UNIVERSITI PUTRA MALAYSIA

DECISION SUPPORT SYSTEM FOR OPTIMAL DESIGN AND OPERATION OF PONDS FOR WATERSHED RUNOFF MANAGEMENT

ABDULWAHAB MUJAHED HASAN Al-ANSI

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BY

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

September 2010

DEDICATION

This work is dedicated to my dear Parents, Wife, Daughters, Brother and Sisters your patience and support has been my motivation

Abstract of the thesis submitted to the Senate of Universiti Putra Malaysia in fulfillment of the requirement for the degree of Doctor of Philosophy

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Chairman: **Professor Mohd Amin Mohd Soom, Ph.D., P.Eng., FIEM.**

Faculty: **Engineering**

With climate change and rapid land development the extremes in occurrence of floods and droughts are inevitable. More frequent floods are occurring with bigger losses and damage to properties and lives. On the other hand, agricultural droughts are also more frequent causing shortages of water for crop irrigation during dry seasons. Severe floods and droughts in any watershed or river basin under rapid development make water resources management a very important criteria for environmental and agriculture sustainability.

The Upper Bernam River Basin (UBRB) Malaysia is the main source of irrigation water supply for a 20,000 ha rice granary. There is no dam reservoir for irrigation, but irrigation is by river diversion of the river irrigation system. Landuse has rapidly changed from 1984 until today. This result in shortage of irrigation water supply during low flow months whereas several floods incidents were observed lately. Therefore, it is very important to control floods during high flow months and also

maintain high base flows so that enough water is available for irrigation during the low flow months. Understanding how the landuse change influences the river basin hydrology may enable planners to formulate policies to minimize the undesirable effects of land development. The objectives of this study were to assess the impacts of landuse changes on the watershed runoff in a humid tropical river basin and to develop a decision support system based on continuous hydrological simulation integrated with optimization algorithm to determine the optimal ponds locations, sizes and operations for floods control during high flow months and maintain river flow during low flow months. The need for spatial and temporal land-cover change detection over a larger scale makes satellite imagery the most cost effective, efficient and reliable source of data. The applicability of GIS makes it an important and efficient tool for spatial hydrologic modeling. In this study the integration of GIS and Soil and Water Assessment Tool (ARCSWAT) were used to evaluate the impacts of current and planed of landuse changes on stream flow quantity in the study area.

The study was conducted using 27 years of records (1981-2007). Calibration and validation of the model were performed initially. Model performance was checked using both graphical and statistical indicators. During calibration, the annual, monthly and daily flow results were 0.82, 0.65, 0.68, 0.81, 0.62 and 0.58 for R^2 and E, respectively and 1.00, 0.93, 0.89, 0.99, 0.92 and 0.88 respectively during validation. As for forecasting validation, R^2 and E were 0.98, 0.86, 0.55, 0.91, 0.84 and 0.53 respectively. In general, the model showed good performance in simulating flow as well as forecasting. Five scenarios were performed to identify the individual effect of mixed landuse change on stream flow. The scenario results demonstrated that landuse changes were responsible for an increase in the annual flow depth of 8%

to 39%, and 16% to 59% during high flow months. Landuse changes also caused a decrease of 3% to 32% during low flow months. Flow forecasting for the year 2020 using 30 forecasting cycles was found to be the optimal for the study area. The results showed that there was a decrease by 50% below the monthly irrigation water demand during low flow months, which emphasized the need to include structural best management practices (BMPs) such as ponds in the study area for future land development plan to mitigate the future landuse changes on flow quantity. A watershed runoff management decision support system model (WARM-DSS) was developed to maintain the future development rate with concern for mitigation of its impact to the environment and water quantity. The model showed generally good performance in simulating the runoff with reasonable statistical indicators (3.75, 4.46, 0.034, 0.99 and 0.98 for *MAE*, *RMSE*, *U*, R^2 and *E*, respectively).

For 2020 expected landuse changes in the study area, the model was applied with flood and drought return periods of 2, 5, 10, 20, 50 and 100 years. The results were twelve ponds with total maximum area of 2900 ha, maximum storage capacity of 1.45×10^8 m^3 and specific daily operation were found to be the optimal to achieve the targeted flow during both high flow months and low flow months. The reduction in floods were 20%, 59%, 79%, 140%, 206% and 304% for the return periods of 2, 5, 10, 20, 50 and 100, respectively. While the increases in flow for the drought return periods were 19%, 40%, 47%, 43%, 37% and 30%.

The developed model in this study has high potentiality to be applied for any future development plans to predict the hydrological impacts, to mitigate the risk of floods, and to avoid the shortage of irrigation water. The model also works as a framework

for science-based decision making tool when formulating landuse policies. It can be a practical tool for hydrologists, engineers and town and country planners. The irrigation engineers can use this tool during the planning for irrigation water supply and determination of future ponds location and size to increase the availability of the irrigation water and temporary storage of flood water.

Abstrak tesis yang dibentangkan kepada Senat Universiti Putra Malaysia untuk memenuhi keperluan ijazah Doktor Falsafah

SISTEM SOKONGAN MEMBUAT KEPUTUSAN UNTUK REKA BENTUK DAN PENGENDALIAN KOLAM TAKUNGAN YANG OPTIMUM PENGURUSAN AIR LARIAN DI TADAHAN DALAM

Oleh

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Memang tidak dapat dinafikan lagi dengan perubahan iklim dan pembangunan yang pesat menyebabkan banjir dan kemarau yang semakin meningkat. Kekerapan banjir menyebabkan kerugian yang besar dan kerosakan kepada harta benda dan nyawa. Dalam pada itu, kemarau yang panjang disebabkan oleh kekurangan hujan memberi impak yang besar terhadap pertanian. Banjir dan kemarau yang dahsyat berlaku akan memberi kesan terutama sekali terhadap kawasan tadahan air hujan kerana ia

merupakan kriteria yang utama dalam perancangan sumber air untuk memastikan kestabilan alam sekitar dan pertanain yang mampan.

Lembangan Hulu Sungai Bernam Malaysia adalah merupakan sumber bekalan air yang digunakan untuk pengairan kawasan seluas 20,000 hektar tanaman padi. Tidak terdapat sebarang takungan empangan bagi tujuan pengairan tersebut, tetapi pengairan adalah berpunca daripada anak-anak sungai dari sistem oengairan sungai. Perubahan guna tanah yang berleluasa sejak tahun 1984 sehingga hari ini menyebabkan berlakunya kekurangan bekalan air untuk sistem pengairan ketika musim kemarau sedangkan banjir turut berlaku pada musim tengkujuh. Oleh itu, amatlah penting untuk mengawal paras air banjir pada musim tengkujuh dan juga memantau aliran asas supaya memastikan air mencukupi untuk pengairan semasa musim kemarau. Pihak perancang perlu memahami bagaimana guna tanah boleh mempengaruhi kawasan tadahan air hujan untuk meminimumkan impak yang tidak diingini kesan daripada pembangunan.

Objektif kajian ini adalah untuk mengenalpasti impak perubahan guna tanah terhadap kawasan tadahan air hujan di kawasan tropika yang lembap dan membangunkan sistem sokongan membantu keputusan berdasarkan simulasi hidrologi bersepadu dengan algoritma yang optimum untuk mengenal pasti lokasi kolam yang optima, saiz dan kawalan operasi mengawal banjir di musim tengkujuh dan memantau aliran asas ketika musim kemarau. Imej satelit adalah salah satu teknik pengumpulan data yang efektif, berkesan dan kos yang berpatutan untuk skala data yang besar. Fungsi GIS membuktikan ia penting dan efektif untuk model hidrologi spatial. Dalam kajian ini integrasi antara GIS dan alat penilaian tanah dan air (ARCSWAT) telah

digunakan untuk mengenalpasti impak terhadap perubahan guna tanah terancang pada masa kini dalam perubahan kuantiti aliran sungai dalam kawasan kajian. Kajian ini menggunakan rekod 27 tahun dari tahun 1981 hingga 2007. Prestasi model telah ditentukan dengan kalibrasi dan validasi. Model prestasi telah di uji dengan menggunkan graf dan teknik statistik. Dalam proses kalibrasi, data bagi setiap tahun, setiap bulan dan setiap hari masing-masing adalah 0.82, 0.65, 0.68, 0.81, 0.62 dan 0.58 untuk R^2 dan E diikuti dengan 1.00, 0.93, 0.89, 0.99, 0.92 dan 0.88 ketika dalam proses validasi model. Untuk penilaian ramalan, nilai R^2 dan E adalah 0.98, 0.86, 0.55, 0.91, 0.84 dan 0.53. Secara amnya, hasil model menunjukkan persembahan data simulasi aliran adalah lancar seperti juga dalam ramalan.

Lima senario telah diwujudkan untuk mengenal pasti setiap kesan terhadap guna tanah yang bercampur dengan perubahan aliran sungai. Setiap keputusan demonstrasi bagi setiap senario menunjukkan perubahan terhadap guna tanah mempengaruhi peningkatan tahunan aliran dari 8% kepada 39% dan 16% kepada 59% ketika musim tengkujuh. Perubahan guna tanah menyebabkan penurunan aliran dari 3% kepada 32% ketika musim kering. Ramalan aliran sungai pada tahun 2020 menggunakan 30 kitar ramalan telah didapati optimum untuk kawasan kajian. Keputusan menunjukkan penurunan sebanyak 50% ke bawah dalam pengairan bulanan yang memenuhi kehendak semasa di mana ia menunjukkan kepentingan hasil data tersebut untuk memasukkan perancangan struktur yang terbaik (BMP) seperti kolam dalam kawasan kajian untuk perancangan masa depan bagi mengurangkan kesan perubahan guna tanah dari segi kuantiti aliran.

Model sistem pengurusan tadahan air sungai (WARM) telah dibangunkan untuk mengawal kadar pembangunan masa depan dengan mengambil kira penurunan kualiti air dan kesan terhadap alam sekitar. Model yang telah direka menunjukkan persembahan data simulasi dengan baik menggunakan penanda statistik (3.75, 4.46, 0.034, 0.99 dan 0.98 untuk *MAE*, *RMSE*, *U*, R^2 dan *E*). Untuk keadaan perubahan tanah pada 2020, model ini telah dilengkapi dengan simulasi kemarau dan banjir pada kala kembali 2, 5, 10, 20, 50 dan 100 tahun. Keputusan menunjukkan 12 kolam dengan jumlah keluasan maksimum sebanyak 2900 hektar, kapasiti simpanan maksimum sebanyak 1.45 X $10^8 m^3$ dengan pengoperasian harian yang spesifik adalah optimal untuk dicapai dengan aliran yang ditetapkan ketika musim kemarau dan tengkujuh. Pengurangan sebanyak 20%, 59%, 79%, 140%, 206% dan 304% pada kala kembali 2, 5, 10, 20, 50 dan 100 tahun. Peningkatan dalam aliran limpahan keluar ketika musim kemarau berkurang sebanyak masing-masing 19%, 40%, 47%, 43%, 37% dan 30%.

Model yang dibangunkan ini mempunyai potensi yang tinggi bagi diaplikasikan pada pelan pembangunan masa hadapan untuk meramal impak hidrologi, pengurangan risiko terhadap banjir dan mengelakkan kekurangan air untuk sistem pengairan semasa musim kemarau. Model ini juga berfungsi sebagai rangka asas untuk membuat keputusan berdasarkan fakta saintifik yang menggunakan alat apabila membentuk polisi guna tanah. Ia adalah persediaan yang praktikal terutamanya kepada pakar hidrologi, jurutera, perancang bandar dan desa. Jurutera pengairan juga boleh menggunakan alat ini untuk merancang sistem bekalan air pengairan dan menentukan kedudukan lokasi dan saiz kolam takungan sementara bagi

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I certify that a Thesis Examination Committee has met on 17 September 2010 to conduct the final examination of Abdulwahab Mujahed Hasan Al-Ansi on his thesis entitled "Decision Support System for Optimal Design and Operation of Ponds for Watershed Runoff Management" in accordance with Universities and University colleges Act 1971 and the constitution of the Universiti Putra Malaysia [P.U. (A) 106] 15 March 1998. The Committee recommends that the student be awarded the Doctor of Philosophy.

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DECLARATION

I 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 and is not concurrently, submitted for any other degree at Universiti Putra Malaysia or other institutions.

ABDULWAHAB MUJAHED HASAN AL-ANSI

Date: 17 September 2010

TABLE OF CONTENT

		Page
DEDICATION		ii
ABSTRACT		iii
ABSTRAK		vii
ACKNOWLEDGEMENTS		xi
APPROVAL		xiv
DECLARATION		xv
LIST OF TABLES		xix
LIST OF FIGURES		xxii
LIST OF ABBREVIATIONS		xxvi
CHAPTER		
1	**INTRODUCTION**	1.1
	1.1 General	
	1.2 Theory and Importance of the Study	1.1
	1.3 Problem Statement	1.3
	1.4 The Scope of the Work	1.6
	1.5 Goals and Objectives	1.7
	1.6 Thesis Organization	1.9
		1.10
2	**LITERATURE REVIEW**	2.1
	2.1 Introduction	2.1
	2.2 Watershed Hydrology	2.1
	2.3 Watershed Hydrological Problems in Malaysia	2.2
	2.3.1 Floods Causes and Management in Malaysia	2.3
	2.3.2 Drought Causes and Management in Malaysia	2.5
	2.4 Upper Bernem River Basin	2.6
	2.5 Watershed Hydrological Modeling Approaches	2.8
	2.5.1 Event Based Models	2.8
	2.5.2 Continues Simulation Models	2.10
	2.6 Spatial Information Technology in Watershed Hydrological Modeling	2.15
	2.6.1 Geographic Information Systems	
	2.6.2 Remote Sensing	2.16
	2.6.3 Digital Terrain Analysis	2.18
	2.7 Hydrological Modeling in GIS Environment	2.19
	2.8 Best Management Practices (BMP) Applications for Watershed Runoff Management	2.24 2.28
	2.8.1 Non-Structural Best Management Practices (NSBMP)	2.29
	2.8.2 Structural Best Management Practices (SBMP)	

2.9 Decision Support System Applications in Watershed Runoff Management 2.31
2.10 Summary 2.34
2.39

4 **RESULTS AND DISCUSSION** 4.1

4.1 Introduction 4.1
4.2 Precipitation and Runoff Data Analysis 4.1
4.2.1 Rainfall and Flow Data Consistency 4.1
4.2.2 Stormwater Return Periods and Frequencies Analysis 4.7
4.2.3 Flood Runoff Frequency and Return period 4.10
4.2.4 Drought Runoff Frequency and Return Period 4.12
4.3 Landuse Changes in the Study Area 4.14
4.4 Assessment of the Effects of Landuse Changes on Watershed Hydrology 4.15
4.4.1 Evaluation of SWAT Model for Flow Simulation 4.15
4.4.2 Evaluation of SWAT Model for Flow Forecasting 4.23
4.5 The Sensitivity of Watershed Stream flow Pattern to the Changes in Mixed Landuse 4.28
4.6 The Forecasted Effects of Future Land-use Changes on Stream Flow Quantity 4.30
4.7 WARM-DSS for Watershed Runoff Management 4.32
4.7.1 Evaluation of WARM-DSS Performance 4.33
4.7.2 Application of WARM-DSS for Floods Control 4.47
4.7.3 Application of WARM-DSS for River Base Flow Maintaining 4.51
4.7.4 Application of WARM-DSS for Dual Purposes of Flood Control and Maintaining River Base Flow 4.53
4.7.5 The Practical Ponds Implementation in the Study Area 4.55

5 **SUMMARY, CONCLUSION AND RECOMMENDATION** 5.1

5.1 Summary 5.1
5.2 Conclusion 5.3
5.3 Recommendations 5.5

REFERENCES R.1
APPENDICES A.1
BIODATA OF STUDENT B.1
LIST OF PUBLICATIONS B.2