



UNIVERSITI PUTRA MALAYSIA

**DEVELOPMENT OF A RESERVOIR INFLOW FORECASTING
MODEL FOR AN UNGAUGED CATCHMENT**

HUANG YUK FENG

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By

HUANG YUK FENG

**Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia,
in Fulfilment of the Requirements for the Degree of Doctor of Philosophy**

April 2005



*Dedicated to the author's beloved Grandmother, Mother, Sisters, Brothers,
and in memory of his beloved Father*



Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

**DEVELOPMENT OF A RESERVOIR INFLOW FORECASTING
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April 2005

Chairman: Associate Professor Ir. Lee Teang Shui, PhD

Faculty: Engineering

A user-friendly single-event distributed reservoir inflow forecasting model for the ungauged Batu Dam Catchment is presented. The Batu Dam Catchment located in the Gombak District, Selangor Darul Ehsan, approximately 20 km north of Kuala Lumpur, is a 50.7 km² tropical forested rural catchment. The model consists of five sub-models, namely the physical data input sub-model, the rainfall data input and excess rainfall computation sub-model, the rainfall runoff simulation sub-model, the baseflow volume computation sub-model and the reservoir water level increment simulation sub-model. The whole formulation of model was set up using the MapBasic and MapInfo Geographical Information System package. The catchment was delimited based on the finite element concept. The rainfall losses in the catchment were assumed to be consistent throughout an event and uniform over the entire catchment. The catchment losses rate concept developed was assumed to be dependent on catchment antecedent soil moisture condition (catchment wetness index) and weighted average rainfall intensity. A catchment wetness index was formulated empirically based on the net total rainfall volume retained in the catchment cumulated from a five-day period prior to the simulated event following



the 5-day Antecedent Precipitation Index (API5) approach. This catchment losses rate works in conjunction with the areal reduction factor to compute excess rainfall. With excess rainfall as input, the rainfall runoff simulation sub-model was developed based on the one dimensional Saint-Venant equations with kinematic wave approximation and solved using the finite element standard Galerkin's residual method, and incorporating Manning's equation. The spurious oscillatory behaviour of the simulated direct runoff hydrographs when approximated by the standard Galerkin's residual method can be suppressed by using a one minute time increment based on investigations taking into consideration the Courant condition. An empirical equation for computing baseflow volume for reservoir water level increment simulation was developed based on the five previous day approach similar to that in the API5. The reservoir water level increment sub-model is used to simulate the reservoir water level increment, by considering all the other inflows and outflows of the reservoir.

Historical rainfall events from 1989 to 2001 were used for model parameter calibration and model verification purposes. One hundred and forty cases selected were divided into thirteen groups according to their weighted average rainfall intensities. Cases from each group were then further sub-divided randomly into two separate sets in order to form two sets of cases. One set was used for the calibration of the unknown parameter, catchment losses rate. The Catchment Losses Rate-Catchment Wetness Index-Weighted Average Rainfall Intensity (LWRI) curves were proposed. Seven LWRI curves were finalized and selected, and were programmed into the model for model verification and forecasting purposes. The accuracy of Manning's coefficients used in model parameter calibration was

confirmed by extending the 24-hour simulation period of the selected calibration cases to 48 hours. The 0.400 and 0.040 Manning's coefficients for overland and channels were confirmed to be accurate. This was supported with statistical tests on the simulated increment and the respective measured increment, where a very strong 0.9799 correlation coefficient from the correlation analysis, a relatively small mean absolute error that does not exceed 1.47 cm at 95% level of confidence from the single mean t -test, and not enough evidence to support that the means and the variances of simulated increments and measured increments are different through the paired t -test and the F -distribution variance ratio test respectively.

The other set of cases was used for LWRI curves verification and model verification purposes. The LWRI curves were found to be accurate in determining catchment losses rates. The model was verified to be able to simulate the reservoir water level increment accurately. This was supported by the results of the statistical tests carried out on the simulated and the respective measured increments. A very strong 0.9799 correlation coefficient from the correlation analysis, a relatively small mean of absolute error not exceeding 2.20 cm at 95% level of confidence from the single mean t -test, and not enough evidence to support the means and the variances between the simulated increment and the measured increment are different from the paired t -test and the F -distribution variance ratio test.

The model was evaluated by comparing it with the rational method. Results of statistical tests show the model performing much better than the rational method. The respective correlation coefficient and mean of absolute error for the rational method were found to be 0.8602 and does not exceed 12.58 cm at 95% level of

confidence, respectively, while the paired *t*-test shows that there is not enough evidence to support that the simulated increment and the measured increment are the same. The computed Theil's coefficients for the model and the rational method, which are 0.062 and 0.266 respectively, also show that the model is more reliable compared to the rational method.

From the sensitivity analyses, the impact of changing Manning's Coefficient of overland on the simulated direct runoff hydrograph, as well as the reservoir water level increment, is higher than the impacts of changing Manning's Coefficient of the channels. The study reveals that more caution and effort should be emphasized in deciding Manning's coefficient of overland than that of channels. The results also show that the impact decreases with increasing rainfall intensity. The impact of catchment wetness index on the catchment losses rate and the corresponding reservoir water level increment was found can be moderately high, but is case dependent.

Keywords: ungauged reservoir inflow forecasting model, finite element rainfall runoff simulation, catchment wetness index, catchment losses rate, baseflow.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia
sebagai memenuhi keperluan untuk Ijazah Doktor Falsafah

**PEMBANGUNAN MODEL PERAMALAN ALIRAN MASUK
TAKUNGAN UNTUK TADAHAN TAK-TERUKUR**

Oleh

HUANG YUK FENG

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Satu model peramalan aliran masuk takungan teragih berperistiwa tunggal untuk tadahan tak-terukur Empangan Batu ditunjukkan. Tadahan Empangan Batu yang terletak di Daerah Gombak, Selangor Darul Ehsan, lebih kurang 20 km ke utara dari Kuala Lumpur, merupakan sebuah tadahan berhutan tropika yang berkeluasan 50.7 km². Model terdiri daripada lima buah sub-model, iaitu sub-model masukan data fizikal, sub-model masukan data hujan dan pengiraan lebat hujan lebihi, sub-model penyelakuan hujan air larian, sub-model pengiraan isipadu aliran dasar dan sub-model penyelakuan tokokan paras air takungan. Perumusan keseluruhan model diperbangunkan dengan menggunakan pakej MapBasic dan Sistem Maklumat Geografi MapInfo. Tadahan telah dibahagi berdasarkan konsep unsur terhingga. Kehilangan hujan dalam tadahan dianggap tetap sepanjang peristiwa dan seragam di keseluruhan tadahan. Konsep kehilangan tadahan yang dibangunkan dianggap bergantung kepada keadaan kelembapan tanah tadahan dahulu (indeks kebasahan tadahan) dan keamatan hujan purata berpemberat. Indeks kebasahan tadahan dirumuskan empirik berdasarkan hasil bersih jumlah isipadu hujan ditahankan di dalam tadahan dilonggokkan daripada satu jangkamasa lima-hari sebelum peristiwa

diperselakukan mengikut pendekatan Indeks Curahan Dahulu (API5). Kadar kehilangan tadahan ini berfungsi bersama-sama dengan faktor pengurangan luasan demi untuk mengira lebat hujan lebihi. Dengan lebat hujan lebihi sebagai masukan, sub-model penyelakuan hujan air larian dibentukkan berdasarkan persamaan-persamaan Saint-Venant berdimensi satu bersama anggapan ombak kinematik dan diselesaikan dengan menggunakan kaedah unsur terhingga baki Galerkin piawaian, serta termasuk persamaan Manning. Kelakuan ayunan lainan grafhidro air larian langsung yang diselakukan apabila ditaksirkan dengan kaedah baki Galerkin piawaian boleh ditindas dengan menggunakan tokokan masa sebanyak satu minit berdasarkan kajian-kajian yang mempertimbangkan keadaan Courant. Satu persamaan empirik untuk mengira isipadu aliran dasar dalam penyelakuan tokokan paras air takungan telah dibangunkan berdasarkan pendekatan lima hari dahulu sama dengan yang terdapat di dalam API5. Sub-model tokokan paras air takungan digunakan untuk menyelaku tokokan paras air takungan, dengan mempertimbangkan kesemua aliran masuk dan aliran keluar dari takungan.

Peristiwa-peristiwa hari hujan sejarah dari 1989 ke 2001 telah digunakan dalam penentukuran parameter model dan tujuan pentahkikan model. Seratus empat puluh kes yang terpilih dibahagikan kepada tiga belas kumpulan mengikut keamatan hujan purata berpemberat masing-masing. Kes-kes daripada setiap kumpulan kemudian dibahagikan lagi secara rawak kepada dua set berasingan untuk membentuk dua set kes-kes. Satu set digunakan dalam penentukuran parameter yang tidak diketahui, iaitu kadar kehilangan tadahan. Lengkungan-lengkungan Kadar Kehilangan Tadahan-Indeks Kebasahan Tadahan-Keamatan Hujan Purata Berpemberat telah dicadangkan. Tujuh lengkungan LWRI telah dilukis dan dipilih untuk diprogramkan

ke dalam model bagi tujuan pentahkikan model dan peramalan. Kejituan pekali Manning yang digunakan dalam penentuan parameter model telah dikenalpasti dengan memperpanjangkan jangkamasa penyelakuan 24-jam kes-kes terpilih kepada 48-jam. Pekali Manning 0.400 dan 0.040 untuk permukaan tanah dan terusan masing-masing telah dikenalpasti betul. Ini disokong oleh ujian-ujian statistik keatas tokokan yang diselakukan dan tokokan terukur masing-masing, dimana satu pekali sekaitan kuat 0.9799 daripada analisis keyakinan, satu ralat mutlak purata nisbi kecil yang tidak melebihi 1.46 cm pada paras keyakinan 95% daripada ujian- t purata tunggal, serta tiada bukti yang mencukupi untuk menyokong bahawa kedua-dua purata dan varians tokokan yang diselakukan dan tokokan terukur adalah berbeza, melalui ujian- t berpasangan dan taburan- F ujian nisbah varians masing-masing.

Set kedua telah digunakan untuk tujuan pentahkikan lengkungan LWRI dan pentahkikan model. Lengkungan LWRI didapati jitu dalam penentuan kadar kehilangan tadahan. Model ditahkikkan mampu menyelaku tokokan paras air takungan dengan tepat. Ini disokong oleh keputusan ujian-ujian statistik yang dijalankan keatas tokokan yang diselakukan dan tokokan yang diukur masing-masing. Satu pekali sekaitan kuat 0.9799 daripada analisis keyakinan, satu ralat mutlak purata nisbi kecil yang tidak melebihi 2.20 cm pada paras keyakinan 95% daripada ujian- t purata tunggal, serta tidak terdapat bukti yang mencukupi demi untuk menyokong bahawa kedua-dua purata dan varians tokokan diselakukan dan tokokan terukur adalah berbeza melalui ujian- t berpasangan dan taburan- F ujian nisbah varians.

Model tersebut dinilai dengan membandingkannya dengan kaedah rasional. Keputusan ujian-ujian statistik menunjukkan bahawa model tersebut lebih baik jika dibandingkan dengan kaedah rasional. Pekali sekaitan dan ralat mutlak purata kaedah rasional didapati bersamaan dengan 0.8602 dan tidak melebihi 12.58 cm pada tahap paras keyakinan 95% masing-masing. Sementara itu, ujian-*t* berpasangan menunjukkan bahawa tidak terdapat bukti yang mencukupi untuk menyokong bahawa kedua-dua tokokan diselakukan dan terukur adalah sama. Pekali Theil yang dikira untuk model dan kaedah rasional didapati bersamaan dengan 0.062 dan 0.266 masing-masing. Ini juga menunjukkan bahawa model tersebut lebih boleh dipercayai dibandingkan dengan kaedah rasional.

Daripada analisis-analisis kepekaan, impek perubahan pekali Manning permukaan tanah keatas hidrograf air larian langsung yang diselakukan, serta tokokan paras air takungan, adalah lebih besar daripada yang disebabkan oleh perubahan pekali Manning terusan. Daripada kajian ini, didapati bahawa lebih perhatian dan ikhtiar perlu ditumpukan semasa memilih pekali Manning permukaan tanah jika dibandingkan dengan pekali Manning terusan. Keputusan-keputusan juga menunjukkan bahawa impek berkurangan dengan peningkatan keamatan hujan. Impek indeks kebasahan tadahan keatas kadar kehilangan tadahan dan tokokan paras air takungan sepadan didapati sederhana tinggi, akan tetapi ia bergantung kepada keadaan kes.

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I certify that an Examination Committee met on 06 April 2005 to conduct the final examination of HUANG YUK FENG on his Doctor of Philosophy thesis entitled “Development of a Reservoir Inflow Forecasting Model for an Ungauged Catchment” 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:

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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.

HUANG YUK FENG

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TABLE OF CONTENTS

	Page
DEDICATION	ii
ABSTRACT	iii
ABSTRAK	vii
ACKNOWLEDGEMENTS	xi
APPROVAL	xii
DECLARATION	xiv
LIST OF TABLES	xviii
LIST OF FIGURES	xix
LIST OF PLATES	xxvi
LIST OF ABBREVIATIONS	xxvii
LIST OF NOTATIONS	xxix
 CHAPTER	
I INTRODUCTION	1
Background	1
Statement of Problem	3
Objectives	5
Scope of Work	6
Significance of the Study	6
II LITERATURE REVIEW	8
Preliminary	8
Separation of Catchment Losses and Rainfall Excess	10
Evaporation	12
Flow Routing	13
Saint-Venant Equations	14
Kinematic Wave Theory and Applications	17
Catchment Modeling	22
Finite Element Applications and Modeling	23
Existing Well-Known Hydrological Models	27
Flow Prediction in Ungauged Catchments	29
Geographical Information Systems in Hydrological Models	31
Summary	33
III THE CASE STUDY	35
Description of Study Area	35
Topography of Batu Dam Catchment and Availability of Physical Data	37
Climate Conditions and Availability of Hydrological Data	40
Features and Operation Procedures of the Batu Reservoir	41
IV MODEL CONCEPTUALIZATION, FORMULATION AND DEVELOPMENT	44



Finite Element Formulation and Application	45
Approximation for Overland and Channel Flows	46
Formulating Finite Element Equations	46
Determining and Impact of Time Increment Used	57
Evaluating Linear and Quadratics Interpolation Function Models Using a Fictitious Catchment	59
Impact of Cross Sectional Spacing on Runoff Routing	60
Finite Element Catchment Delimitation	62
Delimitating Sub-Catchments	62
Delimitating Finite Element Overland Strips	63
Application of Geographical Information Systems in Model	66
Digitizing Maps	66
Designing and Building Database	67
Displaying Digitized Map Features	69
Reservoir Inflow Forecasting Model Formulation and Development	71
Physical Data Input Sub-Model	73
Rainfall Data Input and Excess Rainfall Computation Sub-Model	73
Rainfall Runoff Simulation Sub-Model	79
Baseflow Volume Computation Sub-Model	81
Reservoir Water Level Increment Simulation Sub- Model	86
 V	
MODEL APPLICATION	97
Using Model for Forecasting	97
Physical Data Input	98
Rainfall Data Input and Excess Rainfall Computation	102
Executing Rainfall Runoff Simulation	112
Simulating Reservoir Water Level Increment	115
Baseflow Volume Computation	137
Using Model for Model Parameter Calibration and Model Verification Purposes	143
 VI	
RESULTS AND DISCUSSIONS	149
Preliminary of Model Parameter Calibration and Model Verification	149
Model Parameters Selection and Description	150
Rainfall Event Cases Selection and Grouping	151
Model Parameter Calibration	153
Development of the LWRI Curves	154
Verifying the Manning's Coefficients of Surface Roughness Used	162
Model Verification	175
Correlation Analysis on the Simulated and Measured Increments for the Model Verification Cases	179
Statistical Paired <i>t</i> -Test and Single Mean <i>t</i> -Test on the Simulated and Measured Increments for the Model Verification Cases	180

Statistical <i>F</i> -distribution Variance Ratio Test on the Simulated and Measured Increments for the Model Verification Cases	182
Model Evaluation	183
Model Testing	183
Comparison with Rational Method	184
Accuracy and Stability of Model	192
Sensitivity Analysis	195
Impact of Changing Manning's Coefficients of Surface Roughness on the Simulated Results	196
Impact of Catchment Wetness Index on the Catchment Losses Rate and the Simulated Results	208
Overall Model Performance	212
Limitations in Model Application	215
VII SUMMARY, CONCLUSIONS AND RECOMMENDATIONS	217
Summary	217
Conclusions	218
Recommendations for Future Work	220
REFERENCES	222
APPENDICES	230
BIODATA OF THE AUTHOR	270



LIST OF TABLES

Table		Page
2.1	Assumptions of Momentum Equation Used in Various Hydraulic Routing Methods	16
6.1	List of Parameters Used in the Model	151
6.2	Grouping of the Selected Rainfall Event Cases	153
6.3	Details of the Model Parameter Calibration Cases	155
6.4	Simulated and Measured Reservoir Water Level Increments for the Selected Cases for Verifying the Manning's Coefficients Used	164
6.5	Categorization of Correlation Coefficient	166
6.6	Simulated and Measured Reservoir Water Level Increments for the Model Verification Cases	177
6.7	Reservoir Water Level Increments Simulated by the Rational Method with the Measured Values for the Model Verification Cases	188
6.8	Results of Sensitivity Analysis for Changing Manning's Coefficients of Surface Roughness of Overland and Channels	199
6.9	Results of Sensitivity Analysis of Impacts of Catchment Wetness Index on the Catchment Losses Rate and the Simulated Results for the Selected Case 171290 (Group B: 5 mm/hr)	209
6.10	Results of Sensitivity Analysis of Impacts of Catchment Wetness Index on the Catchment Losses Rate and the Simulated Results for the Selected Case 141191 (Group F: 15 mm/hr)	209
6.11	Results of Sensitivity Analysis of Impacts of Catchment Wetness Index on the Catchment Losses Rate and the Simulated Results for the Selected Case 130300 (Group J: 25 mm/hr)	209

LIST OF FIGURES

Figure		Page
3.1	Location Map of Batu Dam Catchment	36
3.2	Topography Map of Batu Dam Catchment	38
4.1	Finite Element Delimitation Process	48
4.2	Finite Element Coordinate System	49
4.3	Sub-Catchments Delimitation of Batu Dam Catchment	63
4.4	Finite Element Overland Strips Delimitation of Batu Dam Catchment	65
4.5	Physical Data Browser Tables of the Overland and Channel Elements of the Model	68
4.6	Map Window with an Info Tool List Window	70
4.7	Tabular Data in an Expanded Info Tool List Window	70
4.8	Illustration of Reservoir Elevation-Capacity Curve	91
4.9	Flow Chart of Model Parameter Calibration	93
4.10	Flow Chart of Model Verification	94
4.11	Flow Chart of Reservoir Water Level Increment Forecasting	95
4.12	Flow Chart of Baseflow Volume Computation	96
5.1	Display of Main Menu for the Reservoir Inflow Forecasting Model showing the Batu Dam Catchment Finite Element Delimitation Map in MapInfo Windows	98
5.2	Selecting Sub Menu Items for Physical Data Input Sub-Model	99
5.3	Dialog Box for Selecting and Browsing Catchment Physical Data Tables	99
5.4	Dialog Box for Editing Manning's coefficients of Surface Roughness for Overland and Channels	100

5.5	Display of Result of Edited Manning's coefficients of Surface Roughness for Overland and Channels	101
5.6	Selecting Sub Menu Items for Rainfall Data Input and Excess Rainfall Computation Sub-Model	103
5.7	Dialog Box for Browsing and Resetting Rainfall Data Table	103
5.8	Display of Rainfall Data Table with Forecasted Rainfall Data for the Illustration Case in MapInfo Windows	104
5.9	Dialog Box for Resetting Rainfall Data Table	104
5.10	Dialog Box for Selecting Number of Rainfall Sub-Periods for Catchment Sections	106
5.11	Dialog Box for Inputting Rainfall Sub-Periods for Lower Catchment Section for the Illustration Case	107
5.12	Display of ARFs for Lower Catchment Section for the Illustration Case	107
5.13	Dialog Box for Selecting Number of Catchment Losses Rates for Catchment Sections	108
5.14	Dialog Box for Inputting Catchment Losses Rate and Corresponding Period for Lower Catchment Section for the Illustration Case	110
5.15	Dialog Box for Various Data Input prior to Computing Recommended Catchment Losses Rate for Catchment Sections for the Illustration Case	110
5.16	Display of Recommended Catchment Losses Rate for the Illustration Case	111
5.17	Dialog Box for prompting Excess Rainfall Computation	111
5.18	Series of Dialog Boxes for Total Routing Time Input in MapInfo Windows	112
5.19	Series of Dialog Boxes for prompting Direct Runoff Simulation in MapInfo Windows	113
5.20	Display of Simulated Direct Runoff Volumes and Corresponding Hydrograph in MapInfo Windows for the Illustration Case	114

5.21	Series of Dialog Boxes for Selecting Number of Water Levels Desired and Corresponding Water Level Simulation Periods Input	116
5.22	Display of Simulated Direct Runoff Volumes for three consecutive Water Level Simulation Periods of the Illustration Case	117
5.23	Main Dialog Box for Simulating Final Reservoir Water Levels and Reservoir Water Level Increments for three consecutive Water Level Simulation Periods of the Illustration Case	118
5.24	Dialog Box for Seepage Rates Input for three consecutive Water Level Simulation Periods of the Illustration Case	119
5.25	Display of Results of Seepage Rates and Volumes for three consecutive Water Level Simulation Periods of the Illustration Case	119
5.26	Series of Dialog Boxes for Baseflow Volumes Input for three consecutive Water Level Simulation Periods of the Illustration Case	121
5.27	Display of Results of Baseflow Volumes for three consecutive Water Level Simulation Periods of the Illustration Case	121
5.28	Series of Dialog Boxes for Baseflow Rates Input for three consecutive Water Level Simulation Periods of the Illustration Case	122
5.29	Display of Results of Baseflow Rates and Volumes for three consecutive Water Level Simulation Periods of the Illustration Case	123
5.30	Series of Dialog Boxes for Inputting Puncak Niaga Discharge Volumes for three consecutive Water Level Simulation Periods of the Illustration Case	124
5.31	Series of Dialog Boxes for Inputting Puncak Niaga Discharge Rates for three consecutive Water Level Simulation Periods of the Illustration Case	125
5.32	Dialog Box for Total Evaporation Data Input for three consecutive Water Level Simulation Periods of the Illustration Case	126

5.33	Display of Results of Total Evaporations for three consecutive Water Level Simulation Periods of the Illustration Case	126
5.34	Dialog Box for Total Direct Rainfall Onto Reservoir Data Input for three consecutive Water Level Simulation Periods of the Illustration Case	127
5.35	Sub Main Dialog Box for Simulating Final Reservoir Water Level and Water Level Increment for the First Water Level Simulation Period of the Illustration Case	129
5.36	Dialog Box for Initial Reservoir Water Level Input for the First Water Level Simulation Period of the Illustration Case	130
5.37	Display of Computed Total Discharge Volume through the 10-inch Bypass Pipe for the First Water Level Simulation Period of the Illustration Case	131
5.38	Series of Dialog Boxes for Computing Total Discharge Volume from the Regulating Gate for the First Water Level Simulation Period of the Illustration Case	132
5.39	Display of Result of Total Discharge Volume from the Regulating Gate for the First Water Level Simulation Period of the Illustration Case	133
5.40	Display of Computed Reservoir Net Inflow Volume with its Components for the First Water Level Simulation Period of the Illustration Case	134
5.41	Display of Results of Simulated Final Reservoir Water Level and Reservoir Water Level Increment for the First Water Level Simulation Period of the Illustration Case	135
5.42	Display of Simulated Initial Reservoir Water Level for the Second Water Level Simulation Period of the Illustration Case	136
5.43	Display of Results of Simulated Final Reservoir Water Levels and Increments for three consecutive Water Level Simulation Periods of the Illustration Case	137
5.44	Main Dialog Box for Computing Baseflow Volume into Reservoir for the First Event Day or the First 24 hours of the Simulation Period	138



5.45	Dialog Box for Inputting Seepages Rates of Event Previous Day in Baseflow Volume Computation	139
5.46	Dialog Box for Inputting Puncak Niaga Discharge Volumes of Event Previous Day in Baseflow Volume Computation	140
5.47	Dialog Box for Inputting Total Evaporation of Event Previous Day in Baseflow Volume Computation	140
5.48	Dialog Box for Inputting Total Direct Rainfall onto Reservoir of Event Previous Day in Baseflow Volume Computation	141
5.49	Dialog Box for Inputting Initial and Final Reservoir Water Levels of Event Previous Day in Baseflow Volume Computation	141
5.50	Display of Computed Total Discharge Volume through 10-inch Bypass Pipe for Event Previous Day in Baseflow Volume Computation	142
5.51	Dialog Box for Computing Total Discharge Volume from the Regulating Gate of Event Previous Day in Baseflow Volume Computation	142
5.52	Display of Computed Baseflow Volume into Reservoir for the First Event Day or the First 24 hours of the Simulation Period of the Illustration Case	143
5.53	Main Dialog Box for Simulating Final Reservoir Water Levels and Reservoir Water Level Increments for three consecutive Event Days in Model Parameter Calibration and Model Verification	145
5.54	Dialog Box for Initial Reservoir Water Levels Input for three consecutive Event Days in Model Parameter Calibration and Model Verification	146
5.55	Display of Computed Total Discharge Volumes through the 10-inch Bypass Pipe for three consecutive Event Days in Model Parameter Calibration and Model Verification	146
5.56	Dialog Box for Computing Total Discharge Volumes from the Regulating Gate for three consecutive Event Days in Model Parameter Calibration and Model Verification	147
5.57	Dialog Box for Selecting Number of Event Days for Baseflow Volumes Computation for Model Parameter Calibration and Model Verification Purposes	148