Stream Gauging Stations and the Watershed Boundary	36
3.3	Layout of Gauging and Telemetric Rainfall Stations	39
3.4	Availability of Water Level and Discharge Data	40
3.5	Availability of Rainfall Data	41
3.6	Theissen Polygon for the Study Site	43
3.7a	Catchment Division Map of Kelantan River Basin	46
3.7b	Schematic Diagram of Kelantan River Basin in Modified Tank Model	47
3.8	Typical Tank Configuration for Catchment Basin	48
3.9a	Rating Curve of Guillemard Bridge for 1995	53
3.9b	Rating Curve of Dabong for 1996	53
3.9c	Rating Curve of Kampung Tualang for 1996	54
3.10	Typical Set of Calibrated Coefficients Used in the Trial and Error Process	55

3.11 Flow Chart of Modified Tank Model Calibration Procedures..... 56

4.1a Observed and Simulated Hydrograph at Guillemard Bridge for 1991 with the Coefficients in Figure 3.9..... 65
4.1b Observed and Simulated Hydrograph at Guillemard Bridge for 1991 with the Coefficients in Figure 3.9..... 65

4.2 The Accepted Set of Calibrated Coefficients Obtained After Several Hundred Times of Trial and Error..... 66

4.3a Observed and Simulated Hydrograph at Guillemard Bridge for 1990..... 67
4.3b Observed and Simulated Hydrograph at Guillemard Bridge for 1991..... 67
4.3c Observed and Simulated Hydrograph at Guillemard Bridge for 1992..... 68
4.3d Observed and Simulated Hydrograph at Guillemard Bridge for 1994..... 68

4.4a Relationship Between Observed and Simulated Flood Level for 1990..... 71
4.4d Relationship Between Observed and Simulated Flood Level for 1991..... 72
4.4c Relationship Between Observed and Simulated Flood Level for 1992..... 72
4.4d Relationship Between Observed and Simulated Flood Level for 1994..... 73

4.5a Relationship Between Residue and Residue Lag 1for 1990..... 74
4.5b Relationship Between Residue and Residue Lag 2 for 1990..... 74
4.5c Relationship Between Residue and Residue Lag 3for 1990..... 75
4.5d Relationship Between Residue and Residue Lag 4 for 1990..... 75

4.6a Relationship Between Residue and Residue Lag 1 for 1991..... 76
4.6b Relationship Between Residue and Residue Lag 2 for 1991..... 76
4.6c Relationship Between Residue and Residue Lag 3 for 1991..... 77
4.6d Relationship Between Residue and Residue Lag 4 for 1991..... 77

4.7a Relationship Between Residue and Residue Lag 1 for 1992..... 78
4.7b Relationship Between Residue and Residue Lag 2 for 1992..... 78
4.7c Relationship Between Residue and Residue Lag 3 for 1992..... 79
4.7d Relationship Between Residue and Residue Lag 4 for 1992..... 79

4.8a Relationship Between Residue and Residue Lag 1 for 1994..... 80
4.8b Relationship Between Residue and Residue Lag 2 for 1994..... 80
4.8c Relationship Between Residue and Residue Lag 3 for 1994..... 81
4.8d Relationship Between Residue and Residue Lag 4 for 1994..... 81

4.9a Relationship Between Residue and Residue Lag 1 for 1998..... 82
4.9b Relationship Between Residue and Residue Lag 2 for 1998..... 82
4.9c Relationship Between Residue and Residue Lag 3 for 1998..... 83
4.9d Relationship Between Residue and Residue Lag 4 for 1998..... 83

4.10a Comparison of Observed, Simulated and Adjusted-6hr Hydrograph at Guillemard Bridge for1990..... 85
4.10b Comparison of Observed, Simulated and Adjusted-6hr Hydrograph at Guillemard Bridge for1991..... 86

4.10c Comparison of Observed, Simulated and Adjusted-6hr Hydrograph at Guillemard Bridge for1992 86
4.10d Comparison of Observed, Simulated and Adjusted-6hr Hydrograph at Guillemard Bridge for1994 87

4.11a Relationship Between Observed and Adjusted-6hr Flood Level for 1990.. 87
4.11b Relationship Between Observed and Adjusted-6hr Flood Level for 1991.. 88
4.11c Relationship Between Observed and Adjusted-6hr Flood Level for 1992.. 88
4.11d Relationship Between Observed and Adjusted-6hr Flood Level for 1994.. 89

4.12a Relationship Between Observed and Adjusted-12hr Flood Level for 1990. 91
4.12b Relationship Between Observed and Adjusted-12hr Flood Level for 1991. 92
4.12c Relationship Between Observed and Adjusted-12hr Flood Level for 1992. 92
4.12d Relationship Between Observed and Adjusted-12hr Flood Level for 1994. 93

4.13a Relationship Between Observed and Adjusted-18hr Flood Level for 1990. 93
4.13b Relationship Between Observed and Adjusted-18hr Flood Level for 1991. 94
4.13c Relationship Between Observed and Adjusted-18hr Flood Level for 1992. 94
4.13d Relationship Between Observed and Adjusted-18hr Flood Level for 1994. 95

4.14a Relationship Between Observed and Adjusted-24hr Flood Level for 1990. 95
4.14b Relationship Between Observed and Adjusted-24hr Flood Level for 1991. 96
4.14c Relationship Between Observed and Adjusted-24hr Flood Level for 1992. 96
4.14d Relationship Between Observed and Adjusted-24hr Flood Level for 1994. 97

4.15a Comparison of Observed Flood Level with Adjusted 6hr, 12hr, 18hr and 24hr Forecast for 1990 at Guillemard Bridge 98
4.15b Comparison of Observed Flood Level with Adjusted 6hr, 12hr, 18hr and 24hr Forecast for 1991 at Guillemard Bridge 99
4.15c Comparison of Observed Flood Level with Adjusted 6hr, 12hr, 18hr and 24hr Forecast for 1992 at Guillemard Bridge 100
4.15d Comparison of Observed Flood Level with Adjusted 6hr, 12hr, 18hr and 24hr Forecast for 1994 at Guillemard Bridge 101

4.16 Example of Rainfall, Observed and Forecasted Flood Levels at Guillemard Bridge Show in the Modified Tank Model Forecast Function..... 102

4.17 Example of Simulated and Adjusted (Forecasted) Flood Levels at Guillemard Bridge for the Three Different Rainfall Cases Show in the Modified Tank Model..... 103

4.18a Comparison of Observed Flood Level with Adjusted-12hr, 18hr and 24hr Forecast for 1990 at Guillemard Bridge (Case A)..... 105
4.18b Comparison of Observed Flood Level with Adjusted-12hr, 18hr and 24hr Forecast for 1991 at Guillemard Bridge (Case A)..... 106
4.18c Comparison of Observed Flood Level with Adjusted-12hr, 18hr and 24hr Forecast for 1992 at Guillemard Bridge (Case A)..... 107
4.18d Comparison of Observed Flood Level with Adjusted-12hr, 18hr and 24hr Forecast for 1994 at Guillemard Bridge (Case A)..... 108

4.19a Comparison of Observed Flood Level with Adjusted-12hr, 18hr and 24hr Forecast for 1990 at Guillemard Bridge (Case B)..... 110
4.19b Comparison of Observed Flood Level with Adjusted-12hr, 18hr and 24hr Forecast for 1991 at Guillemard Bridge (Case B)..... 111
4.19c Comparison of Observed Flood Level with Adjusted-12hr, 18hr and 24hr Forecast for 1992 at Guillemard Bridge (Case B)..... 112
4.19d Comparison of Observed Flood Level with Adjusted-12hr, 18hr and 24hr Forecast for 1994 at Guillemard Bridge (Case B)..... 113

4.20 Observed and Simulated Hydrograph at Guillemard Bridge for 1998..... 116

4.21 Relationship Between Observed and Simulated Flood Level for 1998..... 117

4.22 Relationship Between Observed and Adjusted-6hr Forecast Flood Level for 1998..... 117

4.23 Hydrograph of Observed, Simulated and Adjusted-6hr Flood Level at Guillemard Bridge for 1998..... 118

4.24 Relationship Between Observed and Adjusted-12hr Forecast Flood Level for 1998.....119

4.25 Relationship Between Observed and Adjusted-18hr Forecast Flood Level for 1998.....120

4.26 Relationship Between Observed and Adjusted-24hr Forecast Flood Level for 1998.....120

4.27 Comparison of Observed Flood Level with Adjusted-12hr, 18hr and 24hr Forecast Flood Levels for 1998 at Guillemard Bridge 121

4.28 Comparison of Flood Peak Level for Five years Study Periods..... 126

LIST OF ABBREVIATIONS

a	tank coefficient
f	infiltration capacity
h	depth of tank in mm
i	intensity
n	number of data
q	runoff in mm
t	time
B	catchment basin
C	tank coefficient
E	evaporation
H	height of tank outlet in mm
I	infiltration
K	side tank outlet coefficient
L	main stream length
P	precipitation
Q	runoff in mm
R	rainfall
S	weighted mean stream slope
U	urbanisation factor
V	channel velocity in m/s
X	height of tank
C_t	topography coefficient

L_c	main stream length from catchment centroid in miles
P_e	excess precipitation
Q_g	ground water flow
Q_o	overland flow
Q_t	throughflow
R^2	correlation coefficient
t_c	time of concentration
hr	hour
Lg	lag time
Mb	exponential coefficient
Q_o (s)	saturation overland flow
R (t)	precipitation at a given time
AR	autoregressive coefficient
DB	Dabong
EV	evaparation
JG	Guillemard Bridge
KK	Kuala Krai
KT	Kampung Tualang
SQ	simulated discharge
Adj	adjusted
ANN	Artificial Neural Network
HLA	hybrid learning algorithm
MAE	mean absolute factor
DID	Department of Irrigation and Drainage

FFC	Flood Forecast Centre
LPM	Linear Perturbation Model
LVL	simulated flood level
MMS	Malaysian Meteorological Services
NWS	National Weather Service
QIN	inflow
RES	residue
RMS	root mean square error
RFC	River Forecast Centre
SLM	Simple Linear Model
TCM	Thames Conceptual Model
Q_B	runoff of basin
AE_B	area evaporation of basin
IHCM	Institute of Hydrology Conceptual Model
OLVL	observed flood level
QOUT	outflow
SIMQ	simulated flood level
SMAR	soil moisture accounting and routing
TARM	Genetic Threshold Auto-Regressive Model
TS_B	tank storage of basin
TS_C	tank storage of channel
USGS	United State Geological Survey
BFLOW	baseflow
FCSTQ	forecast flood level

INFIL	infiltration
SSARR	Streamflow Synthesis and Reservoir Regulation
TR-20	Technical Release No. 20
INFIL_B	basin infiltration
Arain_B	areal rainfall of basin
$OLVL4_{min}$	minimum observed flood level
$OLVL4_{mean}$	mean observed flood level

CHAPTER I

INTRODUCTION

Tropical countries like Malaysia has an equatorial climate with constantly high temperatures (mean monthly temperature about 27°C) and high relative humidity all year round. Peninsular Malaysia has an area of 131 795 km^2 that lies approximately between latitudes 1°N and 7°N and longitudes 100°E and 105°E. The average annual rainfall is estimated at 2420 mm (600 mm daily rainfall in extreme cases) (Keizrul and Chong, 2001). Peninsular Malaysia is abetted by the North-East Monsoon that prevailing between November and February and causes heavy rainfall deposited along east coast of Peninsular including Kelantan State, one of the most significant affected area. South-West Monsoon prevails from April to September but bring less rainfall as it loses much of its moisture over the mountains of Sumatra.

According to Azmi (1992), flooding is a significant natural hazard during monsoons that affects 2.7 millions people within the 29000 km^2 of flood prone area in Malaysia. Figure 1.1 shows the flood area of Peninsular Malaysia. Therefore, various studies and strategies, both structural (engineering) and non-structural (non-engineering) measures have been proposed in tackling the flood problems. Flood forecasting and warning system is one of the non-structural approach which is more practical and least expensive to minimise flood losses as compared to the structural measures.

Flood forecasting technique used in Malaysia since 1960's was originally called Stage-Correlation Method. Throughout the years, it has been progressively upgraded and

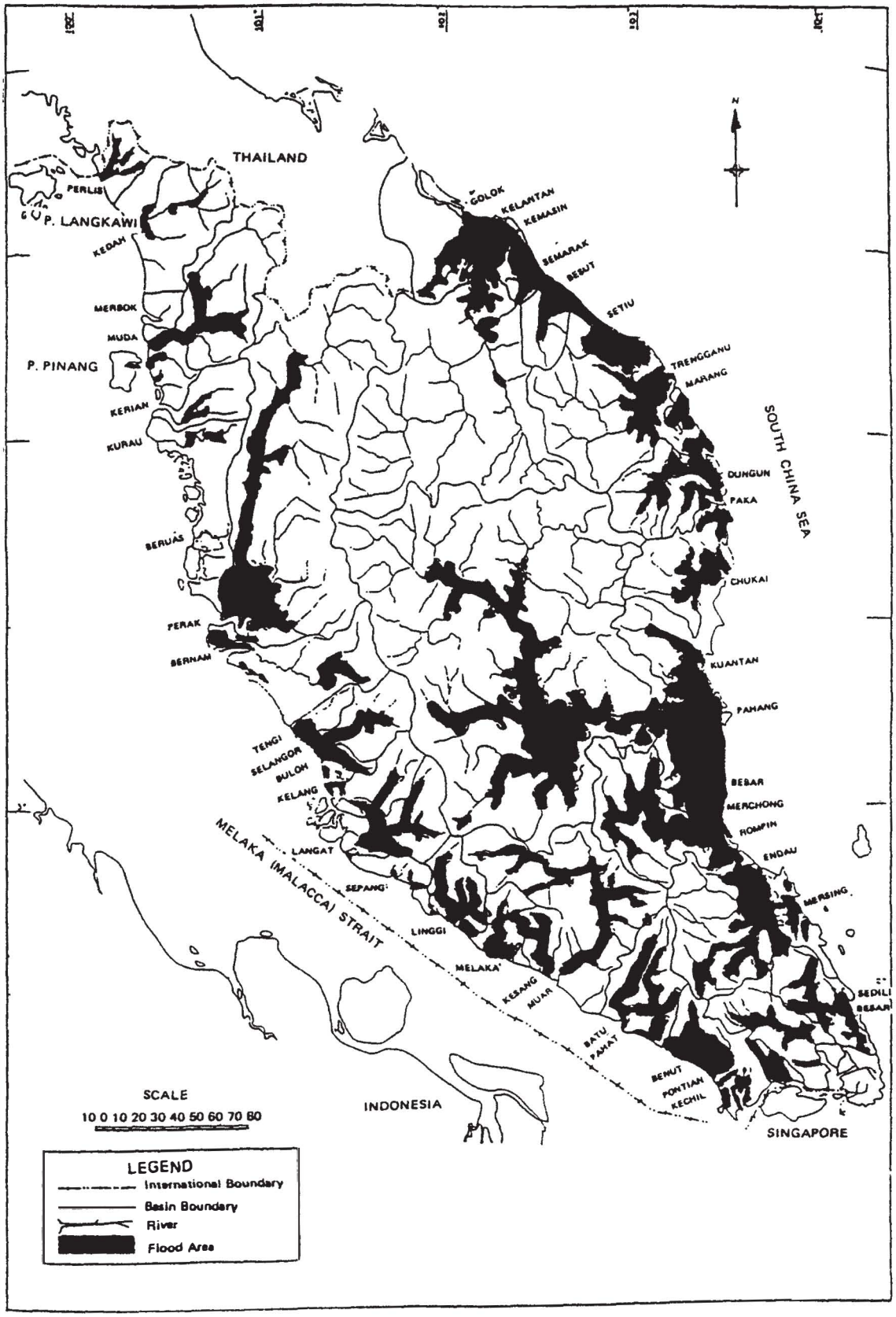

Figure 1.1: Flood prone area of Peninsular Malaysia. (Sources: Paridah, 1995)

improved. Presently, real-time rainfall and river stage data obtained through telemetric systems as well as empirical and mathematical forecasting computer models to carry out the flood forecasts. The forecast on impending floods will enable residents in flood prone areas to be forewarned and take necessary actions to protect their properties and livestock, and thus reduced serious flood damages.

Definitions of flood

The definitions of floods given by different hydrologists and researchers are as follow

"A relatively high flow as measured by either gage height or discharge rate whenever the stream channel in an average section is overtaxed, causing overflow to the usual channel boundaries, the stream is then said to have flood stage."

(Jarvis, 1949)

"Stage at which the stream channel becomes filled and above which is overflows its banks " (Wisler and Brater, 1957)

"The result of runoff from rainfall and/or melting snow in quantities too great to be confined in the low water channels of streams." (Linsley, 1964)