

***Distributed Watershed Modelling of a
Mountainous Catchment***

***Submitted by
Shaban Ali Gholami***

**Thesis Submitted in fulfilment of the requirement for the degree of
Doctor of Philosophy**

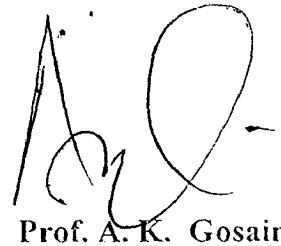


**Department of Civil Engineering
INDIAN INSTITUTE OF TECHNOLOGY
NEW DELHI - 110 016**

MAY 1999

Certificate

This is to certify that the thesis titled **“Distributed watershed Modelling of a Mountainous catchment”** being submitted by **Mr. SHABAN ALI GHOLAMI.**, 94RCE 022 to the Indian Institute of Technology, Delhi, India, for the award of the degree of **DOCTOR OF PHILOSOPHY**, is a record of bonafide research work carried out by him under my supervision and guidance. The thesis work, in my opinion, has reached the standard, fulfilling the requirements of the regulation relating to the said degree. The research report and the results presented in this thesis have not been submitted, in part or in full, to any other university or institute, for the award of any degree or diploma.



Prof. A.K. Gosain

Professor

Department of Civil Engineering

Indian Institute of Technology

New Delhi-110016, INDIA

ACKNOWLEDGEMENTS

I am immensely grateful and deeply indebted to my supervisor **Prof. A.K. Gosain**, Professor of Civil Engineering, Indian Institute of Technology (IIT) Delhi, for his keen interest, constant encouragement supervision and guidance throughout the course of present investigations. His ever helping attitude, excellent leadership and dynamic personality has been or constant source of encouragement for me and also. It is appreciated to him which he has been prepared good facility for working easily in the GIS Laboratory. I am extremely thankful to **Dr. (Mrs.) Sandhya Rao** for valuable help and useful suggestions in the present study.

Sincere thanks are due to the **soil conservation and watershed management** research organization of **Ministry of Jihad-e-Sazandegi**; for providing the adequate data, topographic maps and Aereal photo and also for perusing my financial and administrative works. I am thankful to the **Authorities of Research and Training of Deputy of Jihad-e-Sazandegi Ministry** under the government of Islamic Republic of IRAN who awarded scholarship and financially supported to do this research.

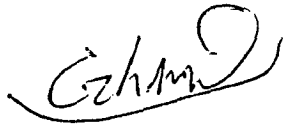
I also wish to express my sincerest thanks to all my friends in the GIS Laboratory for their affectionate assistance.

I would like to record my special heart full thank to my wife **Mrs. Z.B. Taherian** for her excellent cooperation and support during the entire period of this research and also my childrens who were a great companion for their mother.

I would like to express my gratefulness to the **Ministry of Culture and High Education (MCHE)** under the Islamic Republic of IRAM for supporting me to do this research.

New Delhi.

April, 1999


(SHABAN ALI GHOLAMI)

Abstract

Watershed management has been recognised as a widely accepted approach for optimal use of soil and water resources. Therefore, watershed-modelling incorporating hydrological processes takes a crucial role for proper planning and development of these local resources. Invariably, one of the major difficulties encountered in the use of hydrological models is the requirement of calibration of the model on the target area. For the purpose of calibration, most of the hydrological models require a long series of observed runoff data. These long series of data are usually not available on most of the small watersheds. Therefore, it is imperative that hydrological models should be formulated/ identified which can overcome this requirement. One such hydrological model, namely, SWAT (Soil and Water Assessment Tool) model has been identified and implemented on Tehran-Amameh, a mountainous, snow bound, 37.20 sq. km watershed in Iran.

The study has provided an in-sight into the working of the continuous, distributed water balance model, SWAT. The major objective of the study has been to assess the applicability of the model on ungauged watersheds, which has become a necessity in view of the fact that it shall be impracticable to gauge the small watersheds which are accepted as the viable planning and management units in all the countries around the globe.

It has been shown that the ability of the model to be used on ungauged watersheds is not very good since it is not always possible to define the model parameters through the observable characteristics. It has been depicted furthermore that through the use of a small series of observed flow data (about one year), the model performance has appreciably enhanced. It is therefore inferred that the character of the watershed, which is reflected through the observed flows, is not attainable through any other form of information. The structure of the SWAT model has proved to be very stable

but for the snow component of the model which needed improvement and had been modified.

During the course of simulation analysis it has also been observed that the selection of an appropriate interval for analysis is very important. It is not necessary that if the simulation results appear to be good at the monthly interval then they shall also be good at the daily interval. However, the other way round may be true.

The capability of the model to simulate the sediment yield has also been proven. It was very interesting to note that the improvement in the water yield simulation kept on bringing about the corresponding improvement in the sediment yield. This proves the capability of the model for sediment yield simulation beyond doubt.

The capability of SWAT model to generate various management scenarios has also been explored. The present catchment being predominantly a rangeland, there were very limited feasible alternatives that were considered. The impact assessment due to changes in rate of grazing, duration of grazing, and crop rotation, as well as changes due to utilization of fertilizer (Nitrate and Phosphate), has been evaluated on the catchment. It has been observed that the various alternatives considered have not made appreciable difference in the outputs. However, it may be said that this ability of the SWAT model shall go a long way in enhancing the acceptability of the model with the end-users and shall make the model very effective tool of the future.

Table of Contents

<i>Chapter 1 Introduction</i>	<i>1</i>
1.1 General	1
1.2 Objective of the Study	2
1.3 Selection Of the Simulation Model	3
1.4 The Study Area	6
1.5 Model Description	7
1.6 Model Input and Preprocessing	7
1.7 Sensitivity Analysis	8
1.8 The Model Simulation	9
<i>Chapter 2 Literature Review</i>	<i>11</i>
2.1 General	11
2.2 Overview of Watershed Simulation Models	13
Deterministic Models	13
Conceptual Models	16
Lumped Models	19
Distributed Models	24
Semi-Distributed Models	28
2.3 Literature Review of the Hydrological Processes	30
2.3.1 Interception	30
2.3.2 Snow melt and accumulation	39
Energy Balance Approach	41

Air temperature	43
Radiation	43
Wind and Vapour Pressure:	43
Degree-Day Method (Temperature Index)	45
Combination Energy-Temperature Index Snowmelt Model (E-T Index)	49
Snow Accumulation and Runoff	50
2.3.3 Evapotranspiration Process (ET)	53
Potential Evapotranspiration(PET)	55
Reference Evapotranspiration (ET_0)	57
Actual Evapotranspiration (AET)	59
2.3.4 Infiltration Process	63
Rainfall Excess Method:	64
Index Models	64
The Soil Conservation Services (SCS) Method	64
Empirical Infiltration Models	67
Approximate models	70
Physically Based Models	75
2.3.5 Depression and Ponding Storage Process	75
Water balance Method	76
Method based on Map Measurement	77
2.3.6 Runoff Process	81
Infiltration excess method	83
Green-Ampt method	83
Soil Conservation Service (SCS) method	84
2.3.7 Percolation Process	88
2.3.8 Lateral Subsurface Flow	92
EPIC Model	95
SWAT model	96
SPUR MODEL	97
2.3.9 Ground Water Process	98
2.3.10 Erosion and Sediment process	102
USLE Model	104
MUSLE Model	106
ANSWERS Model	106

CREAMS Model	107
SWRRB Model	109
EPIC Model	110
WEPP Model	111
SWAT Model	112
SHESED Model	113
PSIAC METHOD	115
Chapter 3 The Study Area	117
3.1 General Features of Amameh Catchment	117
3.2 The Extent of Data Availability	120
3.2.1.1 Geology and Geomorphology	122
3.2.1.2 Topography	124
3.2.1.3 Soil Survey data	130
3.2.1.4 Land-use	137
3.2.1.5 Agricultural Management Practices	138
3.2.2 Hydrometeorological Data	150
3.2.2.2 Precipitation	152
3.2.2.3 Temperature and Other Climatic Data	152
3.2.2.4 Hydrometric Data	157
3.3 The Existence and Availability of Data	157
3.3.1 The Sources of the Collected Data	157
3.3.2 Computer-based Data Processing	158
3.4 Analysis of Data	160
3.4.1 Precipitation	160
3.4.1.1 Rainfall Data	160
3.4.1.2 Snow fall	162
3.4.2 Analysis of Temperature	163
Chapter 4 Catchment Modelling	166
4.1 Introduction	166
4.2 Model Selection	167

4.4 Model Components	167
4.4.1 Hydrology	169
4.4.1.1 Surface Runoff	169
4.4.1.2 Percolation	173
4.4.1.3 Lateral Subsurface Flow	176
4.4.1.4 Ground-water Flow	177
4.4.1.5 Evapotranspiration	179
4.4.1.6 Snowmelt	184
4.4.1.8 Ponds	185
4.4.2 Weather	185
4.4.2.1 Precipitation	186
4.4.2.2 Air Temperature and Solar Radiation	186
4.4.2.3 Wind Speed and Relative Humidity	186
4.4.3 Sediment Yield	187
4.4.4 Soil Temperature	188
4.4.5 Crop Growth	191
4.4.6 Nutrient	192
4.4.7 Agricultural Management	193
4.4.8 Routing Component in Channel	195
4.4.8.1 Channel Flow Routing	195
4.4.8.2 Channel Sediment Routing	198
Chapter 5 Preprocessing for Simulation	201
5.1 Swat Preprocessor	201
5.2 Input Output Data Organisation	204
5.2.2 Dynamic Data	205
5.3 Spatial Data	206
5.3.1 Processing of Contours	208
5.3.2 Watershed Delineation	208
5.3.3 Generation of basin and Drainage Network Characteristics	211

5.3.4	Watershed Delineation	217
Chapter 6 Sensitivity Analysis		226
6.1	Introduction	226
6.2	Statistical Criteria for Sensitivity Analysis	227
6.3	Sensitivity Analysis of the Model Parameters	230
6.3.1	Snow Threshold Coefficient (TC)	230
6.3.2	Curve Number (CNII)	234
6.3.3	Snow Bound Accumulated Coefficient (T-Laps)	235
6.3.4	Snow Melting Coefficient (CCT)	237
6.3.5	Depth of Soil	238
6.3.6	Saturated Conductivity (SC)	238
6.3.7	Alfa Factor for Groundwater (ABF)	239
6.3.8	Revap Coefficient (REVAPC)	239
6.3.9	Crack-flow (CRCO)	240
6.4	Discussion on Sensitivity of Model	241
Chapter 7 Model Application		260
7.1	Water Yield Simulation	261
7.1.1	Simulation of Ungauged Catchment	261
7.1.2	Improvement in Simulation	265
7.1.2.1	Authentication of the Improvement in Simulation	283
7.1.3	Simulation of the whole Catchment	284
7.1.4	Simulation Performance on the Remaining Period	285
7.2	Sediment Yield Simulation	287
7.2.1	Simulation of Ungauged Catchment	288
7.2.2	Improvement in Simulation	288
7.2.3	Total Sediment Yield using PSIAC method	291

7.3	Scenario Generation	299
7.4	Result and Discussion	302
	<i>Chapter 8 Conclusion</i>	337
	<i>References</i>	341
	<i>Appendix I</i>	362
	<i>Appendix II</i>	369
	<i>Bio-data of Author</i>	372