



UNIVERSITI PUTRA MALAYSIA

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

HO KWEE HONG

FK 2001 53

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

HO KWEE HONG

**MASTER OF SCIENCE
UNIVERSITI PUTRA MALAYSIA**

2001



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

By

HO KWEE HONG

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

July 2001



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

HO KWEE HONG

July 2001

Chairman: Abdul Halim Ghazali

Faculty: Engineering

A distributed lumped conceptual flood forecasting model, namely Modified Tank Model was calibrated in this study for the Kelantan River Basin (12056 km²). 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

HO KWEE HONG

Julai 2001

Pengerusi: Abdul Halim Ghazali

Fakulti: Kejuruteraan

Satu model ramalan banjir, bernama Model Tangki Ubahsuai telah diuji untuk kawasan tadahan Sungai Kelantan (12056 km²). 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 (menggunkan 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 (≈ 3 minggu jangka masa analisis) telah menunjukkan kesemua ralat telah bertambah sedikit jika dibandingkan dengan penyerupaan dan ramalan keseluruhan (≈ 2 bulan). Pengimbangan air tadahan bagi Model Tangki Ubahsuai juga telah ditaksirkan dan keputusan yang memuaskan diperolehi.

ACKNOWLEDGEMENTS

The author would like to express her sincere gratitude to her supervisor, Mr Abdul Halim Ghazali for his understanding, guidance and support. The author is indebted and would like to say thank you to Ir. Chong Sun Fatt (Senior Asst. Director of the Hydrology and Water Resource Division, DID) for giving her the opportunity to carry out this study for DID. Valuable suggestions and guidance of her supervisory committee members comprising Mr. Abdul Halim Ghazali, Ir. Chong Sun Fatt, Dr. Thamer Ahmed Mohammed and Mrs. Badronnisa Yusuf are gratefully acknowledged. The author is also indebted to Ir. Liam We Lin, who developed the software for this study, for his patience and valuable guidance throughout the study. Financial support of the Ministry of Science, Technology and Environment is also acknowledged. The writer is grateful to all staff of Hydrology Division, DID especially Mr. Ratnarajah, Mr. Azlan and Mr. Jayaram for their help in this project. The assistance from her friends is very much appreciated, especially to Mr. Yong Hong Liang for his support and encouragement. Lastly to her dearest mother, sisters and brother for their love and understanding, the author wishes to say thanks.



I certify that an Examination Committee met on 13th July 2001 to conduct the final examination of Ho Kwee Hong on her Master of Science thesis entitled “Calibration and Evaluation of a Flood Forecasting Model (Modified Tank Model) for Kelantan River Basin” in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1981. The Committee recommends that the candidate be awarded the relevant degree. Members of the Examination Committee are as follows:

SALIM SAID, Ph.D.,
Associate Professor,
Lecturer,
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

ABDUL HALIM GHAZALI, M.Sc.,
Lecturer,
Faculty of Engineering
Universiti Putra Malaysia
(Member)

CHONG SUN FATT, M.Sc.,
Senior Asst. Director,
Hydrology and Water Resource Division
Drainage and Irrigation Dept, Malaysia
(Member)

THAMER AHMED MOHAMMED, Ph.D.,
Lecturer,
Faculty of Engineering
Universiti Putra Malaysia
(Member)

BADRONNISA YUSUF, M.Sc.,
Lecturer,
Faculty of Engineering
Universiti Putra Malaysia
(Member)



MOHD. GHAZALI MOHAYIDIN, Ph.D.,
Professor/Deputy Dean of Graduate School,
Universiti Putra Malaysia

Date: '11 SEP 2001

This thesis submitted to the Senate of Universiti Putra Malaysia has been accepted as fulfilment of the requirements for the degree of Master of Science.



**AINI IDERIS, Ph.D.,
Professor,
Dean of Graduate School,
Universiti Putra Malaysia**

Date: 08 NOV 2001

DECLARATION

I hereby declare that the thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at UPM or other institutions.



HO KWEE HONG

Date: 5 September 2001

TABLE OF CONTENTS

ABSTRACT	ii
ABSTRAK	iv
ACKNOWLEDGEMENTS	vi
APPROVAL SHEET	vii
DECLARATION FORM	ix
LIST OF TABLES	xi
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 1 for 1990.....	74
4.5b	Relationship Between Residue and Residue Lag 2 for 1990.....	74
4.5c	Relationship Between Residue and Residue Lag 3 for 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 for 1990.....	85
4.10b	Comparison of Observed, Simulated and Adjusted-6hr Hydrograph at Guillemard Bridge for 1991.....	86



4.10c	Comparison of Observed, Simulated and Adjusted-6hr Hydrograph at Guillemard Bridge for 1992.....	86
4.10d	Comparison of Observed, Simulated and Adjusted-6hr Hydrograph at Guillemard Bridge for 1994.....	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
L_g	lag time
M_b	exponential coefficient
$Q_o (s)$	saturation overland flow
$R (t)$	precipitation at a given time
AR	autoregressive coefficient
DB	Dabong
EV	evaporation
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
OLVL _{4min}	minimum observed flood level
OLVL _{4mean}	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 km² 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 km² 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



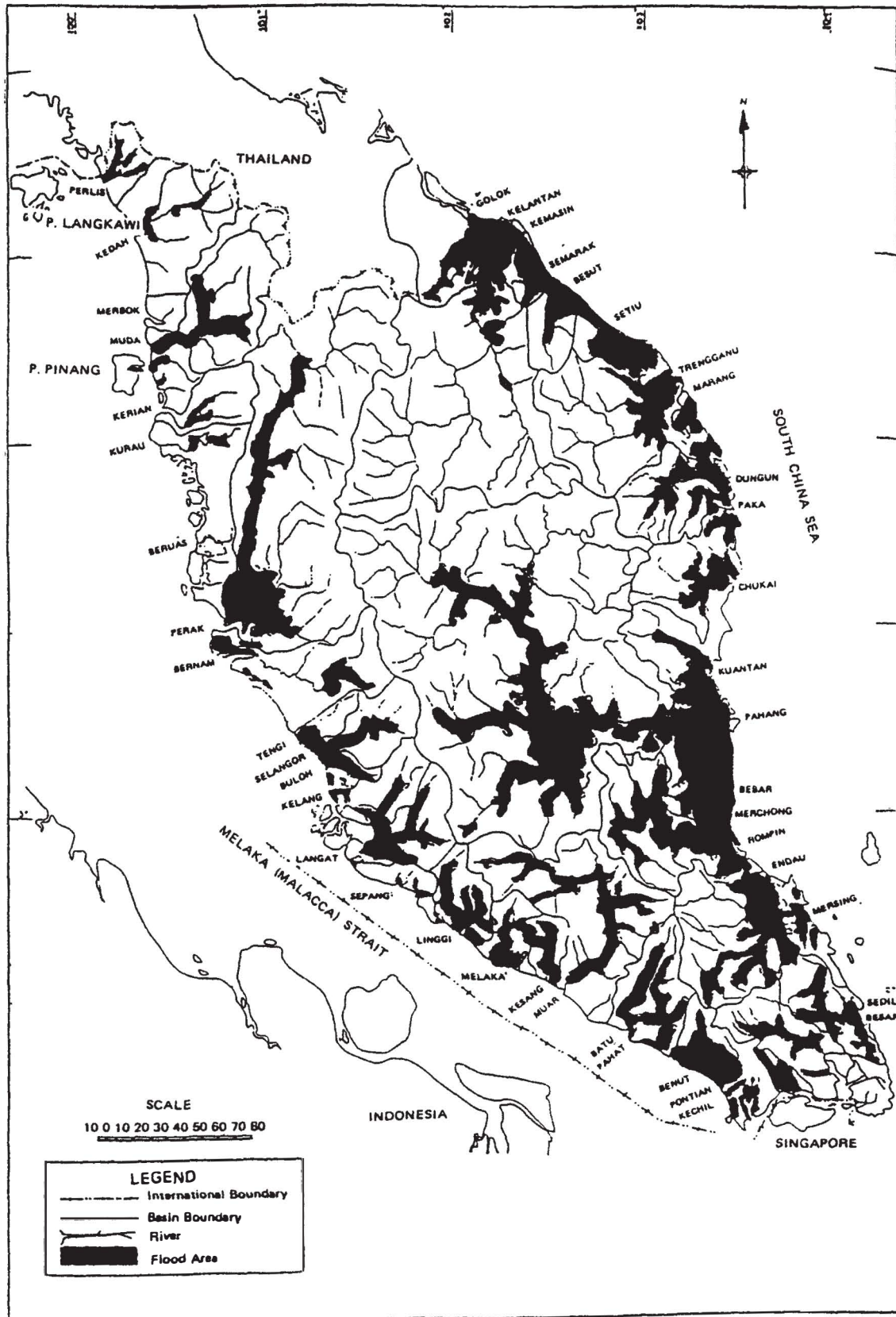


Figure 1.1: Flood prone area of Peninsular Malaysia. (Sources: Paridah, 1995)

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)