UNIVERSITI PUTRA MALAYSIA

MODELING OPTIMAL WATER MANAGEMENT FOR RESERVOIR BASED IRRIGATION PROJECTS

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MODELING OPTIMAL WATER MANAGEMENT FOR RESERVOIR BASED IRRIGATION PROJECTS

By

MD. HAZRAT ALI

Thesis Submitted in Fulfilment of the Requirements for the Degree of Doctor of Philosophy in the Faculty of Engineering Universiti Putra Malaysia

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Dedicated to the author's heartfelt loving parents and wife

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LIST OF ABBREVIATIONS

A	Cross-sectional area
$A_r(t)$	Reservoir surface area
A_v	Area of void
$A_w(t)$	Watershed area during period t
ADAPT	Areal Design and Planning Tool
AGNPS	Agriculture Non-Point Source
ANSWERS	Areal Nonpoint Source Watershed Environmental Response Simulation
ARMA	Autoregressive Moving Average
B	Cross-sectional top width
b	Soil moisture curve parameter
BD	Soil bulk density
BCS	Basin Characteristics System
BGIS	Basin Geographic Information Systems
BRASS	Basin Runoff and Streamflow Simulation
C	Percent clay
c	Kinematic wave celerity
C_p	Specific heat of air at constant pressure
c_s	Soil heat capacity
C_u	Uniformity coefficient
C_1	Constant
C_2	Constant
C_3	Constant
C_4	Constant
CAD	Computer Aided Design
CARL	Central Attributed Raster Line
CEC	Ratio of cation-exchange capacity of clay to percent clay
CRSS	Colorado River Simulation System
D	Hydraulic depth
d_s	Estimated effective soil depth
$\bar{d}$	Mean depth of water stored during irrigation
DHI	Danish Hydraulic Institute
DP	Dynamic Programming
DSS	Decision Support Systems
E	Vapor flux rate

$E(t)$	Evaporation rate at the reservoir surface area
E_c	Conveyance efficiency
E_d	Distribution efficiency
e_d	Mean actual vapor pressure of air at dew point temperature
E_i	Irrigation efficiency
E_p	Free-surface or potential evaporation
E_u	Water use efficiency
e^0	Saturated vapor pressure of the air
EPAD	Edge Probability Attributed Data
ERDAS	Earth Resources Data Analysis System
ERS	European Remote Sensing Satellite
ET	Evapotranspiration
ET_a	Actual evapotranspiration
ET_p	Potential evapotranspiration
$ET_p(t,t+\Delta t)$	Evapotranspiration between t and $t+\Delta t$
$F(t)$	Cumulative infiltration
f	Infiltration rate
FAP	Flood Action Plan
FARIMA	Fractionally differenced autoregressive integrated moving average
G	Soil heat flux
$IG(t)$	Any other gain
GCM	General Circulation Model
GIS	Geographic Information System
GIUS	Geographical Instantaneous Unit Hydrograph
GRASS	Geographic Resources Analysis Support System
h_c	Mean height of the crop
h_0	Ponding depth
HEC	Hydrologic Engineering Center
HYSSR	Hydro System Seasonal Regulation
i	Hydraulic gradient
$I(t,t+\Delta t)$	Infiltration/percolation between t and $t+\Delta t$
I^j	Inflow of water diverted from the source to the conveyance system
IR	Irrigation requirement
IR_R	Amount of water supply from reservoirs
IR_{Rec}	Recycled water supply
IR_{UCF}	Uncontrolled river flow supply

K	Hydraulic conductivity
K_x	Lateral hydraulic conductivity of soil
K_s	Storage coefficient
k_s	Constant
k'	Kinematic ratio
$IL(t)$	Any other loss
L_r	Leaching requirement
LP	Linear Programming
LHDP	Large-system Hierarchical Dynamic Programming
M_e	Effective meteorological input
MADA	Muda Agricultural Development Authority
MWB	Monthly Water Balance
N	Possible maximum number of sunshine hours
n	Actual number of hours of bright sunshine
NAM	Nedbor Afstromnings Model
NNM	Neural Network Method
NOAA	National Oceanic and Atmospheric Administration
O_l	Operational losses
$O_{i,j}$	Overflow in the ith reservoir during the jth month
OM	Percent organic matter
P	Total deep percolation on the farm
$P(t)$	Precipitation falling on the reservoir surface area
$P(t,t+\Delta t)$	Precipitation between t and $t+\Delta t$
P_a	Air pressure
PD	Particle density
PRISM	Potomac River Interactive Simulation Model
Q	Discharge
q	Discharge per unit width
q_i	Lateral inflow
$Q_i(t)$	Inflow to the reservoir per unit watershed area during period t
Q^{j+1}	Water delivered by conveyance system to the field (outflow)
$Q_s(t)$	Uncontrolled releases downstream or spills from the reservoir
R	Hydraulic radius
$R(t)$	Required reservoir release rate
$R(t,t+\Delta t)$	Runoff between t and $t+\Delta t$
R_a	Extra-terrestrial radiation

r_a	Atmospheric vapor resistance
R_n	Net radiation
RH	Relative humidity
R_{nl}	Net long-wave outgoing radiation
R_s	Short-wave solar radiation
r_s	Vegetation canopy vapor resistance
S	Percent sand
$S(t)$	Initial storage volume at the beginning of period t
S_a	Amount of water supplied to the farm
S_e	Energy slope
s_e	Effective saturation
S_f	Slope of the water surface
S_I	Impervious area
$S_I(t+\Delta t)$	Seepage between t and $t+\Delta t$
S_P	Pervious area
S_T	Total surface area
$S_{i,j}$	Storage of the *i*th reservoir during the *j*th month
S_0	Bottom slope of the channel
SAA	Snow Accumulation Ablation
SAM	Special Analysis Methodology
SMA	Soil Moisture Accounting
SP	Seepage and percolation losses
SSARR	Streamflow Synthesis and Reservoir Regulation
SSG	Synthetic Streamflow Generators
SVAD	Single Value Attributed Data
SWAT	Soil and Water Assessment Tool
SWMP	Surface Water Management Plan
T_a	Air temperature
TIN	Triangulated Irregular Networks
U_2	Average wind speed at 2m height
USACE	U.S. Army Corps of Engineers
USDAHL	U.S. Department of Agriculture Hydrograph Laboratory
USGS	U.S. Geological Survey
USNWS	United States National Weather Service
v	Flow velocity
v_s	Seepage velocity

VGFM	Variable Gain Factor Model
W	Catchment average amount of soil moisture content
w	Elementary area soil moisture at saturation
$W(t)$	Soil moisture content at time t
$W(t+\Delta t)$	Soil moisture content at time $t+\Delta t$
w_i	Initial moisture content
W_m	Catchment average soil moisture content at saturation
w_m	Maximum possible soil moisture content
WAM	Weighted Average Method
WAHS	Watershed Hydrology Simulation
WMCS	Water Management and Control Scheme
WUE	Water Use Efficiency
X	Weighting factor
x	Percentage of pervious area at saturation
X_i	Measured value of storage at time i
X_{i+1}	Generated streamflow
y	Average of the absolute values of deviations from the mean
Y_i	Measured transformed value of storage at time i
Y_{i+1}	Transformed generated streamflow
$Y(t)$	Reservoir yield
z	Measurement height
z_0	Surface roughness height
α	Surface albedo
Δ	Gradient of saturation vapor pressure-temperature curve
ε_{i+1}	Random component with mean zero and variance σ_ε^2
η	Porosity of soil
γ	Psychrometric constant
λ	Latent heat of vaporization of water
μ	Unit conversion factor
μ_x	Mean of X
$\rho_x(1)$	First order serial correlation
Ψ	Wetting front soil suction head
σ	Stefan-Boltzmann constant
ρ_a	Air density
θ_e	Effective porosity
θ_r	Residual moisture content

ΔS	Storage increment
Δt	Time step
Δx	Distance step
$\Delta \theta$	Change in moisture content
$\forall_a$	Volume of water applied in an area including rainfall
$\forall_{nt}$	Net volume of water requirement on day t

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

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By

MD. HAZRAT ALI

October 1999

Chairman: **Dr. Lee Teang Shui**

Faculty: **Engineering**

The double cropping of rice in the Muda Irrigation Project depends very much on the volume of water stored in the Muda and Pedu reservoirs. The most important problem affecting the project includes constraints related to poor water management. However, the shortage of reservoir water still remains the most severe constraint on the establishment of stable double cropping of rice. Thus, the main purpose of this study is to develop an optimization model and a solution strategy to solve the water resources of the project in a computationally satisfactory manner. In this study, a water balance model was developed and the performance of a project was evaluated. The water balance components were modeled, without incorporating any model calibration parameters. The model results were compared with observed data satisfactorily. The overall project efficiency for the main and off-seasons were also obtained.

A reservoir simulation model was developed and the model storage capacities were compared with the observed storage capacities satisfactorily. The Markov process with periodicity in hydrologic data was applied to generate monthly streamflows. The generated storage capacities were found to simulate with the observed storage capacities satisfactorily. Three different cases of anticipated future monthly storage were envisaged to assess the risk for predicted monthly storage capacities in 1998-2002 and their probabilities of occurrences were computed. An optimization model was also developed to solve the water resources management of a large project in a computationally satisfactory manner. Twelve different scenarios were analyzed to test the performance of the project and their consequences were illustrated. The optimal reservoir storage, optimal irrigation demand, and optimal reservoir release (i.e., optimal reservoir operating policy) were computed. The optimal mean (1987-1997) model total water requirements for the dry and wet seasons were also computed and the optimal contributions by rainfall, reservoir, uncontrolled river flow, and recycled water were determined. The mean water balance components results for different months were stored in GIS data bases, analyzed, and displayed as the monthly crop water requirements maps. Finally, it can be concluded that the integration of the water balance model together with the models for reservoir simulation, efficiency, hydrologic forecasting, optimization, and GIS holds much promise in the analysis of optimal allocation of water resources of a project.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi sebahagian daripada keperluan ijazah Doktor Falsafah

PEMODELAN PENGURUSAN AIR OPTIMUM UNTUK PROJEK PENGAIRAN BEREMPANGAN

Oleh

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October 1999

Pengerusi: **Dr. Lee Teang Shui**

Fakulti: **Kejuruteraan**

Tanaman padi musim berganda di Projek Pengairan Muda tertakluk kepada isipadu air simpanan didalam empangan Muda dan empangan Pedu. Masalah terpenting mempengaruhi projek termasuk kekangan berkaitan dengan pengurusan air yang kurang memuaskan. Akan tetapi, kekurangan air didalam empangan adalah kekangan terpenting dalam perihal penubuhan setabil tanaman padi musim berganda. Oleh sebab itu, tujuan utama pengajian ini ialah membentukkan sebuah model optimum dan strategi penyelesaian demi untuk mengatasi sumber air projek dengan kaedah pengiraan yang memuaskan. Dalam kajian ini, sebuah model imbangan air telah dimajukan dan prestasi sebuah projek telah dinilaikan. Model imbangan air ini boleh menentukan keperluan air tanaman pada sesuatu jangkamasa tentu. Komponen komponen imbangan air dimodelkan, tanpa mengambilkira parameter penentukuran. Keputusan keputusan model