

**INTEGRATED WATER MANAGEMENT DECISION SUPPORT SYSTEM
FOR SEBERANG PERAK PADDY ESTATE**

By

MOHAMED MUJITHABA MOHAMED NAJIM

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

July 2004

*Dedicated to the author's Mother Mrs. M.H. Fathuma, and Father Mr. A.W.M.
Mujithaba*

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

**INTEGRATED WATER MANAGEMENT DECISION SUPPORT SYSTEM
FOR SEBERANG PERAK PADDY ESTATE**

By

MOHAMED MUJITHABA MOHAMED NAJIM

July 2004

Chairman: Associate Professor Lee Teang Shui, Ph.D.

Faculty: Engineering

A study was carried out to develop an integrated water management decision support system for the Seberang Perak paddy estate. The decision support system incorporated results from a database management system, a model base management system and a rule based knowledge base system.

The domain experts' knowledge on integrated water management were collected together with other secondary historical data that were used in the modeling approach to generate more knowledge on different combinations of possible scenarios. The modeling approaches used in the knowledge generation was evapotranspiration modeling, a flow routing modeling, a water balance modeling and a crop growth and a yield modeling. A GIS was used in the output model to make the decision support system outputs more effective in their presentation.

The evapotranspiration modeling tested the suitability of a few methods to predict evapotranspiration in the project area using 45 years of weather data.

The results suggested applying the Penman-Monteith, the Pan or the Blaney-Criddle models for the project area seems to be the best. Because of its worldwide applicability, the Penman-Monteith model was utilized in the study.

The flow routing routine performed showed good agreement with measured data. Evapotranspiration estimates, flow routing and water balance applied to each of the field plots for all possible scenarios, suggested alternative decisions for the better performance of the paddy estate. All these results were coded to rules and kept in knowledge bases that will be posted as outputs for user queries.

Major problem identified in the Seberang Perak paddy estate was the land preparation water management. Land preparation needs to be completed within 16 days so that the targeted 250% cropping intensity could be achieved. This is only possible when canals are flowing full and a part of the total water requirements is supplemented with rainfall. The modeling approach suggested many possible alternate scenarios and decision alternatives, which were gathered in the knowledge bases.

The knowledge generated through modeling approach was always verified with domain experts from the sub-estates concerned. The acceptable knowledge were then coded to pseudocodes and translated to rules of the knowledge bases. All the added rules to the knowledge bases were verified and validated for the proper functioning of the decision support system components. All the knowledge-based modules (menu module, crop schedule, land preparation

water management, second supply water management, supply after fertilizer application, yield modeling and drainage management) were linked under a same platform. The outputs and results of these components are linked with a GIS and other relevant information.

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

**SISTEM SOKONGAN BERKEPUTUSAN PENGURUSAN AIR BERSEPADU
UNTUK ESTET PADI SEBERANG PERAK**

Oleh

MOHAMED MUJITHABA MOHAMED NAJIM

Julai 2004

Pengerusi: Profesor Madya Lee Teang Shui, Ph.D.

Fakulti: Kejuruteraan

Satu kajian telah dibuat demi membangunkan sebuah sistem sokongan berkeputusan pengurusan air bersepadu untuk Estat Padi Seberang Perak. Sistem sokongan berkeputusan menggabungkan keputusan keputusan daripada satu sistem pengurusan pangkalan data, satu sistem pengurusan pangkalan model dan satu sistem pangkalan ilmu berasas petua.

Ilmu pengurusan air bersepadu pakar domain dikumpulkan bersama sama data sejarah sekunder yang diguna untuk pendekatan menjanakan lebih ilmu mengenai kombinasi senario. Pendekatan pemodelan dipakai menjanakan ilmu ialah pemodelan penyejatpeluhan, pemodelan penghalaan aliran, pemodel pengimbangan air dan pemodelan tumbuhan tanaman dan hasil. Satu GIS telah dipakai dalam model pengeluaran demi mempersembahkan secara berkesan hasil sistem sokong berkeputusan.

Pemodelan penyejatpeluhan mengujikan kesesuaian beberapa kaedah untuk meramalkan penyejatpeluhan dikawasan tersebut dengan 45 tahun data cuaca. Berdasar keputusan keputusan diperolehi boleh diusulkan bahawa kaedah Penman-Monteith, Pan atau Blaney-Criddle untuk kawasan projek merupakan yang terbaik. Oleh kerana penggunaannya di seluruh dunia, model Penman-Monteith telah pakaiguna dlam kajian ini.

Rutin penghalaan aliran yang dijalankan telah menunjuk persetujuan dengan data yang diukurkan. Penaksiran penyejatpeluhan, penglaan aliran dan pengimbangan air yang dipakiaguna dalam setiap plot bagi semua senario yang boleh berlaku, telah mengusulkan keputusan keputusan berlainan demi untuk perlaksanaan lebih baik untuk estet padi itu. Semua keputusan telah dikodkan menjadi petua dan disimpan dalam pangkalan limu yang akan dikeluarkan sebagai hasil berasaskan soaltanya pengguna.

Masalah utama yang disahkan di Estet Padi Seberang perak ialah pengurusan air semasa penyediaan tanah. Penyediaan tanah perlu disiapkan dalam 16 minggu semoga 250% intensiti tanaman boleh dicapai. Ini hanya boleh dicapai sekiranya aliran saluran penuh dan sebahagian jumlah keperluan diisikan hujan. Pendekatan model memberi banyak senario pilihan dan pilihan keputusan yang dikandungkan didalam pangkalan olmu.

Ilmu yang dijanakan melalui pendekatan pemodelan sentiasa disahkan oleh pakar domain daripada subestet berkenaan. Ilmu yang boleh diterima kemudian dikodkan dalam psedokod dan diterjemahkan kepada petua petua

pangkalan ilmu. Semua petua yang ditambah kedalam pangkalan ilmu telah ditentukan dan dinilai demi untuk menjamin fungsi komponen komponen sistem sokongan berkeputusan. Semua modul modul (module menu, jadual tanaman, pengurusan air penyediaan tanah, pengurusan air, pengurusan air bekalan kedua.bekalan selepas semburan baja, pemodelan hasil dan pengurusan salira) telah digabungkan dibawah satu platform. Pengeluran dan keputusan komponen komponen digabungkan dengan GIS dan maklumat lain yang bersabit

ACKNOWLEDGEMENTS

All praise to Almighty Allah for his unlimited graciousness and kindness in all endeavors that have made me to proceed in my life so far.

I would like to express my sincere gratitude to Associate Prof. Dr. Ir. Lee Teang Shui, Department of Biological and Agricultural Engineering, Faculty of Engineering, Universiti Putra Malaysia, advisor, for his invaluable guidance, spontaneous support, constructive comments and continuous encouragement in the successful accomplishment of this thesis. I also would like to express my sincere gratitude to Prof. Dr. Ir. Mohd. Amin Mohd. Soom and Associate Prof. Dr. Ir. Thamer Ahmed Mohammed for their continuous guidance, advise, critical comments and encouragement throughout my study.

I would like to thank the staff of FELCRA Seberang Perak, Kg Gajah, Perak, Malaysia for the technical support in providing me the necessary data. Special thanks are due to Tuan Haji Mohd. Naim Bin Desa, Manager, Paddy Estate, FELCRA Seberang Perak, for his guidance and help through out the data collection period. I would also like to extend my sincere gratitude to all the managers and senior assistant executives in FELCRA Seberang Perak for helping me during the process of decision support system development and validation. I would like to express my sincere thanks to the Department of Irrigation and Drainage, Ampang and Ulu Dedap, and the Malaysian Meteorological Services for providing me weather, canal, and other secondary data.

I would like to express my profound appreciation to the Graduate Research Assistantship donor, the Intensification of Research in Priority Areas (IRPA) program, Ministry of Science, Technology, and Environment, Malaysia for providing financial assistance.

My sincere thanks are due to Mr. Md. Aminul Haque, Mr. Nazrim Marikkar, Mr. Muiyudeen, Mr. Prabath Jayasinghe, and others for allocation of their valuable time when I was in need of help throughout my stay in Malaysia.

Above all, I would like to specially express my indebtedness to my parents Mr. A.W.M. Mujithaba and Mrs. M.H. Fathuma, my wife Mrs. M.S. Najbul Husna and daughter Miss. M.N. Nafla for their sacrifices, patience, continuous encouragement and guidance during my study period in Universiti Putra Malaysia.

I certify that an Examination Committee met on 8 July 2004 to conduct the final examination of Mohamed Mujithaba Mohamed Najim on his Doctor of Philosophy thesis entitled “Integrated Water Management Decision Support System for Seberang Perak Paddy Estate” 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:

Abdul Rashid Bin Mohamed Shariff, Ph.D.
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Abdul Halim Ghazali, Ph.D.
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Member)

Abdul Aziz Zakaria, Ph.D.
Lecturer
Faculty of Engineering
Universiti Putra Malaysia
(Member)

Guido Wyseure, Ph.D
Professor
Faculty of Applied Bioscience and Engineering
Katholieke Universiteit Leuven
Belgium
(Independent Examiner)

GULAM RUSUL RAHMAT ALI, Ph.D.
Professor/ Deputy Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:

This thesis submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee are as follows:

**Lee Teang Shui, Ph.D.
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)**

**Mohd Amin Mohd Soom, Ph.D.
Professor
Faculty of Engineering
Universiti Putra Malaysia
(Member)**

**Thamer Ahmed Mohammed, Ph.D.
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Member)**

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

Date:

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.

MOHAMED MUJITHABA MOHAMED NAJIM

Date:

TABLE OF CONTENTS

		Page
DEDICATION		ii
ABSTRACT		iii
ABSTRAK		vi
ACKNOWLEDGEMENTS		ix
APPROVAL		xi
DECLARATION		xiii
LIST OF TABLES		xvii
LIST OF FIGURES		xix
LIST OF ABBREVIATIONS		xxi
CHAPTER		
I	INTRODUCTION	1
	Background	1
	Statement of The Problem	3
	Objectives of The Study	4
	Scope of The Study	5
II	LITERATURE REVIEW	6
	Introduction	6
	Water Balance Modeling	6
	Channel Routing in Irrigation Projects	12
	Irrigation Scheduling in Rice Fields	14
	Crop Growth, Fertilizer Response and Yield in Rice	15
	Growth, Yield and Water	16
	Growth, Yield and Fertilizer	18
	Direct Seeded Rice	20
	Modeling Water and Fertilizer Effect on Rice Yield	21
	GIS Application in Water Resources Management	26
	Decision Support Tools in Irrigation Management	29
	Concluding Remarks	37
III	METHODOLOGY	39
	Introduction	39
	Database Management Sub-System	39
	Model Management Sub-System	42
	Evapotranspiration Model	42
	Water Balance Model	43
	Flow Routing Model	51
	Crop Growth Modeling	52
	Dialog Sub-System	54
	Knowledge Base Sub-System	54
	DSS Development	55

IV	STUDY AREA AND DATA COLLECTION	60
	Seberang Perak Project Area	60
	Climate	65
	Land and Soil Characteristics in Seberang Perak	69
	Infrastructure Development in Seberang Perak	70
	FELCRA Seberang Perak Management	74
	Data Collection	83
V	KNOWLEDGE GENERATION	85
	Introduction	85
	Problem Identification Through Consultation	85
	Evapotranspiration at Seberang Perak	87
	Crop Schedule	89
	Canal Management	90
	Canal Filling	92
	Canal Flow Time	93
	Flow Management	96
	Management Rules	103
	Water Balance	109
	Land Preparation Water Supply	109
	Second Supply Water Management	114
	Water Management After Fertilizer	115
Application		
	Land Preparation Water Management	115
	Second Supply Water Management	125
	Supply After Fertilize Application	126
	Yield Modeling	127
	Drainage Management	128
VI	DESIGN, DEVELOPMENT AND OPERATION OF DSS	130
	Structure of The DSS	130
	Knowledge Base Structure	132
	Module Designing	136
	Menu Level Module	137
	File Menu Module	140
	Paddy Estate Menu Module	140
	Models Menu Module	142
	Project Management Menu Module	143
	Guidelines Menu Module	143
	About Menu Module	144
	Knowledge Based Program Module	145
	Crop Schedule Module	146
	Canal Management Module	148
	Land Preparation Water Management Module	156
	Second Supply Water Management Module	163
	Supply After Fertilizer Application Module	165
	Yield Modeling Module	165
	Drainage Management Module	167

	User Interface Structure and Its Designing	168
	Verification of The Decision Support System	170
	Validation of The Decision Support System	173
VII	DSS CAPABILITIES AND OUTPUT	174
	Crop Schedule	174
	Canal Management	175
	Canal Filling	175
	Flow Time	175
	Flow Management	176
	Management Rules	177
	Land Preparation Water Management	180
	Second Supply Water Management	185
	Supply After Fertilizer Application	186
	Yield Modeling	186
	Drainage Management	187
	Limitations of PEsIDS	188
VIII	SUMMARY AND CONCLUSIONS	189
	Summary	189
	Conclusions	190
	Suggestions for Future Work	192
	REFERENCES	194
	APPENDICES	205
	BIODATA OF THE AUTHOR	251

LIST OF TABLES

Table		Page
3.1	Water balance condition and net irrigation requirement	46
3.2	Maximum (S_{\max}) and minimum (S_{\min}) allowable water levels for medium duration rice variety	46
4.1	Land and soil characteristics in Seberang Perak	69
4.2	Area and number of plots under each sub-estate	75
5.1	Comparison of evapotranspiration estimation methods	88
5.2	Monthly averages of evapotranspiration at Seberang Perak	89
5.3	Canal simulation results at different gauging stations	90
5.4	Experts' knowledge and experience on canal filling	93
5.5	Sample knowledge on flow approach and filling time	95
5.6	General knowledge on flow management at different depth levels at control D	97
5.7	Sample knowledge on land preparation and normal supply schedule	97
5.8	Land preparation supply in R8 secondary block when the flow level at control D is depth ≥ 2.163 m	102
5.9	Standing water supply by operating a single R8 tertiary canal in a day at sub-estate G	102
5.10	Knowledge on canal filling time	104
5.11	Management knowledge on canal closing	106
5.12	Knowledge on drainage management when it rains	108
5.13	Supply schedule in L1C and L1A secondary blocks	109
5.14	Time to complete land preparation supply in sub-estate E when canal supply is design discharge with no rainfall	110
5.15	Land preparation supply duration and rainfall in sub-estate E for main season with 200% cropping intensity and a case of less than design discharge	111

5.16	Standing water supply schedule for R8 secondary block	113
5.17	Land preparation supply duration in R8 secondary block for main season with 200% cropping intensity	114
5.18	Knowledge generation for sub-estates E and F when supply is design discharge	119
5.19	Knowledge generation for sub-estate G when supply is design discharge and less than design discharges	121
5.20	Knowledge generation for sub-estates E and F when supply is less than design discharge	123
6.1	Knowledge base on crop schedule information system	133
6.2	Organization of the menu level module	138

LIST OF FIGURES

Figure		Page
3.1	Outline of The Decision Support System	40
3.2	Water Balance for The Decision Support System	49
3.3	Linkage of Water Balance, Flow and Yield	50
3.4	Phases of Decision Support System Development	57
3.5	The Conceptual Decision Support System	58
3.6	Decision Support System Components and Their Interactions	59
4.1	Location of Seberang Perak Granary Area and Other Major Rice Growing Areas in Peninsular Malaysia	61
4.2	Seberang Perak Paddy Estate	62
4.3	Average Rainfall in Ulu Dedap	66
4.4	Average Rainy Days in Ulu Dedap	66
4.5	Average Monthly Sunshine Duration and Net Radiation in Sitiawan	67
4.6	Daily Average Evapotranspiration in Seberang Perak	68
4.7	Daily Average Temperature in Seberang Perak	68
4.8	Daily Average Wind Speed and Relative Humidity (RH) in Seberang Perak	69
4.9	A Tertiary Block in FELCRA Seberang Perak	71
4.10	Layout of a Field Lot (Plot) in FELCRA Seberang Perak	73
4.11	Organization Chart of FELCRA Seberang Perak	76
4.12	Secondary Blocks in The Paddy Estate	77
4.13	Organization Chart of Sub-Estates E, F and G	78
4.14	200% Cropping Schedule Practiced by FELCRA Seberang Perak	81
4.15	250% Cropping Schedule Practiced by FELCRA Seberang Perak	82

4.16	Average Yields Achievement in Seberang Perak Paddy Estate	83
5.1	Secondary Canal Layout in Seberang Perak Paddy Estate	91
5.2	Land Preparation Supply Schedule in R8 Secondary Block When the Flow Level at Control D is $\geq 2.163\text{m}$	103
5.3	Land Preparation Supply Schedule When The Flow Level at Control D is $2.069 \leq \text{Depth} < 2.119$	112
6.1	Structure of The Decision Support System	131
6.2	Relationship Among Modules	136
6.3	Appearance of Decision Support System With Modules	137
6.4	Structure of The Knowledge Based Program Module	145
6.5	Structure of Crop Schedule Module	147
6.6	Structure of Canal Filling Sub Module	149
6.7	Sample Output From Canal Filling Sub Module	149
6.8	Structure of Flow Time Sub Module	151
6.9	Flow Management Sub Module Structure	153
6.10	Management Rules Sub Module Structure	155
6.11	Structure of Land Preparation Supply Module	158
6.12	Screen Showing Data Input to The Decision Support System	161
6.13	Structure of Second Supply Water Management Module	164
6.14	Structure of Irrigation Water Supply After Fertilizer Application	166
6.15	Structure of Yield Modeling Module	167
6.16	Structure of Drainage Management Module	168
6.17	Debugging Feature to Locate Errors	172
7.1	Land Preparation Supply Schedule For L6 (Sub-Estate F) Secondary Canal When The Depth Range is $2.069 \leq \text{Depth}$ at Control D $< 2.119\text{ m}$	178

LIST OF ABBREVIATIONS

ρ_a	air density
$(e_a - e_d)$	vapor pressure deficit
A	flow cross-sectional area
AEGIS	Agricultural and Environmental Geographic Information System
AGNPS	AGricultural Non-Point Source
AI	Artificial Intelligence
ANSWERS	Aerial Non-point Source Watershed Environment Response Simulation
A_{pt}	rice area under land preparation during time period t
A_{st}	rice area under soaking during time period t
BERNAS	National Paddy and Rice Authority
CanalMan	Canal Management Software
C_p	specific heat of the air at constant pressure
CropSyst	Cropping Systems Simulation Model
D	Day
DID	Department of Irrigation and Drainage
DMIS	Decision support system for the management of the irrigation schedule
DOA	Department of Agriculture
dp	depth of water required for crop submergence
d_r	relative distance Earth – Sun
DR_j	amount of drainage
ds	depth of water required to saturate the soil
DSS	Decision support system
DSSAT	Decision Support System for Agrotechnology Transfer
e_a	saturation vapor pressure
$e_a(T)$	saturation vapor pressure at temperature T
$e_a(T_{max})$	saturation vapour pressure at T_{max}
$e_a(T_{min})$	saturation vapour pressure at T_{min}
e_d	actual vapor pressure
E	evaporation rate
E_{pan}	Pan-evaporation
ERF_t	effective rainfall during time period t
ET_j	crop evapotranspiration
ET_o	reference crop evapotranspiration
E_u	irrigation efficiency
EXPERDI	Computerized System for the Distribution of Water in Irrigation Modules
FAO	Food and Agriculture Organization
FELCRA	Federal Land Consolidation and Rehabilitation Authority
FOA	Farmer Organization Authority
F_r	Froude number
FSL	Full supply Level
g	ratio of weight to mass
G	soil heat flux
GIS	Geographical Information System
GRASS	Geographic Resources Analysis Support System
h	flow depth

h_c	mean height of the crop
HSPF	Hydrology Simulation Procedure - FORTRAN model
IFCC	Improved Field Capacity Concept
IMSOP	Irrigation Main System Operation model
INCA	Irrigation Network Control and Analysis software
IPM	Integrated Pest Management
IR_j	amount of irrigation water applied
IRRI	International Rice Research Institute
ISM	Irrigation Scheduling Model
j	time period in days
J	number of the day in the year
JICA	Japan International Cooperation Agency
K	Potassium
K_p	Pan coefficient
L	leaf area index
LBC	Left Branch Canal
LPRF	rainfall during land preparation period
M	Month
MARDI	Malaysian Agricultural Research and Development Institute
MMS	Malaysian Meteorological Services
MUDA	Muda Agricultural Development Authority
n	actual duration of sunshine
N	maximum possible duration of sunshine or daylight hours
n/N	relative sunshine fraction
NIR	net irrigation requirement
NIR_{it}	irrigation requirement of rice during time period t
NPS	non-point source
NuDSS	Nutrient Decision Support System
OMIS	Operational Management of Irrigation Systems
OR_{it}	irrigation requirement of offtake i during time period t
P	atmospheric pressure
PEsIDS	Paddy Estate Integrated water management Decision Support
system	
PRF	rainfall during prior period
p_{rt}	land preparation requirement during time period t
Q	flow rate
r_a	aerodynamic resistance
R_a	extraterrestrial radiation
RBC	Right Branch Canal
r_c	vegetation canopy resistance to water vapor transfer
RF_j	rainfall received during j th day
RH	Relative Humidity
RH_{max}	maximum daily relative humidity
RH_{min}	minimum daily relative humidity
R_n	net radiation at crop surface
R_{nl}	net outgoing long-wave radiation
R_{ns}	net incoming short-wave radiation
RO_j	surface runoff
RP	required ponding depth
r_{st}	land soaking requirement during time period t

SDSSs	Spatial decision support systems
S_f	energy loss gradient
SIMRIW	Simulation Model for Rice-Weather Relationship
S_{max}	Maximum allowable water levels
S_{min}	Minimum allowable water levels
S_o	longitudinal bed slope
SP	seepage and percolation rate
SP_j	amount of seepage and percolation loss
T	air temperature
t	elapsed time
T_{max}	maximum daily temperature
$T_{max.k}$	maximum temperature [K]
T_{min}	minimum daily temperature
$T_{min.k}$	minimum temperature [K]
tp	time required to land preparation
ts	time required to saturate the soil
U_2	wind speed measured at 2 m height
U_z	wind speed measurement at height z
V_a	volume of water supplied to the plot per day
V_{nr}	net volume of water requirement in a plot per day
WADPRO	Water Allocation and Distribution Program
WD_j	water ponding depth in the field on the jth day
WD_{j-1}	water ponding depth in the field on the (j-1)th day
x	longitudinal distance in the direction of flow
z	height at which meteorological variables are measured
Z	seepage loss term
z_o	aerodynamic roughness of the surface
γ	psychrometric constant
Δ	slope of the vapor pressure curve
δ	solar declination
λ	latent heat of vaporization
ϕ	latitude
ω_s	sunset hour angle
ΔS	Storage
Δt	computational time step
Δx	spatial increment in the direction of flow
ϕ	spatial weighting factor
θ	temporal weighing factor