

LB/DON/84/04

No 10 03

DCE 26/02

**DEVELOPMENT OF A COMPREHENSIVE GROUNDWATER
MODEL TO ANALYSE THE MANAGEMENT OPTIONS FOR
VAVUNIYA REGION**

S.SHANMUHANANTHAN



624 "OH"
626.811 (548.7)

**DEPARTMENT OF CIVIL ENGINEERING
UNIVERSITY OF MORATUWA**

SRI LANKA

University of Moratuwa



81231

UM Thesis coll.

81231

FEBRUARY 2004

81231

**DEVELOPMENT OF A COMPREHENSIVE GROUNDWATER
MODEL TO ANALYSE THE MANAGEMENT OPTIONS FOR
VAVUNIYA REGION**

**THIS THESIS IS SUBMITTED
TO THE DEPARTMENT OF CIVIL ENGINEERING
IN PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE
DEGREE OF MASTER OF SCIENCE
IN WATER RESOURCES ENGINEERING AND MANAGEMENT**

**By
S.SHANMUHANANTHAN**

Supervised By

**Dr. Nimal P.D.Gamage
Senior Lecturer
Department of Civil Engineering**

**Prof.D.C.H.Senarath
Senior Professor
Department of Civil Engineering**

**Dr. S.P.Samarawickrama
Senior Lecturer
Department of Civil Engineering**

**DEPARTMENT OF CIVIL ENGINEERING
UNIVERSITY OF MORATUWA
SRI LANKA**



DECLARATION

I hereby declare that the work included in this thesis, in part or whole has not been submitted for any other academic qualification at any institution.

Eng.S.Shanmuhananthan,

Certified by:

Dr. Nimal P.D.Gamage

Project Supervisor,

Department of Civil Engineering,

University of Moratuwa.

Sri Lanka

ABSTRACT

Due to low porosity and permeability, the recharge and yield are relatively low in the areas that comprise shallow weathered and rarely fractured hard rocks with thin soil mantle. Therefore the problems in sustainable groundwater management are of major and vital importance in these areas. Prevailing Groundwater condition in Vavuniya district is a typical example of this situation.

The records reveal that the groundwater table in Vavuniya did not reach its previous year maximum level during the past 4 years. This may be due to the excessive exploitation of ground water or due to the reduction in recharge of aquifer or the combination of both. The prime intention of this research is to find out an appropriate strategy to ensure sustainability in groundwater management for this region.

The objective of this study is to understand the groundwater systems of Vavuniya region aquifer and hence to improve the evaluation, development, and management of groundwater resources, and the control of groundwater problems in that aquifer.

The specific objectives are,

- (1) to achieve an understanding of the basic mechanisms that govern the flow in the aquifer through numerical modeling.
- (2) to examine the behavior of the aquifer under various operating conditions.
- (3) to prepare a water balance for the territory.

MODFLOW, the three - dimensional, finite difference groundwater flow Computer Model, developed by Waterloo Hydrogeologic Inc was selected for this study.

As no processed reliable data were found for this study area, all basic physical and hydrological data required for this study were collected as raw material and processed to fit the Modflow model.

Since, it is very difficult to attain more reliable results from calibration of a model if large numbers of variables are to be optimized; some of the important variables were optimized separately.

The surface runoff and the recharge due to irrigation storage losses were optimized against reservoir water balance and rainfall recharge was optimized using Penmen - Grindly model. These optimized data were used for the groundwater model simulation to optimize the other variables such as hydraulic conductivity, specific yield, recharge due to river and recharge due to irrigation.

The degrees of influence of river and subsurface dam conditions in groundwater system were examined separately by removing river boundary condition and by introducing Wall boundary condition to the calibrated model.

The overall water balance of the territory was prepared using the cumulative mass balance resulting from the model simulations, available data and the observed hydraulic head data.

The results reveal that the groundwater usage has already reached its optimum level in this region and immediate action is required not only to control further expansion of groundwater exploitation but also to regulate groundwater withdrawal, especially during low rainfall years.

Further, the analysis shows that the non - perennial river a tributary of Parankiaru has less influence in the groundwater system and the subsurface dam conditions certainly have an impact on groundwater system, but this has to be studied further in detail in order to minimize the negative impact and utilize the merits of this condition.

ACKNOWLEDGEMENT

First of all I would like to express my gratitude to the University of Moratuwa for accepting my enrollment for the research study, the department of Irrigation for granting leave and Asian Development Bank for providing financial assistance.

I am very much thankful to Dr.Nimal P.D.Gamage, for agreeing to be my main supervisor and sincerely guiding me throughout my research and providing necessary software and study materials.

My sincere thanks to Prof.D.C.H.Senarath, for directing my research by viewing the work frequently and helping in identifying the reference materials.

Dr.S.P.Samarawickrama, being one of my supervisors, motivated me whenever the work slackened a bit, in addition to his valuable guidance. I must thank him for his patient guidance and motivation.

Also I must thank Prof.S.S.Wickremasuriya, not only for evaluating and directing my work at progress reviews, but also for his encouragement by providing reference materials and software.

Then I wish to thank the Head of the Department, Prof.A.K.W.Jeyawardena and the Director of Post Graduate Studies, Prof.(Ms).N.Ratnayake and the Course Coordinator, Dr.S.A.S.Kulathilaka for their great commitment in providing necessary facilities and coordinating the activities.

I must thank Eng.S.S.Sivakumar, a PhD candidate in the field of groundwater, not only for sharing his knowledge and valuable data but also for his encouragement.

Finally I thank Mr.H.W.Kumarasinghe, the technical officer in-charge for the hydraulic lab for providing timely assistance throughout my studies.

CONTENTS

Chapter 1

1.0 Introduction

1.1 Background	01
1.2 Objective	03
1.3 Study Site	04
1.3.1 Selection of Study Site	04
1.3.2 Geography and Topography	05
1.3.3 Climate	05
1.3.4 Soil	06
1.3.5 Agriculture	06
1.4 Layout of the Thesis	06

Chapter 2

2.0 Literature Review

2.1 Pumping test analysis	07
2.2 Runoff	12
2.3 Soil moisture budgeting methods	14
2.4 Evapotranspiration	17
2.5 Time steps	18
2.6 Sensitivity to root constant	19
2.7 Recharge from rivers	20
2.8 Recharge from Irrigation storages	21
2.9 Irrigation losses, both from canals and fields	22
2.10 Software used for modeling – Modflow	25
2.11 Calibration & Validation	26

Chapter 3

3.0 Theoretical Background

3.1 Ground water hydrology	29
3.1.1 Ground water occurrence	29
3.1.2 Soil water distribution	29
3.1.3 Field capacity	30
3.1.4 Wilting point	30
3.1.5 Hygroscopic coefficient	30
3.1.6 Moisture equivalent	30
3.1.7 Divisions of sub surface water	30
3.1.8 Root constant	31
3.1.9 A conceptual soil moisture budgeting procedure	31
3.1.10 Ground water movement	31
3.1.11 Darcy's law	31
3.1.12 General form of the ground water flow equation	32
3.1.13 Steady flow equation	33
3.1.14 Unsteady flow equation	33
3.2 Groundwater Modeling	33
3.2.1 Objectives of Groundwater Modeling	34
3.2.2 Data required for developing a groundwater model	34
3.2.3 Topography	35
3.2.4 Geology	35
3.2.5 Type of aquifers	36



3.2.6 Unconfined aquifer	36
3.2.7 Confined aquifer	36
3.2.8 Aquifer thickness and lateral extent	37
3.2.9 Aquifer boundaries	37
3.2.10 A zero - flow boundary	38
3.2.11 A head controlled boundary	38
3.2.12 A flow-controlled boundary	39
3.2.13 Aquifer Characteristics	39
3.2.14 Type and extent of recharge areas	41
3.2.15 Rate of recharge	41
3.2.16 Main recharge sources	42
3.2.17 Methods for recharge estimation	42
3.2.18 Direct recharge	43
3.2.19 Methods for estimating direct recharge	44
3.2.20 Evapotranspiration	44
3.2.21 Indirect recharge	45
3.2.22 Recharge from rivers	45
3.2.23 Irrigation losses, both from canals and fields	46
3.2.24 Water losses from irrigation canals	46
3.2.25 Recharge from irrigated fields	47
3.2.26 Recharge from Irrigation storages	47
3.2.27 Type and extent of discharge areas	48
3.2.28 Rate of discharge	48
3.2.29 Calibration	49
3.2.30 Validation	49

Chapter 4

4.0 Aquifer Description

4.1 Source of Data	51
4.1.1 Topography	51
4.1.2 Geology & Aquifer physical parameters	51
4.1.3 Aquifer properties	51
4.1.4 Land usage	51
4.1.5 Water-table fluctuation	52
4.1.6 Rainfall & Evapotranspiration data	52
4.1.7 Root Constant	52
4.1.8 Irrigation Schemes	52
4.1.9 Ground water withdrawal	52
4.2 Physical framework	53
4.2.1 Geology and Aquifer Type	53
4.2.2 Aquifer Properties	53
4.2.3 Zone division	54
4.2.4 Land usage	56
4.3 Hydrological stress	57
4.3.1 Water-table fluctuation	57
4.3.2 Rainfall recharge	58
4.3.2.1 Runoff	58
4.3.2.2 Evapotranspiration	59
4.3.2.3 Root Constant	61
4.3.3 Irrigation Recharge	63
4.3.3.1 Recharge from Irrigation Storages	64
4.3.3.2 Recharge from channel losses	64
4.3.3.3 Recharge from field losses	65
4.3.4 River Recharge	65
4.3.5 Groundwater withdrawals	66

Chapter 5

5.0 Modeling Groundwater Flow

5.1 Model Buildup	67
5.1.1 Identifying type of model	68
5.1.2 Discretizing the problem Domain	68
5.1.3 Setting Boundary Conditions	69
5.1.3.1 Zero flow boundary condition	69
5.1.3.2 River Boundary Condition	71
5.1.3.3 Constant Head Boundary Condition	73
5.1.3.3 Recharge Boundary Condition	73
5.1.3.4 Ground water withdrawal	74
5.1.4 Setting Initial Conditions	74
5.1.5 Specifying the Extreme Hydraulic Heads Observed	76
5.2 Model Runs	77
5.2.1 General Overview	77
5.2.2 Model Calibration and Verification (R1,R2,R3,R4)	79
5.2.3 Sensitivity Analysis (R5, R6)	80
5.2.4 Mass balance	81
5.2.5 Model Case Studies	81
5.2.5.1 R1 – Steady state groundwater flow simulation	81
5.2.5.2 R2 – Steady state groundwater flow simulation	81
5.2.5.3 R3 – Transient state groundwater flow simulation	82
5.2.5.4 R4 – Transient state groundwater flow simulation	83
5.2.5.5 R5 – Transient state groundwater flow simulation	83
5.2.5.6 R6 – Transient state groundwater flow simulation	83

Chapter 6

6.0 Results of the Model Runs

6.1 Steady State Runs	85
6.1.1 Steady state groundwater flow simulation	85
6.1.1.1 Model Calibration (Run R1)	86
6.1.1.2 Model Calibration (Run R2)	87
6.1.1.3 Boundary Conditions and Groundwater flow Results (R1, R2)	89
6.2 Transient State Runs	90
6.2.1 Transient state groundwater flow simulation - R3	90
6.2.1.1 Model Calibration and Verification (R3)	91
6.2.1.2 River Boundary Conditions and River Conductance	94
6.2.1.3 Hydraulic conductivity, Specific yield	95
6.2.2 Transient state groundwater flow simulation - R4	97
6.2.2.1 Model Calibration and Verification (R4)	97
6.2.2.2 Recharge from irrigation losses	102
6.2.2.3 Mass Balance	103
6.2.3 Transient state groundwater flow simulation - R5	104
6.2.3.1 Model Run (R5)	104
6.2.4 Transient state groundwater flow simulation - R6	109
6.2.4.1 Model Run (R6)	109

Chapter 7

7.0 Discussion

7.1 Water Balance	115
7.1.1 Introduction	115
7.1.2 Rainfall recharge	115
7.1.2.1 Rainfall surface runoff	116
7.1.2.2 Surface Water Balance	117
7.1.3 Recharge from Irrigation schemes	118
7.1.3.1 Recharge from Irrigation Storages	118
7.1.3.2 Recharge from channel losses	120
7.1.3.2 Recharge from field losses	121
7.1.4 River Recharge	122
7.1.5 Groundwater withdrawals	124
7.2 Water Balance of the Territory	125
7.2.1 Apparent Recharge	125
7.2.2 Recapitulation of Water Balance	125
7.2.3 Evaluation of Actual Water Balance for the period of 4 years	127
7.3 Evaluation of Computer Model Performance	129
7.4 Present Model Deficiencies	130
7.4.1 Initial Conditions	130
7.4.2 Recharge Rate	130
7.4.3 Withdrawal Rate	133
7.4.4 Evapotranspiration	130
7.4.5 Dry cell	131
7.4.6 Well Diameter	131
7.4.7 Column & Row width	132

7.5 Recommendations for Supplementary Field Investigation	132
7.5.1 Additional Observation Wells	132
7.5.2 Recording monthly well observations	132
7.5.3 Conducting pumping tests	133
7.5.4 Installing river gauging stations	133
7.5.5 Installing pan evaporation station	133

Chapter 8

8.0 Conclusions and Recommendations

8.1 Conclusions	134
8.2 Recommendations	137

References	139
------------	-----

Annex – 4.1: Analysis of pumping test data	147
Annex – 4.2: Seasonal water level fluctuation	154
Annex – 4.3: Rainfall Summary	155
Annex – 4.4: The details of irrigation schemes	156
Annex – 7.1: Details of daily reservoir water balance	161
Annex – 7.2: Zone wise seasonal rainwater balance	167
Annex – 7.3: Sample workout of rainwater balance	168
Annex – 7.4: Detail computation of irrigation recharge	174
Annex – 7.5: Detail computation of Domestic withdrawal	182
Annex – 7.6: Detail computation of agriculture withdrawal	183
Annex – 7.7: Zone wise seasonal recharge	184



LIST OF TABLES

Table 4.1 - Zone Area Details	55
Table 4.2 - Land Usage Details	56
Table 4.3 - Zone Wise Land Usage Details	57
Table 4.4 - Average Daily Potential Evapotranspiration	59
Table 4.5 - Average Daily Potential Evapotranspiration	60
Table 4.6 - Zone Wise Weighted Root Constant	61
Table 4.7 - Sensitivity Analysis for Root Constant	62
Table 4.8 - Summary of Irrigation Schemes	63
Table 5.1 - The Observed Well Water Levels	76
Table 5.2 - The Stressed Period Details	84
Table 6.1 - Difference in the observed and predicted heads for run R3	92
Table 6.2 - Root mean square error of simulation run R3	93
Table 6.3 - The range within which the difference in observed and predicted heads lies during run R3.	93
Table 6.4 - The optimized values of River Conductance	95
Table 6.5 - Optimized values of Hydraulic conductivity, Specific yield	95
Table 6.6 - Difference in the observed and predicted heads for run R4	99
Table 6.7 - The range within which the difference in observed and predicted heads lies during run R4.	99
Table 6.8 - The range within which the difference in observed and predicted heads lies during run R4 and R3.	100
Table 6.9 - The comparison of Root mean square error between R3 simulation run and R4 simulation run	100
Table 6.10 - summary of the cumulative mass balance for the run R4	103
Table 6.11 - Difference in the observed and predicted heads for run R5	105

LIST OF TABLES

Table 6.12 – Difference in the predicted heads between R4 and R5.	106
Table 6.13 – The comparison of Root mean square error between R4 & R5	107
Table 6.14 – Difference in the observed and predicted heads for run R6	110
Table 6.15 – Difference in the predicted heads between R4 and R6	110
Table 6.16 – The difference in cumulative mass balance between R4 & R6.	113
Table 7.1 – Optimized values of f (empirical factor) and pt (threshold precipitation below which no runoff occurs)	116
Table 7.2 – Percentage of Seasonal Average Surface Runoff out of Rainfall.	116
Table 7.3 – The summary for the seasonal Surface Water Balance	117
Table 7.4 – % of Recharge from Irrigation Storages out of total recharge	119
Table 7.5 – % of Recharge from Channel losses out of total recharge	120
Table 7.6 – % of Recharge from field losses out of total recharge	121
Table 7.7 – The optimized values of River Conductance	122
Table 7.8 – The average values of seasonal recharge by various recharge components	123
Table 7.9 – The average values of seasonal groundwater withdrawal by various components	124
Table 7.10 – The Average Water Balance of the Study Area	126
Table 7.11 – The Water Balance Comparison	127
Table 7.12 – Comparison between Calculation and Model's Prediction	129

LIST OF FIGURES

Figure 1.1 – Maximum Groundwater level at the end of recharging period	04
Figure 5.1 – Topo inset of Project Site	70
Figure 5.2 – No flow Boundary Condition	70
Figure 5.3 – Constant Head Boundary Condition	72
Figure 5.4 – River Boundary Condition	72
Figure 5.5 – Zone division and Observation Wells	74
Figure 5.6 – Sub Surface Dams	84
Figure 6.1 – Comparison of Observed and Predicted Heads for the R1 steady state simulation.	86
Figure 6.2 – Comparison of Observed and Predicted Heads for the R2 steady state simulation.	88
Figure 6.3 – The graphical representation of groundwater flow path	90
Figure 6.4 – The River stretches	94
Figure 6.5 – Comparison of Observed and Predicted Heads for R4 run	98
Figure 6.6 – Comparison between Model Run R3 & Model Run R4	101
Figure 6.7 – Comparison between Model Run R4 & Model Run R5	108
Figure 6.8 – Comparison between Model Run R4 & Model Run R6	114