WATER BALANCE ANALYSIS IN MAHESHGAD WATERSHED USING SWAT MODEL

A thesis submitted to the

Mahatma Phule Krishi Vidyapeeth, Rahuri - 413 722,

by

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Reg. No. 2010/07

In partial fulfillment of the requirements for the degree

of

MASTER OF TECHNOLOGY

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in

SOIL AND WATER CONSERVATION ENGINEERING

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2014

CANDIDATE'S DECLARATION

I hereby declare that this thesis entitled, "Water balance analysis in Maheshgad watershed using SWAT model" or any part thereof has not been previously submitted by me or any other person to any other University or Institute for Degree or Diploma.

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This is to certify that the thesis entitled **“Water Balance Analysis in Maheshgad Watershed using SWAT Model”**, submitted to the Mahatma Phule Krishi Vidyapeeth, Rahuri, Dist. Ahmednagar (M.S.) in the partial fulfillment of the requirement for the award of the degree of **Master of Technology (Agricultural Engineering)** in **Soil and Water Conservation Engineering,** embodies the results of bonafide research work carried out by **Mr. Sambhaji Subhash Ghotekar** under my guidance and supervision and no part of the thesis has been submitted to any other University or Institute for degree or diploma.

The assistance and help received during the course of this investigation has been duly acknowledged.

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Date : */ /2014* ***(S. S. Ghotekar)***

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LIST OF ABBREVIATIONS

Abbreviations		**Description**
Agril.	:	Agricultural
ARS	:	Agriculture Research Service
cm	:	Centimeter
DEM	:	Digital Elevation Model
Engg.	:	Engineering
et al.	:	And others
ET	:	Evapotraspiration
Fig.	:	Figure
GIS	:	Geographic Information System
HRU	:	Hydrological Response Unit
i.e.	:	That is
km	:	Kilometer
M.P.K.V.	:	Mahatma Phule Krishi Vidyapeeth
M.S.	:	Maharashtra State
PET	:	Potential evapotranspiration
Res.	:	Research
SWAT	:	Soil and Water Assessment Tool
SUFI	:	Sequential Uncertainty Fitting
TOLOS	:	Total Maximum Daily Load System
USDA	:	United State Department of Agriculture
VRS	:	Variable Source Area

ABSTRACT

TITLE: WATER BALANCE ANALYSIS IN MAHESHGAD WATERSHED USING SWAT MODEL

by

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The challenge of using old models in water resource management is that, these require more detailed data and sophisticated models are computer intensive. In this regards a physical process based Soil and Water Assessment Tool model is used. Mostly SWAT is used for large watershed, but in this study SWAT applies for small watershed of area 45.04 ha. This application also considers small parameters of watershed, that isn’t possible in large watershed. In large watershed streams are generated on the basis of Digital Elevation Model, but for small watershed DEM based streams aren’t exactly match the original streams. Therefore manually digitize streams used as input. Result was more accurate than DEM based stream generation for small watershed.

The present study was conducted for Maheshgad watershed (45.04 ha) in Rahuri Tahsil of Ahmednagar district (M. S). Watershed was divided into eight sub-watershed namely W1A, W1B, W1, W2, W3, W4, W6 and water body (W5). This study focused on the water balance components of watershed under different climatic condition and changing land use pattern in small watershed. The study was conducted with following objectives.

(1) To estimate different water balance components in watershed using SWAT model,

(2) To calibrate and validate the SWAT model for Maheshgad watershed,

(3) To study the effect of different land use on water balance components in Maheshgad watershed using SWAT model.

The result obtains in this study, for estimation of different water balance components in watershed data of 1997 and 1998 were used. The components of water balance for 1997 were estimated as Base lateral flow = 16.63 mm, Base flow = 1.36 mm, Percolation = 2.28 mm, Potential Evapotraspiration = 2082.28 mm, Runoff = 42 mm, Soil water = 434.38 mm, Evapotraspiration = 566.45 mm. The components of water balance for 1998 were estimated as Base lateral flow = 24.33 mm, Base flow = 5.55 mm, Percolation = 6.73 mm, PET = 1806 mm, Runoff = 81.24 mm, Soil water = 778.99 mm, ET= 749.65 mm. For calibration and validation of SWAT model daily runoff data of 1997 and 1998 were used. Nash and Suctclife efficiency for calibration and validation of runoff was 0.62 and 0.74 respectively. Coefficient of determination for calibration and validation of runoff was 0.98 and 0.95 respectively. For land use effect on water balance components three land use or Scenario were selected namely Scenario 1, Scenario 2 and Scenario 3. Runoff in Scenario 1 is more than Scenario 2 and Scenario 3. Base flow, base lateral flow and percolation in Scenario 1 are less than Scenario 2 and Scenario 3. Soil water content in Scenario 3 is more than Scenario 1 and Scenario 2. PET and ET in Scenario 2 are more than Scenario 1 and Scenario 3.

Thus it can be concluded that: (1) For calibration six factors were selected for Maheshgad, Ground water delay (days) = 20 days, Available water capacity (mm water/ mm soil) = 0.95, Soil depth (mm) = 125 mm, Soil evaporation compensation factor = 0.7, Threshold water depth in the shallow aquifer for flow (mm) = 200 mm and Initial curve number (II) value = 0.9 of original value. (2) SWAT model was calibrated and validated for Maheshgad watershed for runoff. For calibration Model efficiency = 0.62 and Coefficient of determination = 0.98. For validation Model efficiency = 0.74 and Coefficient of determination = 0.95. (3) If land use in the watershed was changed from Scenario 1 (present land use) in to Scenario 2 (orchard) or Scenario 3 (forest-mixed and agriculture) then runoff of watershed decreases, but Base flow, base lateral flow, percolation and water yield increases. Soil water was higher in Scenario 3 and ET and PET losses are more in Scenario 2.

CONTENTS

1. INTRODUCTION

India receives an annual precipitation of about 4000 km^3. The total annual flow per year from the Indian rivers is estimated as 1953 km^3. The total annual replenishable groundwater resources are assessed at 432 km^3. The annual utilizable surface water and groundwater resources of India are estimated as 690 km^3 and 396 km^3/year, respectively (Kumar *et al*., 2005). Total water requirement of the country for various activities around the year 2050 has been assessed to be 1450 km^3/year. Therefore, when compared with the current availability of 500 km^3/year, the water availability around 2050 needs to be almost tripled. With the population of India expected to stabilize around 1640 million by the year 2050, the gross per capita water availability will decline from 1820 m^3/year in 2001 to as low as 1140 m^3/yr in 2050 (Gupta and Deshpande, 2004).

Water resource management is the activity of planning, developing, distributing and managing the water resources for its optimum use. It is a sub-set of water cycle management. In an ideal world, water resource management planning has regard to all the competing demands for water and seeks to allocate water on an equitable basis to satisfy all uses and demands. This is rarely possible in practice.

To deal with water management issues, one must analyse and quantify the different elements of hydrologic processes taking place within the area of interest. Obviously, this analysis must be carried out on a watershed basis because all these process are taking place within individual micro watersheds. Only after understanding the spatial and temporal variation and the interaction of these hydrologic components one can scientifically formulate strategies for water conservation. To achieve this goal the choice and use of an appropriate watershed model is a must.

The area of land draining into a stream or a water course at a given location is known as catchment area. It is also called as drainage area or drainage basin. In United State of America, Africa and Asia it is known as watershed. A catchment area is separated from its neighboring areas by a ridge line. It is normal to assume the ground water divide to coincide with surface divide. Thus, the catchment area affords a logical and convenient unit to study various aspects relating to the hydrology and water resources of a region.

Water occurs on the earth in all its three states, viz. liquid, solid and gaseous, and in various degrees of motion. Evaporation of water from water bodies such as oceans and lakes, formation and movement of clouds, rain and snowfall, stream flow and groundwater movement are some examples of the dynamic aspects of water. Total quantity of water on earth planet remains constant. Same criteria are applied for the quantity of water in watershed.

An expression for the water budget of a catchment is written as,

$$P - R - G - E - T = \Delta S$$

Where,

P = Precipitation
R = Surface runoff
G = Net ground water flow out of the catchment
E = Evaporation
T = Transpiration
ΔS = Change in storage

Water balance analysis problems associated with estimation of surface and ground water resources and their efficient utilization in order to sustain the available scare commodity for future needs had traditionally been carried out using simple analytical methods based on experience. Models are useful in simulating water balance scenarios under different management options, thereby taking corrective measures for the efficient utilization of water resources. The simulation approach attempts to replicate real world complexity by integrating components of the physical hydrogeologic system and climatic effects. Recently, water balance simulation models are being widely used in different parts of the world including India.

Water balance models have been developed at various time scales (e.g. hourly, daily, monthly and yearly) and to varying degrees of complexity. Monthly water balance models were first developed in the 1940s by Thornthwaite (1948). The challenge of using such models in water resource management is that, these require more detailed data and sophisticated models are computer intensive.

In this study SWAT has been used for studying the water balance of watershed. SWAT is the acronym for Soil and Water Assessment Tool. It is a river basin or watershed, scale model developed by Dr. Jeff Arnold for the United State Department of Agriculture Agricultural Research Service (ARS). In SWAT was developed to predict the impact of land management practices on water, sediment and agricultural chemical yields in large complex watershed with varying soils, land use and management condition over long periods of time. Rather than incorporating regression equation to describe the relationship between input and output variables, SWAT requires specific information about weather, soil properties, topography, vegetation and land management practices occurring in watershed. The physical processes associated with water movement, crop growth, nutrient cycling etc are directly modulated by SWAT using this input data.

For modeling purposes, a watershed is partitioned into a number of sub-watershed or subbasins. The use of subbasins in a simulation is particularly beneficial when different areas of watershed are dominated by land uses or soils dissimilar enough in properties to impact hydrology. By partitioning the watershed into subbasins, the user is able to reference different areas of watershed to one another spatially. Input information for each subbasin is grouped or organized into different categories: climate; hydrologic response units or HRUs; ponds/wetlands, groundwater; and the main channel, draining the subbasin. Hydrologic response units are lumped land areas within the subbasin that are comprised of unique land cover, soil, and management combinations.

Simulation of hydrology of a watershed can be separated into two major divisions. The first division is the land phase of the hydrologic cycle. The land phase of the hydrologic cycle controls the amount of water, sediment, nutrient and pesticide loadings to the main channel in each subbasin. The second division is the water or routing phase of the hydrologic cycle which can be defined as the movement of water, sediment etc, through the channel network of the watershed to the outlet.

In this study SWAT is applied to a small watershed Maheshgad (45.04 ha), which is located in Rahuri Tahsil in Ahmednagar district in Maharashtra (INDIA). Climatic data i.e. rainfall, relative humidity, temperature, land use/land cover data and soil data were available. The SWAT model is applied to the Maheshgad watershed with the following specific objectives.

Objectives:

1. To estimate different water balance components in watershed using SWAT model.
2. To calibrate and validate the SWAT model for Maheshgad Watershed.
3. To study the effect of different land use on water balance components in Maheshgad watershed using SWAT model.

2. REVIEW OF LITERATURE

This chapter briefly deals with the reviews on water balance of watershed and application of SWAT to different watersheds. Models which give a comprehensive picture of the various hydrologic processes are called as integrated watershed models. Choice of watershed development model depends upon the hydrologic components to be incorporated in the water balance. The most important hydrologic elements from the water management point of view are surface runoff, lateral flow, base flow and evapotranspiration. There are a number of integrated physically based distributed models. Amoung them, researchers have identified SWAT as the most promising and computationally efficient. Hence, in this study, an attempt has been made to calculate water balance parameters, calibrate, validate the SWAT model and to determine the effect of land use change on water balance components of watershed. In this chapter the work done previously on this aspect is reviewed.

2.1 Water balance analysis

Water balance of a basin is the most important aspect in water resources development and management programmes. Major hydrological processes can be quantified with the help of water balance equations. The components of water balance of a basin are influenced by climate, the physical characteristics of the watershed such as morphology, landuse and soil. Understanding the relationship between these physical parameters and hydrological components are very essential for any water resources development related work. Since the hydrologic processes are very complex, their proper comprehension is essential and for this watershed models are widely used. Most of the watershed models basically simulate the transformation of precipitation into runoff, sediment outflow and nutrient losses.

Randall *et al*. (2011) characterized the shallow aquifer supplying water to the Jandu spring. Water quality and geochemistry data were analyzed, discharge recession analysis was performed, and two water balance models were developed and tested. Jandu geochemistry suggested a shallow, environmentally recharged aquifer system with short circulation times. This study addresses the potential impacts of changing climate on dry-season water storage and discharge from a small, mountain catchment in Tanzania (92 km^2). They found that the catchment behaviour could be represented by a linear storage model with an average recession constant of 0.151/month from 2004-2010. Two modified Thornthwaite-Mather Water Balance models were calibrated using historic rainfall and discharge data and shown to reproduce dry-season flows with Nash-Sutcliffe efficiencies between 0.86 and 0.91.

Xu *et al.* (2012) investigated the general pattern of long-term water balance and vegetation cover among 193 study catchments in Australia (127 km^2) through statistical analysis. They then employed the elasticity analysis approach for quantifying the effects of climate variability on hydrologic partitioning (including total, surface and subsurface runoff) and on vegetation cover (including total, woody and non-woody vegetation cover). Based on the results of statistical analysis, they concluded that annual runoff (R), evapotranspiration (E) and runoff coefficient (R/P) increase with vegetation cover for catchments in which woody vegetation was dominant and annual precipitation was relatively high. Control of water available on annual evapotranspiration in non-woody dominated catchments was relatively stronger compared to woody dominated ones. The ratio of subsurface runoff to total runoff (Rg/R) also increases with woody vegetation cover.

Abazi *et al.* (2013) developed water balance model to simulate the effect of different soil management alternatives, as for instance conventional tillage or cover crop, on soil water balance. In spite of the simplified interface for the user, the model uses process-based methodologies to describe the key processes controlling water balance in rainfed olive orchards, such as runoff, deep percolation, cover crop growth, soil evaporation and olive and cover crop transpiration. Model predictions were evaluated using 3-year period of runoff and soil moisture data for different soil managements from an experimental field located in an olive orchard in Southern Spain. They concluded that the model predicts satisfactorily runoff losses and soil moisture. Thus, annual runoff simulation provided a RMSE of 4.4 mm and the model efficiency was in general higher than 0.5.

Soja *et al.* (2013) tested Multidecadal oscillation indices against patterns of precipitation, air temperature and hydrological parameters of Lake Neusiedl in Austria (413 km^2). The clearest relation was observed between air temperature and North Atlantic oscillation index ($p < 0.0001$). Water level and volume of Lake Neusiedl were very sensitive to precipitation changes with after effects of individual years lasting up to 2 years. Summer precipitation was more important for lake water amount than the other seasons. The major surface water input to Lake Neusiedl was coming from River Wulka. Annual discharge (15 years moving averages) showed a variable, moderately decreasing trend for the period 1961–2010 by $-1.2 \pm 0.6 \times 10^6$ m^3/decade. Waste water treatment plants contributed up to 68% of monthly flow of River Wulka into the lake. They concluded that precipitation of the current and the previous year, and in some months also temperature influenced Wulka's flow significantly.

2.2 Application of SWAT for water balance analysis

SWAT is a complex integrated river basin scale model which operates either on daily or hourly time step. The model has been developed by United State Department of Agriculture (USDA) and has undergone many capability expansions. The model can predict water balance parameters of watershed. It can assist the land and water managers to assess the impact of land management practices in hydrology. SWAT divides the watershed into sub watersheds based on land slope direction and channel network. The sub basin is further classified into smaller modelling units, known as Hydrologic Response Units (HRU) depending upon the variation of land use and soil.

Spruill *et al.* (1993) evaluated SWAT and parameter sensitivities were determined while modeling daily stream flows in a central Kentucky watershed (34 km^2) over a two-year period. Parameters selected for sensitivity analysis were drainage area, slope length, channel length, saturated hydraulic conductivity and available water capacity. They concluded that saturated hydraulic conductivity, alpha base flow factor, drainage area, channel length and channel width were the most sensitive parameters in modeling.

Chanasyk *et al.* (2002) conducted a study at Stavely Research Station (5.93ha), Alberta to determine the runoff from small grassland watersheds under three intensities, control, heavy (2.4 animal unit months per hectare) (AUM /ha) and very heavy (AUM /ha) grazing. Total annual precipitation in 1998, 1999 and 2000 was 648, 399 and 263 mm, respectively. Surface runoff for 1999 and 2000 was simulated using SWAT. They developed a continuous time distributed parameter model for ungagged basins.

Pikounis *et al.* (2003) investigated the hydrological effects of specific land use changes in catchment of the river Pinios in Thessaly (Ali Efenti catchment) (2976 km^2), through the application of SWAT on monthly time step. Three land use change scenarios were examined, namely expansion of agricultural land, complete deforestation, expansion of urban area. All three scenarios resulted in an increase in discharge during wet months and a decrease during dry periods. The deforestation scenario was the one that resulted in the greatest modification of total monthly runoff.

Tripathi *et al.* (2003) calibrated SWAT model for small watershed Nagwan (92.46 km^2) located in Upper Damoder Valley Corporation in the Hazaribagh district of Bihar, India. and used for identification and prioritization of critical sub-watershed to develop an effective management plan. Daily rainfall and runoff data of 7 years (1992-1998) were used in this study. Besides these data, the topographical map, soil map, land resources data and satellite imageries of the study watershed were used in this study. They concluded that SWAT model successfully be used for identifying and prioritising critical sub-watersheds for management purposes.

Chaplot (2005) determined the impact of the mesh size of the digital elevation model, DEM (from 20 to 500 m) and the soil map scale (1/25,000; 1/250,000 and; 1/500,000 scale) within the SWAT to simulate runoff of an agricultural watershed (2183 ha). He concluded that decreasing the mesh size beyond 50 m threshold didn’t substantially affect the computed runoff flux.

Jayakrishnan *et al* (2005) described some recent advances made in the application of SWAT and the SWAT–GIS interface for water resources management. Tested watershed was San Bernard river basin in Texas (3050 km^2). Four case studies were presented. This study demonstrated the usefulness of radar rainfall data in distributed hydrologic studies and the potential of SWAT for application in flood analysis and prediction.

Watson *et al.* (2005) studied the effect of water balance on agricultural and rural catchment (1157 km^2). SWAT was used to determine whether it was suitable for modelling the water balance of catchments in the southwest region of Victoria and to determine if it could be adopted as a planning tool to manage land use change. The results achieved in this initial application of SWAT were very pleasing. However it was shown that the groundwater and tree growth components of the model were not entirely adequate. They recommended that both these components be modified to improve model performance.

Kannan *et al.* (2006) evaluated the performance of the SWAT-2000 using stream flow at the outlet of the 142 ha Colworth catchment (Bedfordshire, UK). The soil type consisted of clay loam and a rotation of wheat, oil seed rape, grass, beans and peas were grown. Acceptable performance in hydrological modeling, along with correct simulation of the process driving the water balance was essential first requirements for predicting transport. They concluded that initial model application resulted in good simulation of observed hydrographs and the modelling of internal catchment processes was incorrect.

Kang *et al.* (2006) applied the SWAT to develop total maximum daily load (TMDL) programs for a watershed containing paddy fields in the Republic of Korea (2979 ha). The total maximum daily load system (TOLOS), based on ArcView SWAT (AVSWAT) using geographic information system (GIS) and remote sensing (RS), was incorporated with the SWAT model to simulate water balance from irrigated paddy fields. Model parameters related to hydrology were calibrated and validated by comparing model predictions with the field data collected for 4 years. The results indicated that the simulated runoff was acceptably close to the observed data.

Kangsheng and Johnston.(2007) stated that the process based hydrological models were usually calibrated prior to application to ensure that they closely match reality. Different hydrological response to varied climatic conditions might affect model calibration and validation. A case study was conducted for a 901 sq. km watershed of northern Michigan to compare the effect of calibrating the SWAT model with different climatic data sets representing drought versus average conditions.

Schuol and Abbaspour.(2007) developed a daily weather generator algorithm that used the currently available 0.5° monthly weather statistics from the Climatic Research Unit (4 million km^2). They tested dGen in two ways. (1) They made a direct comparison of the measured and generated precipitation and maximum–minimum temperatures by looking at some long-term statistics in a few stations in West Africa (4 million km^2). (2) They ran the model “Soil and Water Assessment Tool” with dGen-generated and measured daily weather data to simulate 25 years of annual and monthly river discharges at some gauging stations. They concluded that discharge simulations using generated data were superior to the simulations using available measured data from local climate stations.

Rokhsare *et al.* (2008) used SWAT to model runoff in the Beheshtabad (3860 km^2) and Vanak (3198 km^2) watersheds in the northern Karun catchment in central Iran. Model calibration and uncertainty analysis were performed with sequential uncertainty fitting (SUFI-2), which was one of the programs interfaced with SWAT, in the package SWAT-CUP (SWAT Calibration Uncertainty Programs). Two measures were used to assess the goodness of calibration and uncertainty analysis: (a) the percentage of data bracketed by the 95% prediction uncertainty (95PPU) (P factor), and (b) the ratio of average thickness of the 95PPU band to the standard deviation of the corresponding measured variable (D factor). Ideally, the P factor should tend towards 1 with a D factor close to zero. These measures together indicated the strength of the calibration-uncertainty analysis. Runoff data from four hydrometric stations in each basin were used for calibration and validation.

Zachary *et al*. (2008) re-conceptualized the SWAT model to distribute overland flow in ways consistent with VSA (variable source areas) hydrology by modifying how the CN and available water content were defined; the modeling approach was called SWAT-VSA. Both SWAT and SWAT-VSA were applied to a sub watershed. The test watershed is a 37 km2 rural watershed located in the Catskill Mountains of New York State. They found that SWAT-VSA predicted distributed soil water leaving the watershed better than the original SWAT.

Nathaniel *et al*. (2009) focused on quantitative prediction of environmental impacts of land use changes in watersheds for developing sound watershed management schemes, especially for Philippine watersheds with agroforestry systems. ArcSWAT a river basin scale model developed to quantify the impact of land management practices on water was parameterized and calibrated in selected Manupali River sub-watersheds with an aggregate area of 200 ha to simulate the effects of land use on runoff volumes and stream flows. Calibration results showed that ArcSWAT adequately predicts peaks and temporal variation of runoff volumes with Nash and Sutcliffe coefficient ranging from 0.77 to 0.83

Agrawal *et al.* (2010) used SWAT model for simulating runoff of agricultural watershed Chhokranala in Chhattisgarh (1731ha) using generated rainfall. The maps of watershed/sub-watershed boundaries, drainage networks, and slope and soil texture were developed using a GIS. A supervised classification method was used for land use/cover classification from satellite imageries. Model simulated monthly rainfall for the period of four years (2002-05) was compared with observation and simulated monthly rainfalls, runoff for monsoon season of four years (2002-05) were also compared with their observed values. In general monthly averages rainfall predicted by the model was in close agreement with the observed monthly average values. Besides, simulated monthly average values of surface runoff using generated rainfall compared with observed values during the monsoon season of the years (2002-05). Results of this study revealed that the generated values of Rainfall and runoff SWAT were in close agreement and this technique could be employed any watershed located in similar conditions.

Fikadu *et al.* (2010) calibrated and validated SWAT for measured stream flow at Bahir Dar near Kessie and at the border of Sudan for flow gauging stations (284 km^2). The model performance evaluation statistics (Nash–Sutcliffe model efficiency (NSE) and coefficient of determination (r^2)) are in the acceptable range (r^2 in the range 0.71 to 0.91 and NSE in the range 0.65 to 0.90).

Mukundan (2010) tested the effect of spatial resolution of soil data on the SWAT model predictions of flow. The state soil geographic database mapped at 1:250,000 scales was compared with the soil survey geographic database mapped at 1:12,000 scale in an ArcSWAT model of the North Fork Broad River in Georgia (182 km^2). Model outputs were compared for the effect of soil data before calibration using default model parameters as calibration could mask the effect of soil data. The model predictions of flow by the two models were similar, and the differences were statistically insignificant ($\alpha = 0.05$). These results were attributed to the similarity in key soil property values in the two databases that govern stream flow. The two models after calibration had comparable model efficiency in simulating stream flow. He concluded that less detailed soil data used because more time, effort, and computational resources were required to set up and calibrate a model with more detailed soil data, especially in a larger watershed.

Sathian and Syamala.(2010) used SWAT model to analyze and quantify the water balance of a river basin namely, Kunthipuzha (64000 km^2) in Kerala. AV-SWAT model was built for the basin with the help of GIS and remote sensing software. DEM, land use, soil and digitized stream network were prepared in ILWIS GIS package developed by ITC, Netherlands. Model was calibrated using observed river flow data. Calibration had been performed first on annual basis followed by monthly and ten days basis. The calibration and validation of the model for different time steps viz. annual, monthly and 10 days daily gives very promising results. The calibration efficiency was tested by Nash Sutcliff efficiency and coefficient of determination. Both these efficiency measures figured above 80% indicating very high predictive ability of the model. They recommended that SWAT model can be effectively used for assessing the water balance components of a river basin.

Talita *et al.* (2010) evaluated SWAT model in a small rural watershed (1.19 km^2) located on the basalt slopes of the state of Rio Grande do Sul in southern Brazil, where farmers had been using cover crops associated with minimum tillage to control soil erosion. Values simulated by the model were compared with measured hydro-sedimentological data. They concluded that (1) The SWAT model, when used without calibration, was able to adequately reproduce runoff and total flow discharge on monthly and annual time scales but not on daily scales and (2) SWAT without calibration, and the model's limitations in representing the hydrological and sedimentological processes for small watersheds could be responsible for these results.

Jha (2011) applied SWAT model to the Maquoketa River watershed, located in northeast Iowa, draining an agriculture intensive area of about 5,000 km^2. Meteorological input, including precipitation and temperature from six weather stations located in and around the watershed, and measured stream flow data at the watershed outlet, were used in the simulation. A sensitivity analysis was performed using an influence coefficient method to evaluate surface runoff and base flow variations in response to changes in model input hydrologic parameters. The curve number, evaporation compensation factor, and soil available water capacity were found to be the most sensitive parameters among eight selected parameters. He found at least 86% and 69% of the variability in the measured stream flow data for calibration and validation periods, respectively.

Taesoo *et al.* (2011) used SWAT model to estimate terrestrial inflow to Galveston and Matagorda bays from their contributing watersheds (96 km^2). The term "terrestrial inflows" represents the sum of gauged inflows from gauged sub basins plus model generated flows from ungauged sub-basins. SWAT benefits summarized into two categories. (1) SWAT offers finer spatial and temporal scales, allowing users to observe an output from a particular sub basin within a particular time frame. (2) It considers comprehensive hydrological processes at the sub basin level and within the entire watershed surface runoff.

Tibebe *et al.* (2011) evaluated surface runoff generation for watershed (the Keleta Watershed) in the Awash River basin of Ethiopia (153 km^2) by using the SWAT model. Calibration and validation of the model was performed on monthly basis, and it could simulate surface runoff to a good level of accuracy. The study demonstrates that the SWAT model provides a useful tool for runoff assessment from watersheds and facilitates planning for a sustainable land management in Ethiopia.

Most of scientists tried to apply Soil and Water Assessment Tool model to area more than 100 ha. They have also used the DEM data of various resolutions. But in every time watershed area more than 100 ha isn’t possible. SWAT application for small watershed is difficult, but some data generate manually in Arc-GIS software and then apply SWAT for small area. SWAT is applicable to determine the water balance component. Water balance is a broad term that includes different components. If different water balance components are known then selection of water conservation practices are easy. Water balance component determination by manually is time consuming process. Therefore this study focused on water balance components analysis using SWAT model.

Table 2.1 Water balance analysis

Sr. No	**Author**	**Watershed location**	**Area of watershed**	**Findings**
1	Randall *et al.*	Mountain catchment in Tanzania	92 km^2	Catchment behavior represent by a linear storage model with recession constant of 0.151/month.
2	Xu *et al.*	Catchment in Australia	127 km^2	Annual runoff (*R*), evapotranspiration (*E*) and runoff coefficient (*R/P*) increase with vegetation cover for catchments in which woody vegetation was dominant and annual precipitation was relatively high.
3	Abazi *et al.*	Olive orchard in southern Spain	192 m^2 experimental field	Annual runoff simulation provided a RMSE of 4.4 mm and the model efficiency was higher than 0.5.
4	Soja *et al.*	Lake Neusiedl in Austria	413 km^2	Precipitation and temperature influenced flow significantly.

Table 2.2 Application of SWAT for water balance analysis

Sr. No	**Author**	**Watershed location**	**Area of watershed**	**Findings**
1	Spruill *et al.*	Central Kentucky	34 km^2	Saturated hydraulic conductivity, alpha base flow factor, drainage area and channel width were the most sensitive parameters in modeling.
2	Chanasyk *et al.*	Stavely research station	5.93 ha	Developed a model for ungagged basins (continuous time).

3	Pikounis *et al.*	Catchment of river Pinios in Thessaly	2976 km^2	The deforestation scenario was the one that resulted in the greatest modification of total monthly runoff.
4	Tripathi *et al.*	Nagwan watershed (Damoder valley)	92.46 km^2	Identifying and prioritising critical sub-watersheds for management purposes.
5	Chaplot	Agriculture watershed	2183 ha	Decreasing the mesh size beyond 50 m threshold didn't substantially affect the computed runoff flux.
6	Jayakrishnan *et al.*	San Bernard river basin in Texas	3050 km^2	Demonstrated the usefulness of radar rainfall data in distributed hydrologic studies and the potential of SWAT for application in flood analysis and prediction.
7	Watson *et al.*	Catchment in the Southeast region of Victoria	1157 km^2	Groundwater and tree growth components of the model were not entirely adequate.
8	Kannan *et al.*	Colworth (Poedfordshire, UK)	142 ha	Model application resulted in good simulation of observed hydrographs and the modelling of internal catchment processes was incorrect.
9	Kang *et al.*	Paddy field in Republic Korea	2979 ha	Simulated runoff was acceptably close to the observed data.
10	Kangsheng *et al.*	Northern Michigan	901 km^2	Different hydrological response to varied climatic conditions might affect model calibration & validation.

11	Schuol *et al.*	West Africa	4 million km^2	Discharge simulations using generated data were superior to the simulations using available measured data.
12	Rokhsare *et al.*	Beheshtabad and Vanak	3860 km^2	Model calibration and uncertainty analysis were performed with sequential uncertainty fitting.
13	Zachary *et al.*	Catskill mountains of New York state	37 km^2	SWAT-VSA predicted distributed soil water leaving the watershed better than the original SWAT.
14	Nathaniel *et al.*	Philippine watershed	200 ha	Predicts peaks and temporal variation of runoff volumes with Nash and Sutcliffe coefficient (NSE) ranging from 0.77 to 0.83
15	Agrawal *et al.*	Chhokranala	1731 ha	Generated values of Rainfall and runoff SWAT were in close agreement and this technique could be employed any watershed located in similar conditions.
16	Fikadu *et al.*	Bahir Dar near Kessie and at the border of Sudan	284 km^2	Model performance evaluation statistics (Nash–Sutcliffe model efficiency (ENS) and coefficient of determination (r^2)) are in the acceptable range (r^2 in the range 0.71 to 0.91 and ENS in the range 0.65 to 0.90).

17	Mukundan	North forkbroad river in Georgia	182 km^2	The model predictions of flow by the two models were similar, and the differences were statistically insignificant.
18	Sathian *et al.*	Kunthipuzha in Kerala	6400 km^2	SWAT model can be effectively used for assessing the water balance components.
19	Talita *et al.*	Rio Grande do sul	1.19 km^2	The SWAT model, when used without calibration, was able to adequately reproduce runoff and total flow discharge on monthly and annual time scales but not on daily sales.
20	Jha *et al.*	Maquoketa river watershed located in northeast Iowa	5000 km^2	At least 86% and 69% of the variability in the measured stream flow data for calibration and validation periods, respectively.
21	Taesoo *et al.*	Galveton and Matagorda	96 k m^2	SWAT offers finer spatial and temporal scales, allowing users to observe an output from a particular sub basin within a particular time frame.
22	Tibebe *et al.*	Keleta watershed (Awash river basin of Ethipopia)	153 km^2	SWAT model provides a useful tool for runoff assessment from watersheds and facilitates planning for a sustainable land management.

3. MATERIAL AND METHODS

This chapter deals with the material and methods used for determining water balance components of watershed using SWAT model. Further, statistical indices used to evaluate the prediction performance and validation of model for the watershed is also discussed in this chapter.

3.1 Watershed description

3.1.1 Location

The Maheshgad watershed is located towards South of Central Campus of Mahatma Phule Krishi Vidyapeeth and North East of Maheshgad hill. It is having 45.04 ha area. It lies at 19^0 $19^,$ N longitude and 74^0 $38^,$ E latitude. The average annual rainfall in the study area is 553 mm.

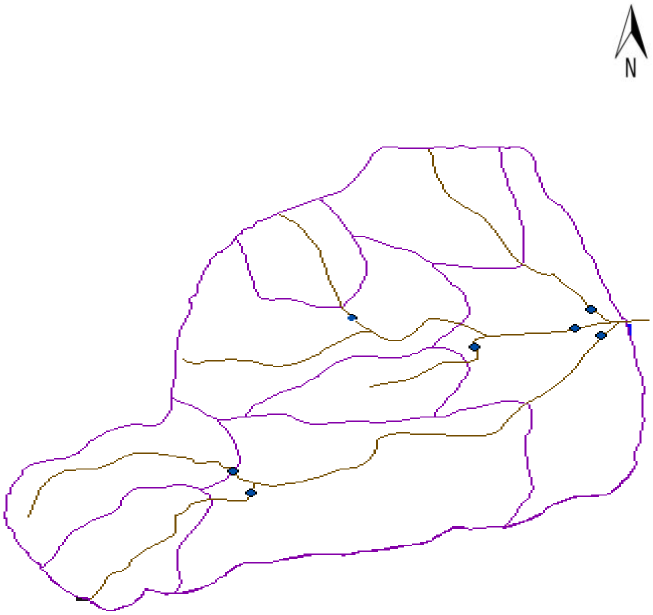


Fig.3.1 Map of different subwatersheds and streams of Maheshgad

3.1.2 Present land use and soil

Maheshgad Watershed is having loamy soil, murum and stony waste (exposed rock). Slope of watershed varies from 8 % to 1.95 %. Watershed is divided into eight sub-watershed namely W1A, W1B, W1, W2, W3, W4, W6 and water body (W5). The area and average slope of each sub-watershed are given in Fig.3.2 and Table 3.1.

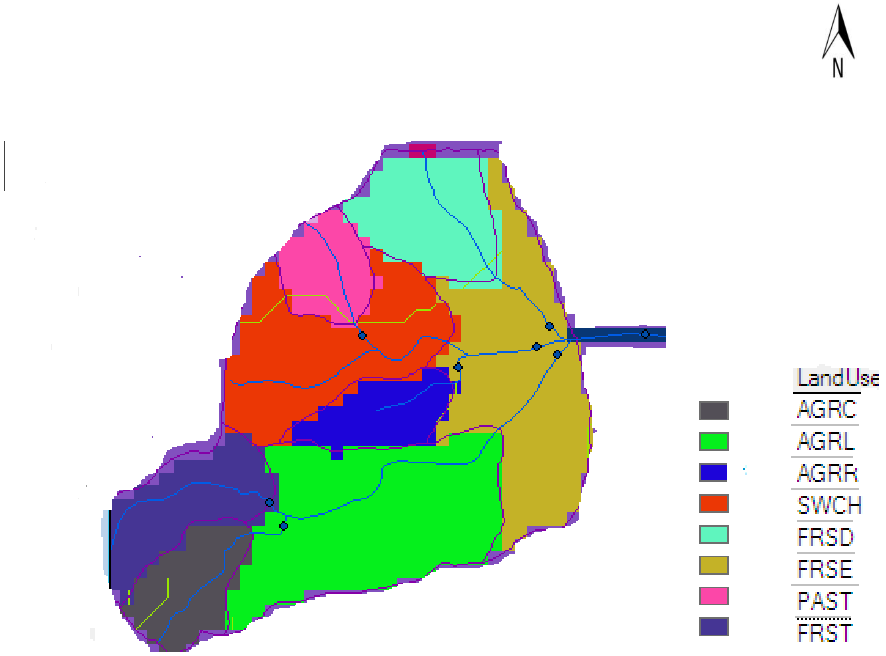


Fig.3.2 Present land use map

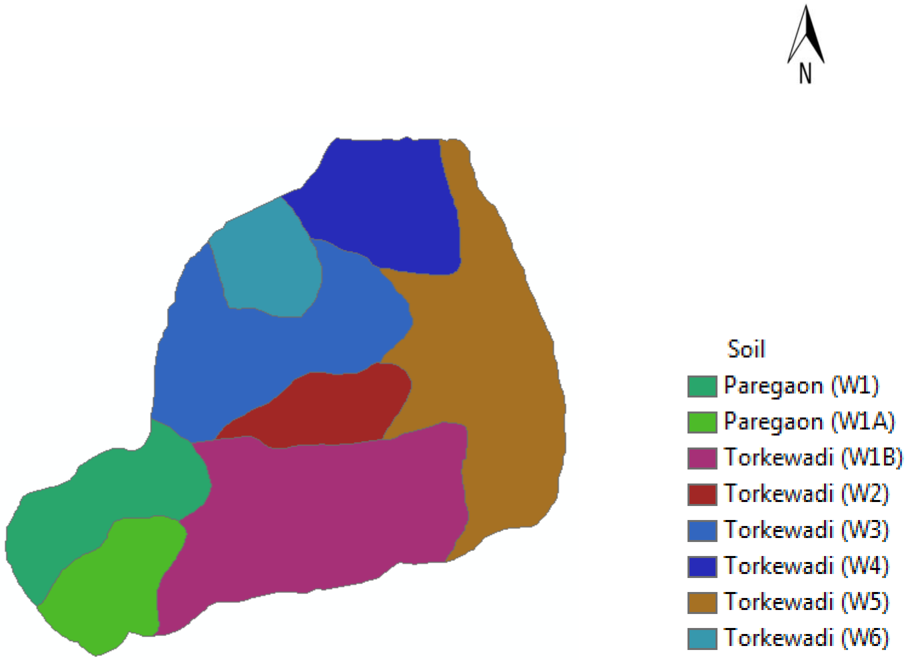


Fig.3.3 Soil Series map

Table 3.1 Area, average slope, soil type and land use in different subwatersheds

Sub-watershed	**Area (ha)**	**Slope (%)**	**Soil type**	**Present Land use**
W1A	2.38	8.00	Exposed rock	Horticulture
W1B	16.28	2.12	Murum	Silvipasture and Horticulture
W1	18.66	8.77	Murum	Silvipasture and Horticulture
W2	2.74	1.95	Loamy soil	Agriculture
W3	9.97	2.54	Murum	Pasture
W4	4.75	3.07	Murum	Silvipasture and Horticulture
W5	8.92	-	Loamy soil	Water body
W6	2.44	3.97	Murum	Horticulture and Pasture

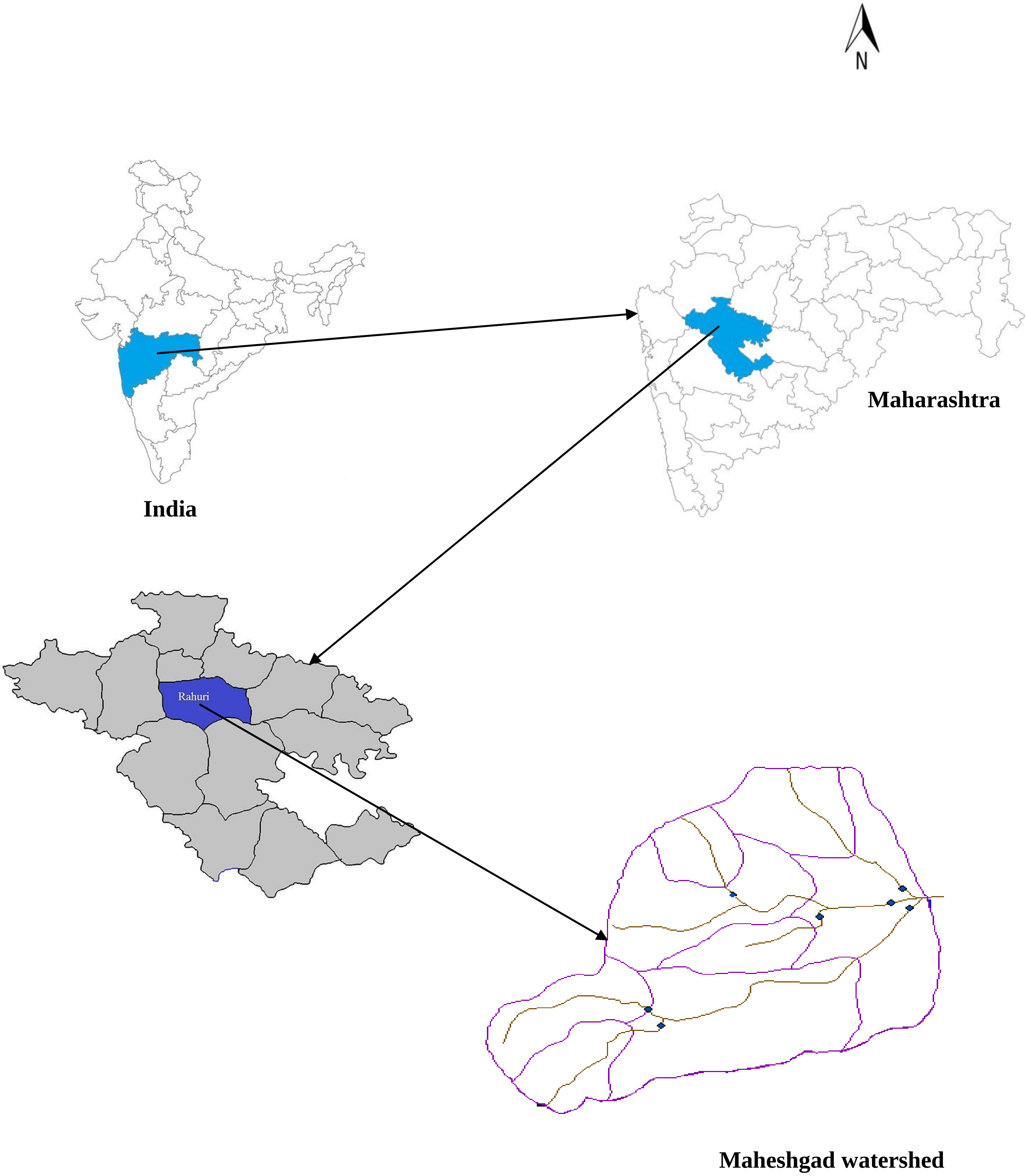


Fig. 3.4 Location map of the study area

3.2 Software:

3.2.1 SWAT model

SWAT was developed by Arnold (1990) to predict the impact of land management practices on water, sediment and agricultural chemical yields in large complex watersheds with varying soils, land use and management conditions over long period of time. To satisfy this objective, the model is physically based. Rather than incorporating regression equations to describe the relationship between input and output variables, SWAT requires specific information about weather, soil properties, topography, vegetation and land management practices occurring in the watershed. The physical processes associated with water movement, sediment movement, crop growth, nutrient cycling etc are directly modeled in SWAT 2005.

Monitoring of runoff, sediment yield and agricultural chemical yield is important component of soil conservation and watershed management. SWAT 2005 model is most widely accepted and frequently used to calculate these parameters. Operating procedure of SWAT 2005 model is given in Appendix-A.

3.2.2.ArcGIS

ArcGIS is a geographic information system (GIS) for working with maps and geographic information. It is used for creating and using maps compiling geographic data analyzing mapped information sharing and discovering geographic information using maps and geographic information in a range of applications and managing geographic information in a database. The system provides an infrastructure for making maps and geographic information available throughout an organization, across a community, and openly on the Web.

ArcGIS includes the following Windows desktop software:

1) ArcReader, which allows one to view and query maps created with the other ArcGIS products;
2) ArcGIS for Desktop is licensed under three functionality levels; ArcGIS for Desktop Basic (formerly known as ArcView), which allows one to view spatial data, create layered maps, and perform basic spatial analysis;

3) ArcGIS for Desktop Standard (formerly known as ArcEditor), which in addition to the functionality of ArcView, includes more advanced tools for manipulation of shapefiles and geodatabases;

4) ArcGIS for Desktop Advanced (formerly known as ArcInfo), which includes capabilities for data manipulation, editing, and analysis.

3.3 HRU generated by SWAT model

SWAT model divide the eight subwatershed into twenty-eight HRU. HRU classification is depending on slope range. Four slope ranges are selected 0-2 %, 2-4 %, 4-6 % and 6-99 %. These HRU's presented in Fig.3.5 and Table 3.2.

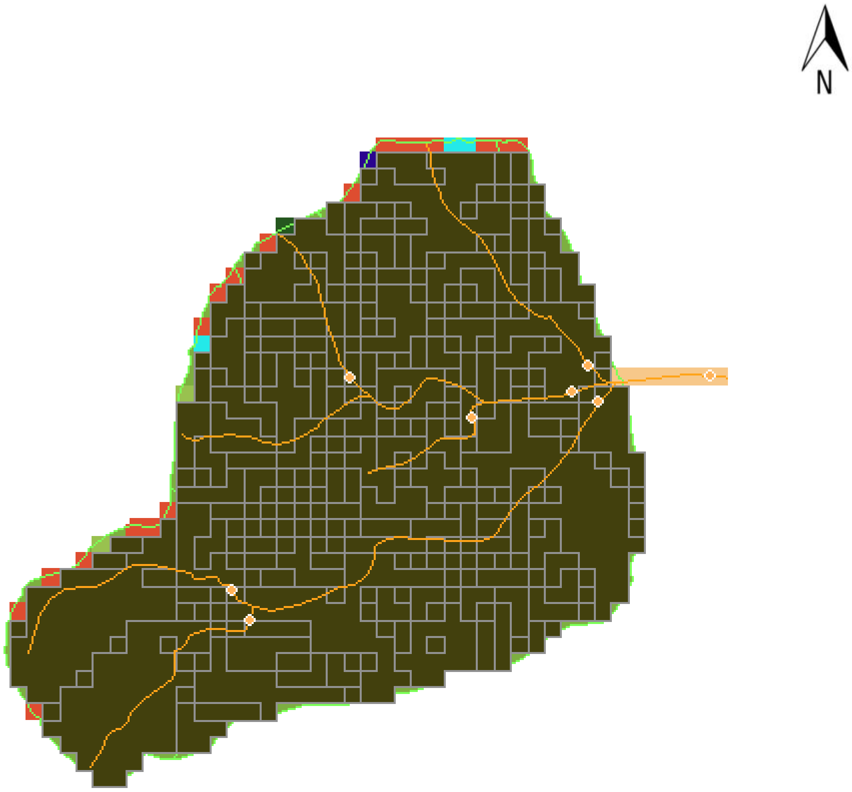


Fig.3.5 Map of HRU

Table 3.2 HRU of different subwatersheds

Sub watershed	**HRU**	**Land use code**	**Area (ha)**	**Slope range (%)**
W1A	1	Forest-Deciduous (FRSD)	3.20	6-99
W1	2	Forest-Mixed (FRST)	2.39	2-4
	3	Forest-Mixed (FRST)	1.74	0-2
	4	Forest-Mixed (FRST)	4.01	6-99
	5	Forest-Mixed (FRST)	2.77	4-6
W2	6	Agricultural Land-Generic (AGRL)	0.99	4-6
	7	Agricultural Land-Generic (AGRL)	0.99	2-4
	8	Agricultural Land-Generic (AGRL)	0.46	6-99
	9	Agricultural Land-Generic (AGRL)	0.35	0-2
W3	10	Pasture (PAST)	2	4-6
	11	Pasture (PAST)	2.12	6-99
	12	Pasture (PAST)	1.80	2-4
	13	Pasture (PAST)	1	0-2
W4	14	Range-Grasses (RNGE)	1.91	6-99
	15	Range-Grasses (RNGE)	0.85	4-6
	16	Range-Grasses (RNGE)	0.85	2-4

	17	Range-Grasses (RNGE)	0.69	0-2
W1B	18	Orchard (ORCD)	0.44	4-6
	19	Orchard (ORCD)	2.98	6-99
	20	Orchard (ORCD)	0.72	2-4
W6	21	Range-Brush (RNGB)	1.1	6-99
	22	Range-Brush (RNGB)	0.59	4-6
	23	Range-Brush (RNGB)	0.48	2-4
	24	Range-Brush (RNGB)	0.37	0-2
W5	25	Water (WATR)	1.66	4-6
	26	Water (WATR)	4.11	6-99
	27	Water (WATR)	2.1	0-2
	28	Water (WATR)	2.40	2-4

3.4 Equations of watershed hydrology use in SWAT:

3.4.1 Water balance equation:

The hydrologic cycle as simulated by SWAT is based on the water balance equation:

$$SW_t = SW_0 + \sum_{i=1}^{t}(R_i - Q_i - ET_i - P_i - QR_i) \quad \ldots(3.1)$$

Where, SW_t and SW_0 are the final and initial soil water (mm) content respectively.

i = day,

R_i = rainfall on $_i^{th}$ day, mm

Q_i = surface runoff on $_i^{th}$ day, mm

ET_i = evapotranspiration on $_i^{th}$ day, mm

P_i = percolation on $_i^{th}$ day, mm

QR_i = lateral flow on $_i^{th}$ day, mm

3.4.2 Surface runoff:

Surface runoff is predicted by equation (USDA-SCS, 1972) :

$$Q = \frac{(R - 0.2s)^2}{R + 0.8s} \qquad \text{For } R > 0.2s \quad \ldots(3.2)$$

$$Q = 0.0 \qquad \text{For } R < 0.2s \quad \ldots(3.3)$$

$$S = 254\left(\frac{100}{CN} - 1\right) \quad \ldots(3.4)$$

Where, Q = daily surface runoff, mm

R = daily rainfall, mm

S = retention parameter, mm

CN = curve number.

CN1 and CN3 are found out as function of CN2

$$CN1 = \frac{20\left(100 - CN2\right)}{\left(100 - CN2 + e^{\left(2.553-0.0636\left(100-CN2\right)\right)}\right)} \qquad \ldots(3.5)$$

$$CN3 = CN2 \times e^{\left(0.00673\left(100-CN2\right)\right)} \qquad \ldots(3.6)$$

Table 3.3 Curve number use by SWAT for different subwatersheds

Sub-watershed	**Slope (%)**	**Present Land use**	**SWAT code for land use**	**Hydrological Group**	**Curve number**
W1A	8.00	Horticulture	FRSD	C	77
W1B	2.12	Silvipasture and Horticulture	ORCD	C	77
W1	8.77	Silvipasture and Horticulture	FRST	C	73
W2	1.95	Agriculture	AGRL	C	83
W3	2.54	Pasture	PAST	C	79
W6	3.97	Horticulture and Pasture	RNGB	C	74
W4	3.07	Silvipasture and Horticulture	RNGE	B	69
W5	-	Water body	WATR	C	92

3.4.3 Base lateral flow:

Lateral flow is predicted by (Sathian and Syamala, 2010):

$$q_{lat} = 0.024 \frac{\left(2S \times SC \times \sin\alpha\right)}{\theta_d \times L} \qquad \ldots(3.7)$$

Where, q_{lat} = lateral flow ,mm/ day,

S = drainable volume of soil water per unit area of saturated thickness ,mm/day,

SC = saturated hydraulic conductivity ,mm/h taken as 25 (standard value),

L = flow length, m taken 897 (measured value),

α = slope of the land taken as per Table 3.3.,

θ_d = drainable porosity taken as 0.15 (standard value).

3.4.4 Base flow:

The base flow is estimated by (Sathian *et al*, 2010):

$$Q_{gwj} = Q_{gwj-1} \times e^{(-\alpha_{gw} \times \Delta t)} + W_{rchrg} \times (1 - e^{(-\alpha_{gw} \times \Delta t)}) \qquad \ldots(3.8)$$

Where, Qgwj = groundwater flow into the main channel on day j,

αgw = base flow recession constant ,0.048 (standard value),

Δt = time step 20 days (standard value),

W_{rchrg} = quantity of water recharge taken 10% (standard value).

3.5 Calibration and validation procedure

Physically based distributed watershed models should be calibrated before they are made use of in the simulation of hydrologic processes. This is reducing to uncertainty associated with model prediction. Hence, before going for the determination of the hydrologic components, a thorough attempt has been made to tune the parameters of the model so that the predicted values are in very close agreement with available measured data.

SWAT 2005 has been calibrated and validated using daily runoff flow data and monthly Potential evapotranspiration of two years 1997 and 1998. Data pertaining to year 1997 has been used for calibration and 1998 for validation. The calibration simulation period for runoff flow and monthly Potential evapotranspiration was started from January to December 1997. The related SWAT model parameters were adjusted to correct the overestimation of average daily runoff flow. After calibration, the curve number (CN2), Ground water delay (GW_delay), Available water capacity (SOL_AWC), Soil depth (SOL_Z), Soil evaporation compensation factor (ESCO) and Threshold water depth in the shallow aquifer for flow (GMQMN) were determined as listed in. As a result, the simulated water flow was acceptable. These parameters were more sensitive therefore selected for calibration. These parameters were more affect the runoff flow and potential evapotranspiration.

3.6 Performance evaluation of model:

The simulated and observed components are compared for accuracy by using following criteria.

3.6.1 Coefficient of efficiency:

Nash and Sutcliffe (1970) suggested that the relative performance of two approaches could be compared effectively based on standardization of residual variance with initial variance. The coefficient of efficiency, CE is determined by following mathematical relationship;

$$E = 1 - \frac{\sum_{i=1}^{n}(q_{obs} - q_{swat})^2}{\sum_{i=1}^{n}(q_{obs} - q_{mean})^2} \qquad \ldots(3.9)$$

Where, q_{obs} = observed value,

q_{swat} = simulated value,

q_{mean} = mean of observed value.

The perfect agreement between observed and estimated values yields CE as 1. Zero values of CE signify the estimate equals to mean of observed values. The negative value of CE implies estimate values to be less than observed mean.

3.6.2 Coefficient of determination

Coefficient of determination calculated by formula (Glantz and Slinker, 1990)

$$R^2 = 1 - \frac{SS_{res}}{SS_{tot}} \qquad \ldots(3.10)$$

Where, SS_{res} = $\sum_i (y_i - f_i)^2$, the sum of squares of residuals, also called the residual sum of squares,

SS_{tot} = $\sum_i (y_i - \bar{y}_i)^2$ the total sum of squares (Propotional to sample variance).

3.7 Data

The data for Maheshgad watershed regarding area, land use, rainfall, relative humidity, maximum and minimum temperature, evapotranspiration were taken from Department of Soil and Water Conservation Engineering, M.P.K.V. Rahuri given in Table 3.4, and Table 3.5. DEM data (30 m) of Rahuri area is taken from Bhuvan website (www.bhuvan.nrsc.gov.in).

Table 3.4 Monthly data of 1997

Month	Rainfall(mm)	Minimum Temperature, ^{0}c	Maximum temperature, ^{0}c	PET (mm)	Relative humidity (fraction)	Wind speed (m/s)
Jan	0	9.46	27.50	126.4	0.61	0.73
Feb	0	8.30	30.36	168.2	0.51	0.79
March	0	13.90	35.00	260.4	0.45	0.88
April	0	16.48	35.59	281.3	0.45	0.98
may	0	18.81	37.94	351.1	0.46	1.51
June	148.2	21.97	33.37	243.6	0.66	2.46
July	21.3	22.21	31.47	199.6	0.73	2.52
Aug	14.6	21.87	30.85	194.7	0.73	2.58
Sept	104.5	20.30	31.94	171	0.71	1.32
Oct	78	17.69	31.83	150.9	0.66	0.7
Nov	77	17.60	30.14	100.5	0.74	0.52
Dec	45.5	14.48	27.33	84.1	0.75	0.71

Table 3.5 Monthly data of 1998

Month	Rainfall (mm)	Minimum Temperature , ^{0}c	Maximum Temperature, ^{0}c	PET (mm)	Relative humidity (fraction)	Wind sped (m/s)
Jan	0	11.32	29.02	107.30	0.64	0.67
Feb	0	9.68	29.91	143.30	0.57	0.71
March	0	12.74	34.54	221.20	0.47	0.81
April	0	17.02	38.53	282	0.42	1.04
May	0	21.26	39.44	319.80	0.45	1.75
June	200	21.46	34.57	214.8	0.65	1.95
July	111	20.93	29.52	142.4	0.76	1.93
August	115.6	19.15	30.22	118.9	0.79	1.4
Sept	115.5	20.15	29.88	101.8	0.79	1.39
Oct	98.5	18.80	30.16	109.5	0.75	0.89
Nov	30.5	13.81	28.90	89.2	0.69	0.51
Dec	0	8.80	28.32	101.9	0.57	0.51

4. RESULT AND DICUSSION

The basic objectives of the study are to estimate the different water balance components in Maheshgad watershed validate the model for Maheshgad watershed and study the effect of land use change on water balance components of watershed.

The result based on this study pertaining to estimation of the water balance components, validation of the model for watershed and testing by means of statistical indices, is presented and discussed in this chapter.

4.1 Water balance components of Maheshgad watershed

Monthly water balance components of Maheshgad watershed for 1997 and 1998 are calculated using SWAT model.

Table 4.1 Water balance components for 1997

Month	Rainfall (mm)	Base flow (mm)	Base Lateral flow (mm)	Percolation (mm)	Runoff (mm)	PET (mm)	ET (mm)	Soil water (mm)
Jan	0	0	0	0	0	97.86	20.86	33.48
Feb	0	0	0	0	0	142.35	21.63	29.14
March	0	0	0	0	0	197.89	47.44	11.37
April	0	0	0	0	0	210.67	40.13	3.99
May	0	0	0	0	0	280.67	42.71	3.99
June	148.2	0.14	4.98	0.48	8.45	233.12	109.42	33.93
July	21.3	0.27	0.41	0	0	219.67	70.63	18.69
August	14.6	0.06	0.17	0	0	226.6	59.79	12.98
Sept	104.5	0.02	3.46	0.14	9.2	168.55	59.93	54.1
Oct	78	0.1	2.47	0.17	7.92	135.67	62.22	68.77
Nov	77	0.14	1.89	0.62	10.99	92.34	48.11	84.2
Dec	45.5	0.1	3.25	0.7	5.44	76.89	43.51	79.76

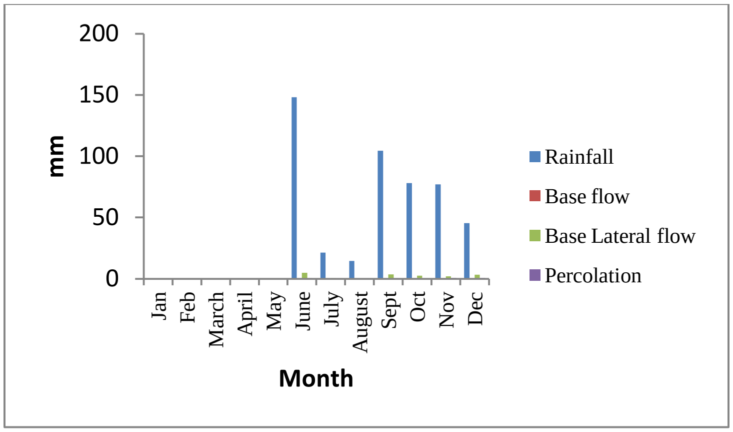


Fig 4.1 Rainfall, Base flow, Base Lateral flow and Percolation in mm for 1997

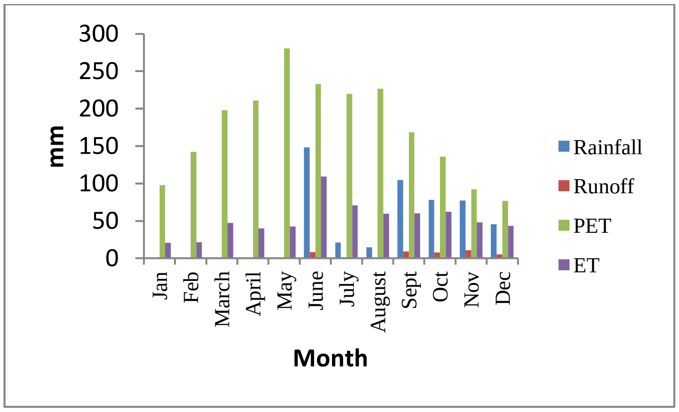


Fig 4.2 Rainfall, Runoff, PET, ET in mm for 1997

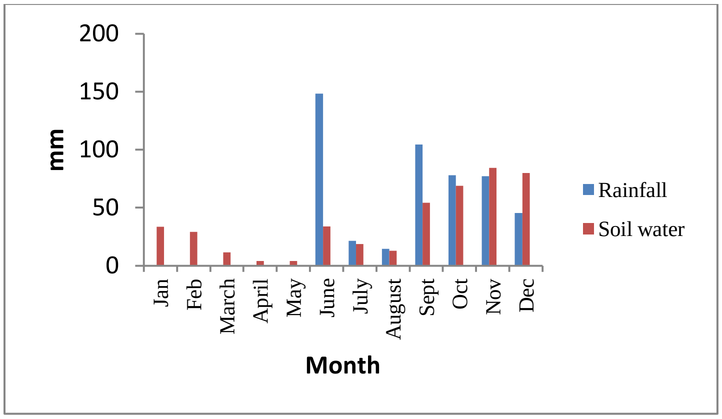


Fig 4.3 Rainfall and Soil water in mm for 1997

Table 4.2 Water balance components for 1998

Month	Rainfall (mm)	Base flow (mm)	Base Lateral flow (mm)	Percolation (mm)	Runoff (mm)	PET (mm)	ET (mm)	Soil water (mm)
Jan	0	0	0	0	0	83.49	32.17	62.65
Feb	0	0	0	0	0	90.95	27.65	52.61
March	0	0	0	0	0	149.26	56.67	25.32
April	0	0	0	0	0	185.2	53.23	5.73
May	0	0	0	0	0	264.39	44.16	3.99
June	200	0.18	6.96	1.47	34.15	233.26	90.73	66.51
July	111	0.74	3.86	0.73	6.38	183.92	89.16	88.27
August	115.6	0.7	4.75	0.89	13.76	185.67	104.84	93.94
Sept	115.5	1.16	3.92	1.35	16.02	152.82	97.29	97.25
Oct	98.5	1.68	4.12	2.29	8.46	125.6	84.24	101.39
Nov	30.5	0.93	0.72	0	2.47	84.75	45.21	95.96
Dec	0	0.16	0	0	0	66.69	24.38	85.37

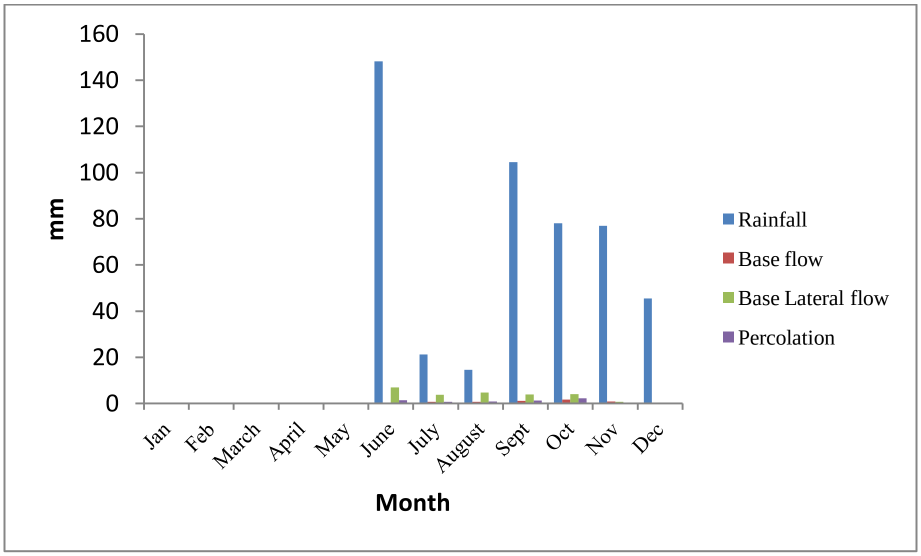


Fig 4.4 Rainfall, Base flow, Base Lateral flow and Percolation in mm for 1998

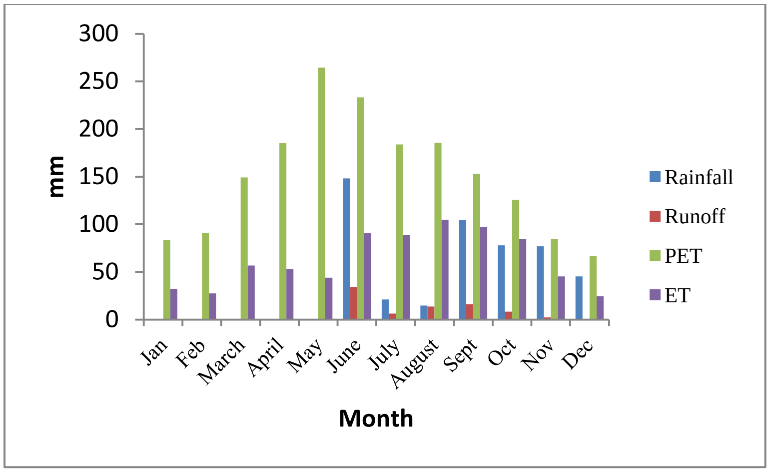


Fig 4.5 Rainfall, Runoff, PET, ET in mm for 1998

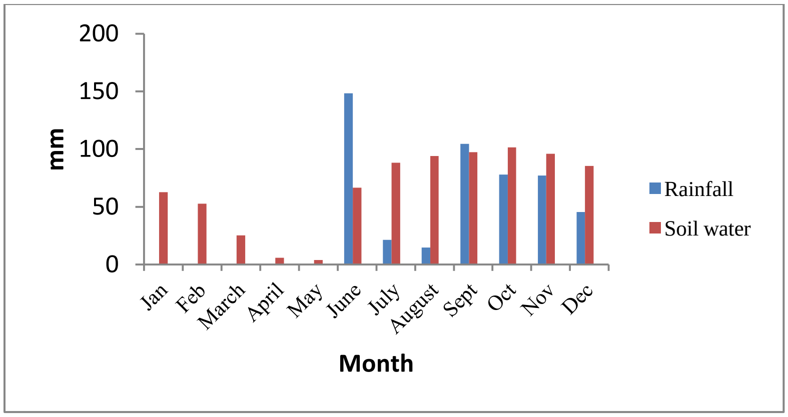


Fig 4.6 Rainfall and Soil water in mm for 1998

Table 4.3 Annual water balance parameters

Year	**Rainfall (mm)**	**Runoff (mm)**	**Base lateral flow (mm)**	**Base flow (mm)**	**Percolation (mm)**	**Soil water (mm)**	**ET (mm)**	**PET (mm)**
1997	488.1	42	16.63	1.36	2.28	434.38	566.45	2082.28
1998	671.1	81.24	24.33	5.55	6.73	778.99	749.65	1806

Table 4.3 shows the different water balance components of Maheshgad watershed for 1997 and 1998.

4.2 Calibration and validation of SWAT model for Maheshgad watershed

Physically based distributed watershed models should be calibrated before they are made use of in the simulation of hydrologic processes. This reduces uncertainty associated with model prediction. Hence, before going for the determination of the hydrologic components, a thorough attempt has been made to tune the parameters of the model so that the predicted values are in close agreement with available measured data.

SWAT 2005 has been calibrated and validated using runoff flow data of two years 1997 and 1998. Data of 1997 has been used for calibration and data of 1998 for validation. List of parameters those affected runoff are given in Table 4.4. Out of which six parameters adjusted for calibration are given in Table 4.5. These parameters are given in the list of calibration parameters of SWAT and also more sensitive for determination of runoff of Maheshgad watershed.

Table 4.4 List of SWAT parameters for calibration

Sr. No	Name	Description
1	GW_delay	Ground water delay (days)
2	SOL_AWC	Available water capacity (mm water/ mm soil)
3	SOL_Z	Soil depth (mm)
4	ESCO	Soil evaporation compensation factor
5	GMQMN	Threshold water depth in the shallow aquifer for flow (mm)
6	CN2	Initial curve number (II) value
7	EPCO	Plant uptake compensation factor
8	ALPHA_BF	Baseflow alpha factor
9	GW_REVAP	Groundwater revap coefficient
10	RECHRG_DP	Deep aquifer percolation fraction
11	SURLAG	Surface runoff lag coefficient (day)

Table 4.5 SWAT model parameters adjusted during calibration

Parameter	**Default value**	**Calibration value**	**Maheshgad watershed**	**Range**
GW_delay	31	20	20 (standard value)	0 to 50 day
SOL_AWC	0.47	0.95	0.95 (standard value)	0 to 1
SOL_Z	100	125	115	0.5 to 1000 mm
ESCO	0	0.7	0.7 (standard value)	0 to 1
GMQMN	0	200	200 (standard value)	0 to 5000 mm
CN2	Initial value	0.9	0.9 of original value	0.85 to 1.15

4.2.1 Calibration of SWAT for runoff

For calibration for daily runoff data of 1997 was used.

Table 4.6 Observed and Simulated runoff (calibration)

Date	**Rainfall (mm)**	**Runoff observed (mm)**	**Runoff Simulated (mm)**
22/9/97	55	5.41	7.71
23/9/97	23	12.69	6.85
22/10/97	20	0.85	0.65
25/10/97	43.5	7.34	7.29
28/10/97	11.5	0.35	0.28

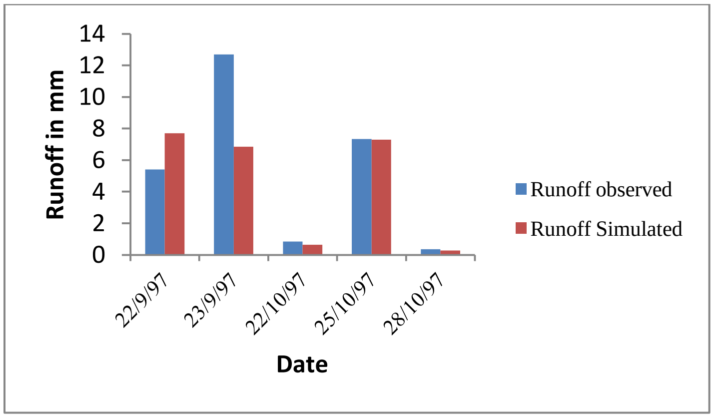


Fig. 4.7 Comparison of observed and simulated runoff (calibration)

4.2.2 Validation of SWAT for runoff

For validation for daily runoff data of 1998 was used.

Table 4.7 Observed and Simulated runoff (validation)

Date	Rainfall (mm)	Runoff observed (mm)	Runoff Simulated (mm)
15/06/1998	62	0.49	0.92
24/06/1998	56.5	13.55	13.22
28/06/1998	10	13.24	7.45
05/10/1998	27.5	9.1	6.32
07/10/1998	18	3.9	2.1

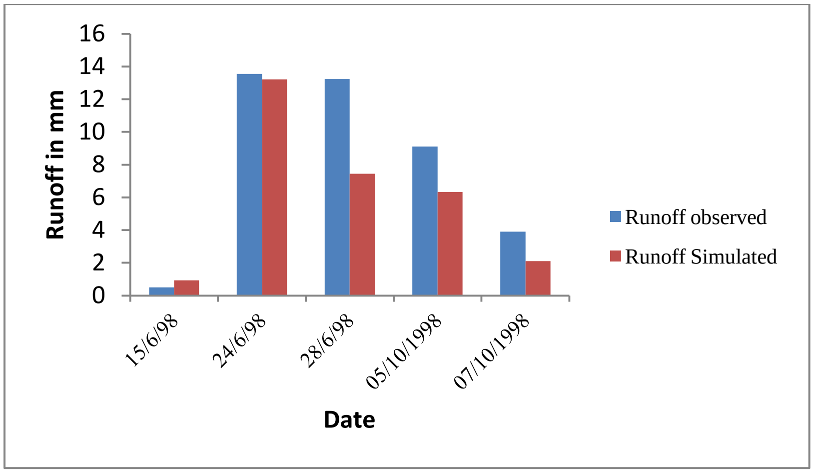


Fig 4.8 Comparison of observed and simulated runoff (validation)

Table 4.8 Descriptive statistics of daily runoff

Statistics	Calibration period	Validation period
Nash efficiency	0.62	0.74
Coefficient of determination	0.98	0.95

It is seen from Table 4.8 and Fig 4.7, Fig 4.8 that the simulated runoff matches with the observed values. Nash Efficiency and coefficient of determination gave very high value both for calibration and validation. The results suggest that the model, very well, be used to predict the runoff.

4.3 Effect of different land use on water balance components

Water balance components are affected by land use pattern of watershed. In this study effect of different land use on the water balance components is considered. Three different land use patterns or scenario are selected. Scenario wise description present in Table 4.9.

Scenario1 (present land use): In this Scenario subwatershed are under cover of horticulture, silvipasture, agriculture, pasture and water body.

Scenario 2 : In this Scenario subwatershed are under cover of orchard and water body.

Scenario 3 : In this Scenario subwatershed are under cover of forest-mixed, agriculture and water body.

Table 4.9 Scenario wise description

Sub-watershed	Present Land use (Scenario1)	Scenario2	Scenario3
W1A	Horticulture	Orchard	Forest-Mixed
W1B	Silvipasture and Horticulture	Orchard	Forest-Mixed
W1	Silvipasture and Horticulture	Orchard	Forest-Mixed
W2	Agriculture	Orchard	Agriculture
W3	Pasture	Orchard	Forest-Mixed
W4	Silvipasture and Horticulture	Orchard	Forest-Mixed
W5	Water body	Water body	Water body
W6	Horticulture and Pasture	Orchard	Forest-Mixed

Table 4.10 SWAT code for land use

Sub-watershed	Present Land use (Scenario1)	Scenario2	Scenario3
W1A	FRSD	ORCD	FRST
W1B	ORCD	ORCD	FRST
W1	FRST	ORCD	FRST
W2	AGRL	ORCD	AGRL
W3	PAST	ORCD	FRST
W4	RNGE	ORCD	FRST
W5	WATR	WATR	WATR
W6	RNGB	ORCD	FRST

Table 4.11 Curve number of different subwatershed under different scenario

Subwatershed	Present land use (Scenario 1)	Scenario 2	Scenario 3
W1A	77	77	73
W1B	77	77	73
W1	73	77	73
W2	83	77	83
W3	79	77	73
W6	74	77	73
W4	69	77	73
W5	92	92	92

Table 4.12 Annual water balance parameters under different Scenario for 1997

Scenario	Rainfall (mm)	Runoff (mm)	Base lateral flow (mm)	Base flow (mm)	Percolation (mm)	Soil water (mm)	ET (mm)	PET (mm)
Scenario1	488.1	42	16.63	1.36	2.28	434.38	566.45	2082.28
Scenario2	488.1	37.82	18.98	5.28	11.26	382.99	608.64	2160.28
Scenario3	488.1	39.89	22.84	6.75	34.94	470.84	565.97	2068.5

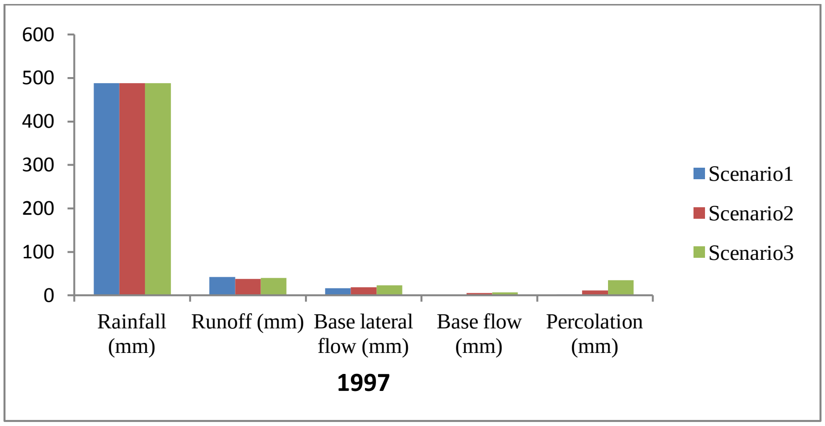


Fig 4.9 Rainfall, Runoff, Base Lateral flow, Base flow and Percolation in mm under different Scenario (1997)

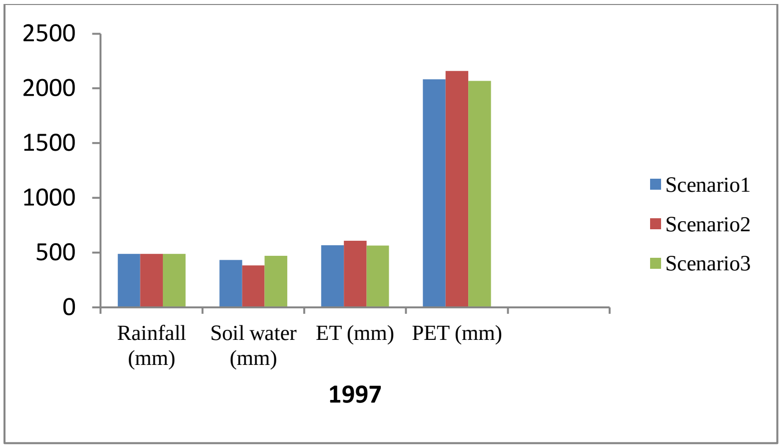


Fig 4.10 Rainfall, Soil water, ET, PET in mm under different Scenario (1997)

Table 4.13. Annual water balance parameters under different Scenario for 1998

Scenario	Rainfall (mm)	Runoff (mm)	Base lateral flow (mm)	Base flow (mm)	Percolation (mm)	Soil water (mm)	ET (mm)	PET (mm)
Scenario1	671.1	81.24	24.33	5.55	6.73	778.99	749.65	1806
Scenario2	671.1	76.73	26.45	25.06	30.52	678.65	740.73	1819.67
Scenario3	671.1	70.52	34.47	66.49	78.94	824	682.14	1805.92

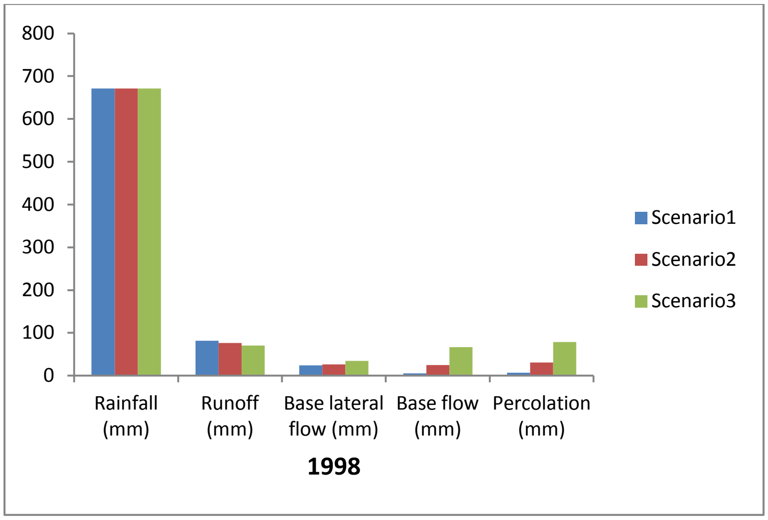


Fig 4.11 Rainfall, Runoff, Base Lateral flow, Base flow and Percolation in mm under different Scenario (1998)

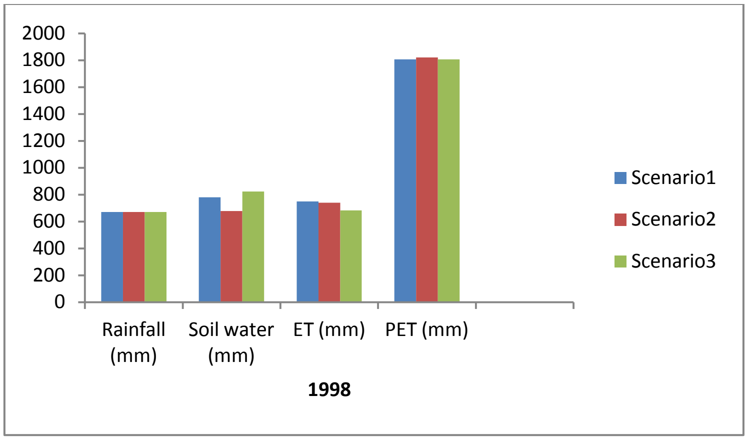


Fig 4.12 Rainfall, Soil water, ET, PET in mm under different Scenario (1998)

It can be seen from Table 4.12, Table 4.13 and Fig 4.9, Fig 4.10, Fig 4.11, Fig 4.12 runoff in Scenario1 is more than Scenario2 and Scenario3. In Scenario 2 most of area covered with orchard and in scenario 3 most of area covered with forest-mixed therefore these two cover generate more obstruction to runoff as compared to scenario 1. Base flow, base lateral flow, percolation and water yield in Scenario1 are less than Scenario2 and Scenerio3.Runoff is more in scenario 1 therefore most of water loss other components are less. Soil water content in Scenario3 is more than Scenario1 and Scenario2. Due to forest-mixed infiltration is more therefore soil hold more water. PET and PE in Scenario2 are more than Scenario1 and Scenario3. In Scenario 2 most of area is covered with orchard therefore open area more than other scenarios. It can be seen from Table 4.12 and Table 4.13 that runoff losses in Scenario 2 is less than scenario 3 in 19997 but reverse condition occurs in 1998. Reason behind that is 1998 rainfall concentrated (more than 100 mm) in June, July and August, September, but in 1997 rainfall pattern is well distributed and lower than 1998 (only June and September rainfall is more than 100 mm). Due to which effectiveness of orchard cover is less in 1998 than 1997.

5. SUMMARY AND COCLUSIONS

Water resources simulation models are often used to provide the information as a basis for decisions regarding the development and management of land and water resources. Water balance analysis problems associated with estimation of surface and ground water resources and their efficient utilization in order to sustain the available scare commodity for future needs had traditionally been carried out using simple analytical methods based on experience. The challenge of using such models in water resource management is that, these more detailed and sophisticated models are computer intensive. SWAT is comprehensive deterministic, distributed and physically based modeling system for simulation of all major hydrological processes in the land phase of the hydrological cycle. SWAT is applicable to a wide range of water resources and environmental problems related to surface water and ground water systems and the dynamic interaction between these. It has great importance for obtaining a better quantitative understanding of the availability of ground water resource and the effect of change in land use/land covers and climate on water resources. The physically based models like SWAT provide quantitative assessment of water resources however their optimum allocation and utilization is prime concern when water is scarce commodity.

5.1 Summary

The basic SWAT module, SWAT 2005 was used for the description of water balance for Maheshgad watershed. Watershed area was under loamy soil, murum and stony waste (exposed rock). Four different types of plantation viz., silvipasture, horticulture, pasture and agriculture were considered. Watershed was divided into eight sub-watershed namely W1A, W1B, W1, W2, W3, W4, W6 and water body (W5). For estimation of different water balance components in watershed data of 1997 and 1998 were used. The components of water balance for 1997 were estimated as Base lateral flow = 16.63 mm, Base flow = 1.36 mm, Percolation = 2.28 mm, PET = 2082.28 mm, Runoff = 42 mm, Soil water = 434.38 mm, ET= 566.45 mm. The components of water balance for 1998 were estimated as Base lateral flow = 24.33 mm, Base flow = 5.55 mm, Percolation = 6.73 mm, PET = 1806 mm, Runoff = 81.24 mm, Soil water = 778.99 mm, ET= 749.65

mm. For calibration and validation of SWAT model daily runoff data of 1997 and 1998 were used. Nash and Suctclife efficiency for calibration and validation of runoff was 0.62 and 0.74 respectively. Coefficient of determination for calibration and validation of runoff was 0.98 and 0.95 respectively. For land use effect on water balance components three land use or Scenario was selected namely Scenario 1, Scenario 2 and Scenario 3. Runoff in Scenario 1 is more than Scenario 2 and Scenario 3. Base flow, base lateral flow and percolation in Scenario 1 are less than Scenario 2 and Scenario 3. Soil water content in Scenario 3 is more than Scenario 1 and Scenario 2. PET and PE in Scenario 2 are more than Scenario 1 and Scenario 3.

5.2 Conclusions

Based on the results obtained the following conclusions are drawn.

1) For calibration six factors were selected for Maheshgad, Ground water delay (days) = 20 days, Available water capacity (mm water/ mm soil) = 0.95, Soil depth (mm) = 125 mm, Soil evaporation compensation factor = 0.7, Threshold water depth in the shallow aquifer for flow (mm) = 200 mm and Initial curve number (II) value = 0.9 of original value.

2) SWAT model was calibrated and validated for Maheshgad watershed for runoff. For calibration, Model efficiency = 0.62 and Coefficient of determination = 0.98. For validation, Model efficiency = 0.74 and Coefficient of determination = 0.95.

3) If land use in the watershed was changed from Scenario 1 (present land use) in to Scenario 2 (orchard) or Scenario 3 (forest-mixed and agriculture) then runoff of watershed decreases, but Base flow, base lateral flow, percolation and water yield increases. Soil water is higher in Scenario 3 and ET and PET losses are more in Scenario 2.

6. LITERATURE CITED

Abazi, U., I. J. Lorite, B. Carceles and A. Martinez. 2013. A conceptual water balance for analyzing rainfall water use in olive orchards under different soil and cover crop management strategies. Computers and Electronics in Agriculture, Vol.91: 35-48.

Agrawal, M. K. Verma and M. P. Tripathi. 2010. Hydrological modeling of chhokranala watershed using weather generator with SWAT model. Indian Journal of Soil Conservation, Vol. 39: 89-94.

Chanasyk, D. S., E. Mapfumo and W. Willm. 2002. Quantification and simulation of surface runoff from fecuse grassland watersheds. Agricultural Water Management, Vol.59: 137-153.

Chaplot, V. 2005. Impact of DEM mesh size and soil map scale on SWAT runoff, sediment, and NO_3-N loads predictions. Journal of hydrology, Vol. 312: 207-222.

Fikadu, F., S. B. Awulachew and N. Teklie. 2010. Development of rainfall-runoff-sediment discharge relationship in the Blue Nile Basin. CP 19 Project workshop proceedings report.

Glantz, S. A. and B. K. Slinker. 1990. Primer of Applied Regression and Analysis of Variance. McGraw-Hill, Vol.07:407-412.

Gupta, S.K. and Deshpande, R.D. 2004. Water for India in 2050: First-order assessment of available options. Current Science, Vol.86(9): 1216-1224.

Jayakrishnan, R. R. Srinivasan, C. Santhi and J. G. Arnold. 2005. Advances in the application of the SWAT model for water resources management. Hydrological Processes, Vol.19: 749-762.

Jha, M. 2011. Evaluating hydrologic response of an agricultural watershed for watershed analysis. Working paper 09-wp 492, www.card.iastate.edu.

Kang, M. S, S.W. Park, J. J. Lee and K.H. Yoo. 2006. Applying SWAT for TMDL programs to a small watershed containing rice paddy fields. Agricultural water management, Vol.79: 72-97.

Kangsheng, W. and C. A. Johnston. 2007. Hydrological response to climatic variability in a Great lakes watershed: a case study with the SWAT model. Journal of Hydrology,Vol. 337: 187-199.

Kannan, N., S. M. White, F. Worrall and M. J. Whelan. 2006. Hydrological modeling of small catchment using SWAT-2000-ensuring correct flow partitioning for contaminant modeling. Journal of Hydrology, Vol.334: 64-72.

Kumar, R., R. D.Singh and K. D. Sharma. 2005. Water resources of India. Current Science, Vol.89(5): 794-811.

Martinec, J. And A. Rango. 1989. Merits of statistical criteria for the performance of hydrological models. Water Resources Bulletin 25, 421–432.

Monteith, J.L., G. Szeicz and P. E. Waggoner. 1965. The measurement and control of stomatal resistance in the field. Journal of Applied Ecology. 2, 345–355.

Mukundan, R., D.E. Radcliffe and L.M. Risse. 2010. Spatial resolution of soil data and channel erosion effects on SWAT model predictions of flow and sediment. Journal of Soil and Water Conservation, Vol.65(2): 92-104.

Nash, J. E. and Sutcliffe .1970. River flow forecasting through conceptual models. Journal of Hydrology, Vol. 10: 282-290.

Nathaniel, R. A., V. B. Ella and M. R. Reyes. 2009. Predicting the effects of land use on runoff and sediment yield in selected sub-watersheds of Manupali river using the ArcSWAT model. World Association of Soil and Water Conservation, pp 253-266.

Pikounis, M., E. Varanou, E .Baltas and A. Dassaklis. 2003. Application of the SWAT model in the pinios river basin under different land use scenarios. Global Nest the Int. Journal, Vol.5(2): 71-79.

Priestley, C. H. B. and R. J. Taylor. 1972. On the assessment of surface heat flux and evaporation using large-scale parameters. Monthly Weather Rev, Vol.100: 81-92.

Randall, E. F. 2011. Using water balance models to approximate the effects of climate change on spring catchment discharge; MT. Hanang Tanzania. www.geo.mtu.edu.

Rokhsare, R., A. Jaleh and M. Afyuni. 2008. Application of a SWAT model for estimation runoff and sediment in rtwo mountainous basins in central Iran. Hydrological sciences-Journal-des sciences Hydrologiques, Vol.53(5): 977-988.

Sathian, K. K. and P. Syamala. 2010. Application of GIS integrated SWAT model for basin level water balance. www.csre.iitb.ac.in.

Schuol, J., and K. C. Abbaspour. 2007. Using monthly weather statistics to generate daily data in a SWAT model application to west Africa. Ecological modeling, Vol. 201 : 301-311.

Soja, G., J. Zuger, M. Knoflacher and P. Kinner. 2013. Climate impacts on water balance of shallow steppe lake in Eastern Austria (Lake Neusiedl). Journal of Hydrology, Vol.480: 115-124.

Susan, L., Neitsch and J. G. Arnold. Overview of Soil and Water Assessment Tool (SWAT) model. World Association of Soil and Water Conservation, Special Publication No.4.

Spruill, C. A., S. R .Workman, J. L. Taraba, J. G. Arnold, P. M. Allen and G. Bernhardt. 1993. A Comprehensive surface-groundwater flow model's. Hydro.142 (1/4): 47-55.

Sivakumar, T. K. 1997. Crop planning in watershed using linear programming. Project report submitted to Department of Soil and Water Conservation Engineering, MPKV, Rahuri.

Taesoo, L., R. Srinivasan and N. Omani. 2009. A Final Report for the Texas Water Development Board Project 2009: 483-890.

Talita, U., G. H. Merten, J. P. G. Minella and M. Moro. 2010. Use of the SWAT model for hydro-sedimentologic simulation on a small rural watershed. Hydrology and Earth System Sciences, Vol.14: 55-66.

Thornthwaite, C. W. 1948. An approach toward a rational classification of climate. Geographical Review, Vol. 38(1):55–94.

Tibebe, D. and W. Bewket. 2011. Surface runoff and soil erosion estimation using the SWAT model in the Keleta Watershed, Ethiopia. DOI, Vol.22(6): 551–564.

Tripathi, M. P., R. K. Panda and N. S. Raghuwanshi. 2003. Identification and prioritization of critical sub watershed for soil conservation management using the SWAT model. Biosystems Engineering, Vol.85 (3): 365-379.

US Department of Agriculture, Soil Conservation Service. 1972. National Engineering Handbook, Hydrology Section 4 (Chapter 4-10).

Watson, B. M., S. Selvalingam and M. Ghafouri. 2005. Evaluation of SWAT for modeling the water balance of the Woady Yaloak River catchment. Journal of Hydrology, Vol.298: 321-332.

www.bhuvan.nrsc.gov.in

Xu, C. Y. and V. P. Singh. 1998. A review on monthly water balance models for water resources investigations. Water resources management, Vol.12: 31-50.

Xu, X., D. Yang and M. Sivapalan. 2012. Assessing the impact of climate variability on catchment water balance and vegetation cover. Hydrology and Earth System Sciences, Vol.16: 43-58.

Zachary, M., Easton, D. R. Fuka and M. T. Walter. 2008. Re-conceptualizing the soil and water assessment tool (SWAT) model to predict runoff from variable source areas. Journal of Hydrology, Vol.348: 279-291.

7. APPENDICES

APPENDIX-A

Operating procedure for SWAT:

Steps:

1. SWAT Project Setup
2. Watershed delineation
3. HRU analysis
4. Write input table
5. Edit SWAT input
6. SWAT simulation

1. SWAT Project Setup

From the SWAT Project Setup menu, click the New SWAT Project command.

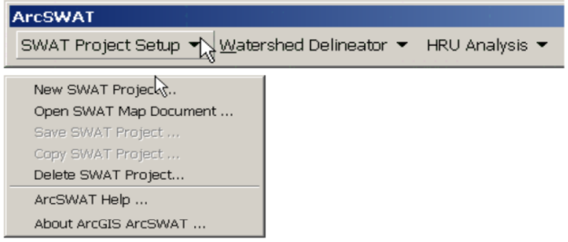
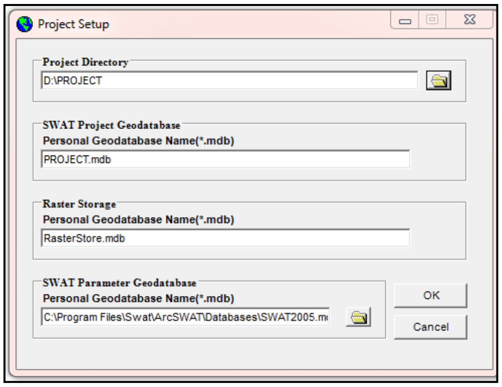


Fig. A.1 SWAT Project Setup

In the Project Set Up dialog, set the Project Directory to a location on your local drive or network in a folder called “PROJECT” (Figure A.2). The SWAT Project Geodatabases automatically set to “PROJECT.mdb” and the raster geodatabases set as “RasterStore.mdb”. The SWAT Parameter Geodatabases set to the SWAT2005.mdb database located in your Arc SWAT install folder (Figure A.2). Click OK. A new ArcSWAT project is created.


Project Setup

Project Directory
D:\PROJECT

SWAT Project Geodatabase
Personal Geodatabase Name(*.mdb)
PROJECT.mdb

Raster Storage
Personal Geodatabase Name(*.mdb)
RasterStore.mdb

SWAT Parameter Geodatabase
Personal Geodatabase Name(*.mdb)
C:\Program Files\Swat\ArcSWAT\Databases\SWAT2005.m

Fig. A.2 Project Setup

2. Watershed delineation

This tool allows the user to delineate sub-watersheds based on an automatic procedure using Digital Elevation Model (DEM) data. The Watershed Delineation carries out advanced GIS functions to aid the user in segmenting watersheds into several "hydrologically" connected sub-watersheds for use in watershed modeling with SWAT.

1. Choose the Automatic Watershed Delineation item from the Watershed Delineation menu.

Fig. A.3 Watershed delineator menu

2. The Watershed Delineation dialog opens. The dialog box is divided into five sections: DEM Setup, Stream Definition, Outlet and Inlet Definition, Watershed Outlet(s) Selection and Definition, and Calculation of Sub-basin Parameters.

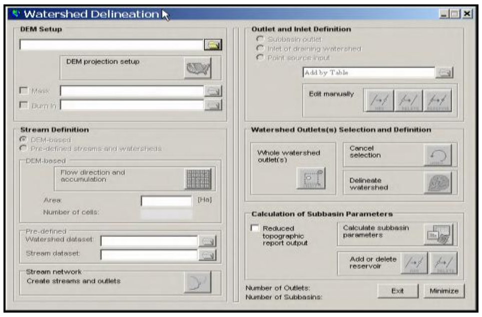


Fig. A.4 Watershed delineation window

3. Load the DEM from the project data folder by clicking on the browse button next to the DEM Setup text box.

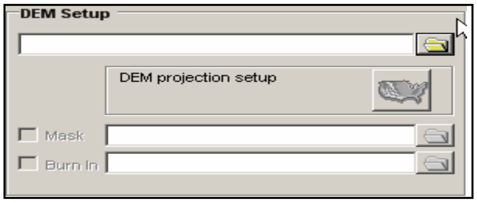


Fig. A.5 DEM Setup window

4. A dialog box is opened to specify which DEM map grid to use.

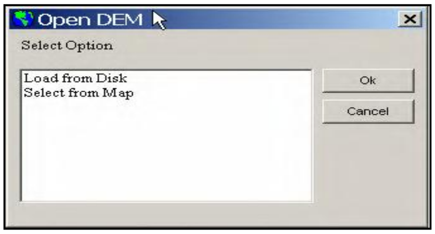


Fig. A.6 Open DEM

5. Click OK after the selection.

6. The elevation grid is imported to the "RasterSTore.mdb" geodatabase associated with the current ArcSWAT project. The name of the elevation grid (from within the "RasterStore.mdb" database) is displayed in the DEM Setup text box on the Watershed Delineation dialog box and the elevation map is displayed.

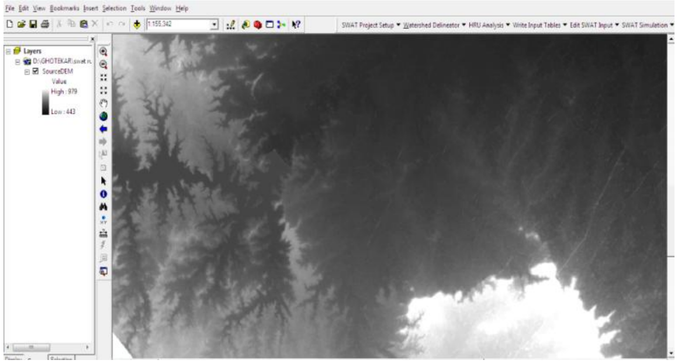
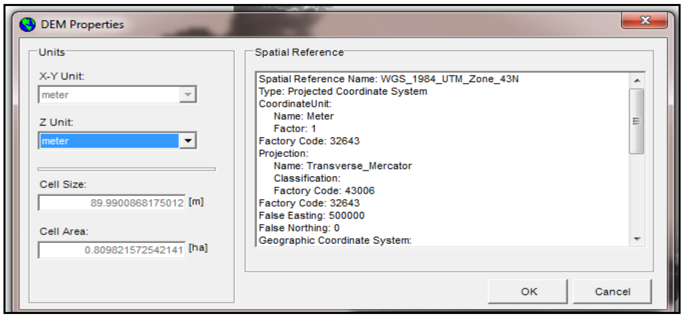


Fig. A.7 DEM data

7. Once your DEM has been properly loaded, click the DEM projection setup button (Figure A.8) to define the properties of the DEM.

Fig. A.8 DEM projection setup

8. The DEM Properties dialog box is open and allow the DEM vertical and horizontal units of measure and the projection to be verified.



X-Y Unit: meter
Z Unit: meter
Cell Size: 89.9900868175012 [m]
Cell Area: 0.809821572542141 [ha]

```
Spatial Reference Name: WGS_1984_UTM_Zone_43N
Type: Projected Coordinate System
CoordinateUnit:
   Name: Meter
   Factor: 1
Factory Code: 32643
Projection:
   Name: Transverse_Mercator
   Classification:
   Factory Code: 43006
Factory Code: 32643
False Easting: 500000
False Northing: 0
Geographic Coordinate System:
```

Fig. A.9 DEM properties

9. Once the DEM properties have been set, click OK. This is close the DEM Properties dialog box.

10. Check the checkbox next to Mask, and then click the adjacent file browse button to browse to the location of the "mask" grid in the project data folder. Choose the "Manually delineate" option when prompted. We have three options for masking an area of the DEM map. To activate one option, highlight the option and click OK. The first option, Load from Disk, allows the user to import a grid map from a disk drive. If this option is selected, a grid data set browser is opened.

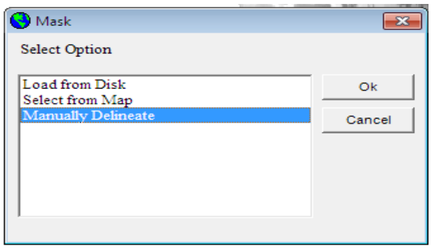


Fig. A.10 Mask menu

11. The mask grid is imported to the "RasterSTore.mdb" geodatabase associated with the current ArcSWAT project. The name of the mask grid (from within the "RasterStore.mdb" database) is displayed in the Mask text box on the Watershed

Delineation dialog box and the mask is displayed (Figure A.11).When a mask grid is used, the stream network is delineated only for the area of the DEM covered by the mask grid.

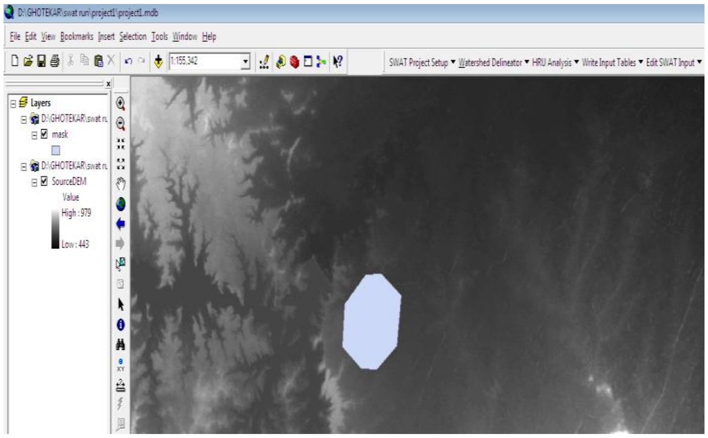
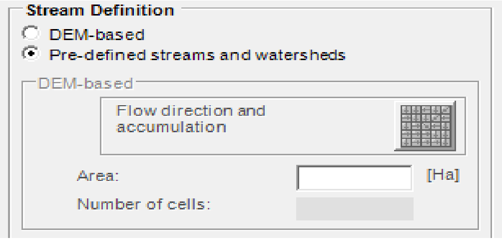


Fig. A.11 Mask on DEM

12. The Stream Definition section is now enabled (Figure A.12). There are two options for defining streams. The first option is DEM-based, which uses the DEM to automatically delineate streams and watersheds. The second option is Pre-defined streams and watersheds. This options requires the user to provide the stream and sub-basin datasets and import them into ArcSWAT. With the Pre-defined option, the DEM is only used to calculate sub-basin and stream parameters such as slope and elevation. In our project, we are using the Pre-defined streams and watersheds approach.



Stream Definition

○ DEM-based

● Pre-defined streams and watersheds

DEM-based

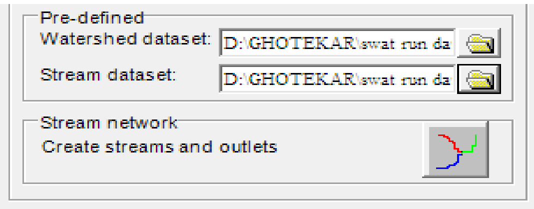
Flow direction and accumulation

Area: [Ha]

Number of cells:

Fig. A.12 Stream definition

13. After that in the Pre-defined section load watershed dataset and stream dataset (Figure A.13).



Watershed dataset: D:\GHOTEKAR\swat run da

Stream dataset: D:\GHOTEKAR\swat run da

Fig. A.13 Pre-defined window

14. Click the Create streams and outlets button to apply the threshold and create a stream network and outlets. In pre-defined method other steps likes outlet and inlet definition and watershed outlets(s) selection and definition are not in function and directly calculate Sub-basin parameters.

15. The Calculation of Sub-basin Parameters section contains functions for calculating geomorphic characteristics of the sub-basins and reaches, as well as defining the locations of reservoirs within the watershed.

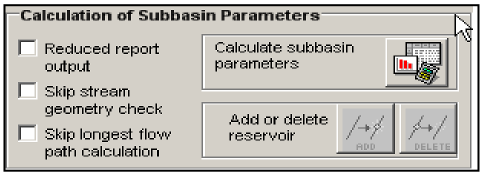


Fig. A.14 Calculation of Subbasin parameters

a. Click the button to begin sub-basin parameter calculation. This function calculates geomorphic parameters for each sub-basin and the relative stream reach. The results of the calculations are stored in the table of attributes of the updated Watershed and Reach themes.

b. When all parameters are calculated, a dialog box appears.

c. A new item named Topographic Report is now available from the Watershed Reports item on the Watershed Delineation menu. This report provides a statistical summary and distribution of discrete land surface elevations in the watershed and all the sub watersheds. In addition, a new layer called Longest Path is added to the map. This represents the longest flow path within each of the sub-basins.

16. When watershed delineation is completed and the Exit button is clicked on the Watershed Delineation form, the raster datasets generated by the Arc SWAT interface

are exported from the SWAT project “Watershed\Grid” folder to the Project Raster Geodatabase. Until watershed delineation is completed, the rasters are stored as ESRI GRID format rasters in the project “Watershed\Grid” folder to improve performance. Once delineation is complete, they are exported to the Raster Geodatabase to simplify the data storage for the project. Never manually move or remove rasters between the “Watershed\Grid” folder and the Project Raster Geodatabase unless you have received some guidance from an Arc SWAT expert.

3. HRU Analysis

Land use, soil, and slope characterization for a watershed is performed using commands from the HRU Analysis menu on the ArcSWAT Toolbar. These tools allow to load land use and soil layers into the current project, evaluate slope characteristics, and determine the land use/soil/slope class combinations and distributions for the delineated watershed(s) and each respective sub-watershed. The datasets can be ESRI grid, shapefile, or geodatabase feature class format.

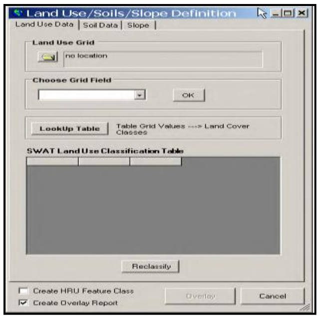
The Land Use/Soils/Slope Classification and Overlay tool allows the user to load the land use and soil datasets and determine land use/soil/slope class combinations and distributions for the delineated watershed(s) and each respective sub-watershed. The land use and soil datasets must be in the same projection as the DEM used in the watershed delineation. Slope characterization is based upon the DEM defined in the watersheds delineation.

3.1 Land Use Data

1. Initiate the Land Use/Soil/Slope Definition tool by selecting Land Use/Soil/Slope Definition in the HRU Analysis menu.

Fig. A.15 HRU Analysis

2. The Land Use/Soils/Slope Definition dialog is open. The dialog is divided into three tabs: Land Use Data and Soil Data and Slope.



no location

☐ Create HRU Feature Class

☑ Create Overlay Report

Fig. A.16 Land use/soils/slope definition

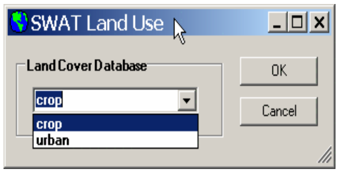
3. To load the example land use grid, click the file browse button in the Land Use Grid section.
4. A prompt box is appeared. Then select Load Land Use dataset (s) from disk and click Open.

○ Select Land Use layer(s) from the map

○ Load Land Use dataset(s) from disk

Fig. A.17 Select land use data

5. A message box appeared reminding the user that the data must be projected. Click Yes.
6. A browser appeared with the User Data directory active. Click the name of the land use map grid “landuse”. Click Select to confirm the choice. Several information messages are appear indicating the overlap area of the land use dataset.
7. The raw land use grid is displayed and clipped to the watershed area.
8. Under the Choose Grid Field combo box, choose “value”, and then click OK.
9. To manually define a land cover class, double click in the Land Use Swat column in the Swat Land Use Classification Table.
10. A dialog appeared and this asked to select either the crop or the urban database to choose a land class.



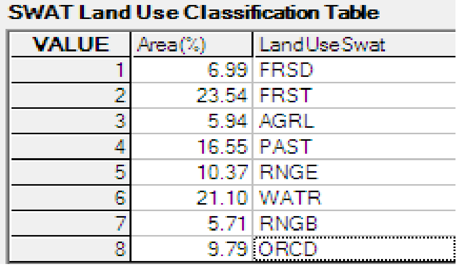
Land Cover Database
crop

Fig. A.18 SWAT land use

11. A dialog box with a list containing the possible classes to choose from appeared. Select the land cover class you want to assign to the current grid land use code and click OK.

12. The selected land cover class appeared in the Land Use Swat column in the SWAT Land Use Classification Table. Repeat this process for all the land uses grid code that you want to define (or redefine).

13. The SWAT land use categories are displayed in the SWAT Land Use Classification Table.



SWAT Land Use Classification Table

VALUE	Area(%)	LandUseSwat
1	6.99	FRSD
2	23.54	FRST
3	5.94	AGRL
4	16.55	PAST
5	10.37	RNGE
6	21.10	WATR
7	5.71	RNGB
8	9.79	ORCD

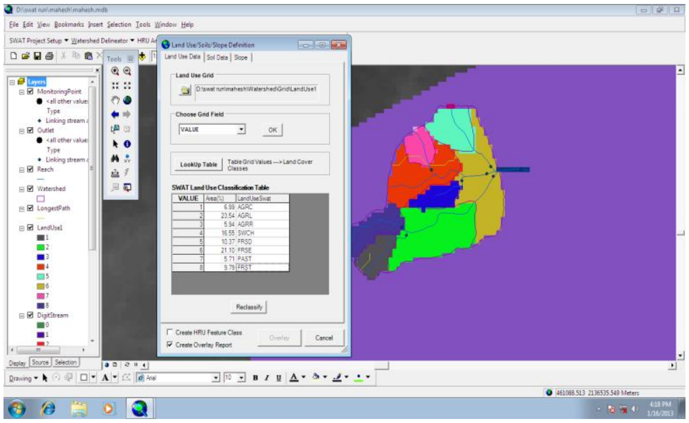
Fig. A.19 SWAT land use classification table

Once a Land Use Swat code has been assigned to all map categories, the Reclassify button is enabled. Click the Reclassify button. A message box is appeared, if reclassification is successful.

Land use reclassify completed!

Fig. A.20 Land use reclassify window

14. The category display for the map shows the SWAT land use codes.



Land Use Grid: D:\swat run\mahesh\Watershed\Grid\LandUse1

Choose Grid Field: VALUE

LookUp Table: Table Grid Values ---> Land Cover Classes

SWAT Land Use Classification Table

VALUE	Area(%)	LandUseSwat
1	6.99	AGRC
2	23.54	AGRL
3	5.94	AGRR
4	16.55	SWCH
5	10.37	FRSD
6	21.10	FRSE
7	5.71	PAST
8	9.79	FRST

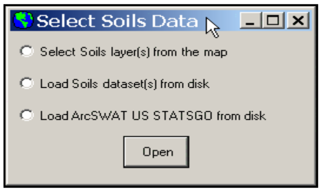
☐ Create HRU Feature Class
☑ Create Overlay Report

Fig. A.21 Effect of land use reclassify on DEM data

3.2 Soil Data Layer

1. Click on the Soil Data tab of the Land Use/Soils/Slope Definition too.

2. Select the soils data layer by clicking the file browse button under the next to the text box labelled Soils Grid. A dialog box labelled Select Soils Data is appeared.



Select Soils Data

○ Select Soils layer(s) from the map
○ Load Soils dataset(s) from disk
○ Load ArcSWAT US STATSGO from disk

Fig. A.22 Select soil data

3. Select Load Soils dataset (s) from disk and click Open.

4. A message box is appeared reminding the user that the data must be projected. Click Yes.

5. A browser is appeared with the User Data directory active. Click the name of the soils grid “soil”. Click Select to confirm the choice. Several information messages are appeared indicating the overlap area of the soils dataset.

6. The raw soil grid is displayed and clipped to the watershed area.

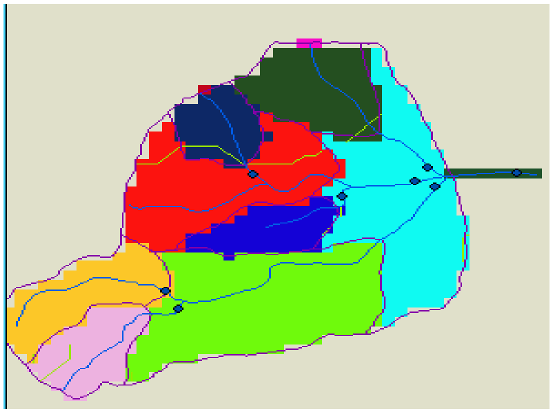


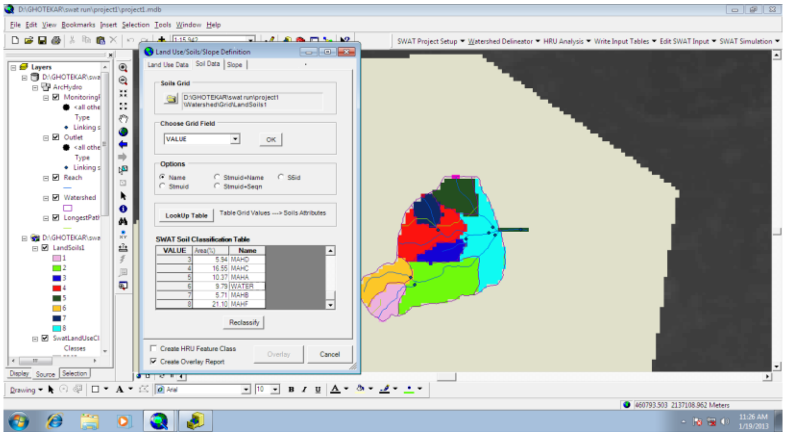
Fig. A.23 Shapefile of soil

7. Under the Choose Grid Field combo box, choose “value”, and then click OK.

8. Select the NAME option. As like landuse, we have to add the soil type name manually. Same procedure is carried out for soil.

9. The soil linkage information is displayed in the SWAT Soil Classification Table**.** Once a name code has been assigned to all map categories, the Reclassify button is enabled. Click the Reclassify button. A message box is appeared if reclassification is successful.

10. The category display for the map shows the soil codes.



Soils Grid: D:\GHOTEKAR\swat run\project1\Watershed\Grid\LandSoils1

Choose Grid Field: VALUE

Options: ● Name ○ Stmuid ○ Stmuid+Name ○ Stmuid+Seqn ○ S5id

Table Grid Values ---> Soils Attributes

SWAT Soil Classification Table

VALUE	Area(%)	Name
3	5.94	MAHD
4	16.55	MAHC
5	10.37	MAHA
6	9.79	WATER
7	5.71	MAHB
8	21.10	MAHF

☐ Create HRU Feature Class
☑ Create Overlay Report

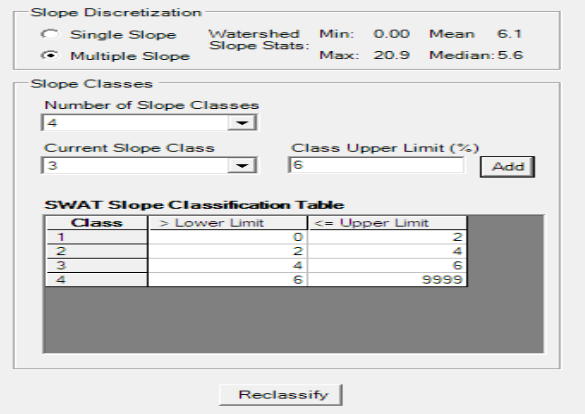
Fig. A.24 Soil selections for sub-watershed

11. To load the slope grid, move to the Slope tab on the Land Use/Soils/Slope Definition form.

12. Click the Multiple Slope option to reclassify the slope grid into multiple slope classifications.

13. Choose 4 slope classes under the Number of Slope Classes combo box.

14. set the upper limit of “slope class 1” to be 2 %, the upper limit of the “slope class 2” to be 4 %, the upper limit of the “slope class 3” to be 6 %. By default the upper limit “slope class 4” is 99.



Slope Discretization

○ Single Slope

● Multiple Slope

Watershed Slope Stats: Min: 0.00 Mean 6.1 Max: 20.9 Median: 5.6

Slope Classes

Number of Slope Classes: 4

Current Slope Class: 3

Class Upper Limit (%): 6

SWAT Slope Classification Table

Class	> Lower Limit	<= Upper Limit
1	0	2
2	2	4
3	4	6
4	6	9999

Fig. A.25 Slope discretization

15. Click the Reclassify button.

16. The slope map for the watershed with the slope classifications is displayed.

17. Once the land use, soil and slope datasets have been loaded and reclassified, click the button labelled Overlay at the bottom of the Land Use/Soil/Slope Definition dialog box.

18. When the overlay of the land use, soil and slope grids is complete, a prompt box is notifying the user that the overlay process is complete. Click OK.

19. A report is generated during the overlay process. To access the report, select HRU Analysis Reports under the HRU Analysis menu. From the list of reports, select Land Use, Soils, and Slope Distribution and click OK.

3.3 HRU Definition

1.Select HRU Definition from the HRU Analysis menu.

2. The HRU Definition dialog box is displayed and Select Multiple HRUs.

3. Set the Land use percentage (%) over subbasins area at 20%

4. Set the Soil class percentage (%) over subbasins area at 10%

5. Set the Slope class percentage (%) over subbasins area at 20%

6. Click Create HRUs.

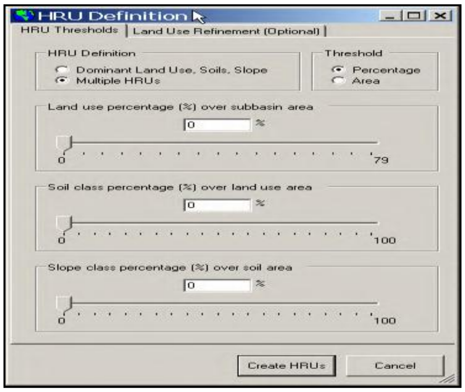
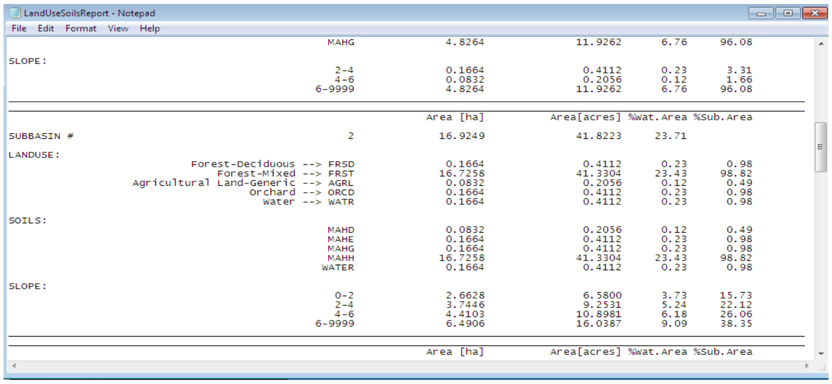


Fig. A.26 HRU definition

7. A message box is displayed notifying the user when setup of HRUs is completed. Click OK.

8. A report is generated during the HRU creation process. To access the report, select HRU Analysis Reports under the HRU Analysis menu. From the list of reports, select Final HRU Distribution and click OK. The total number of HRUs created in the watershed is listed in the top section of the report in bold letters.



```
                                                MAHG        4.8264          11.9262      6.76     96.08

SLOPE:
                                                 2-4        0.1664           0.4112      0.23      3.31
                                                 4-6        0.0832           0.2056      0.12      1.66
                                              6-9999        4.8264          11.9262      6.76     96.08
____________________________________________________________________________________________________________
____________________________________________________________________________________________________________
                                                         Area [ha]      Area[acres] %Wat.Area %Sub.Area

SUBBASIN #                                         2       16.9249          41.8223     23.71

LANDUSE:
                           Forest-Deciduous --> FRSD        0.1664           0.4112      0.23      0.98
                               Forest-Mixed --> FRST       16.7258          41.3304     23.43     98.82
                  Agricultural Land-Generic --> AGRL        0.0832           0.2056      0.12      0.49
                                    Orchard --> ORCD        0.1664           0.4112      0.23      0.98
                                      Water --> WATR        0.1664           0.4112      0.23      0.98

SOILS:
                                                MAHD        0.0832           0.2056      0.12      0.49
                                                MAHE        0.1664           0.4112      0.23      0.98
                                                MAHG        0.1664           0.4112      0.23      0.98
                                                MAHH       16.7258          41.3304     23.43     98.82
                                               WATER        0.1664           0.4112      0.23      0.98

SLOPE:
                                                 0-2        2.6628           6.5800      3.73     15.73
                                                 2-4        3.7446           9.2531      5.24     22.12
                                                 4-6        4.4103          10.8981      6.18     26.06
                                              6-9999        6.4906          16.0387      9.09     38.35
____________________________________________________________________________________________________________
____________________________________________________________________________________________________________
                                                         Area [ha]      Area[acres] %Wat.Area %Sub.Area
```

Fig. A.27 HRU analysis report

9. The remainder of the report lists the land use, soil, and slope modelled in every sub-basins and the percent area distribution of

1) Sub-basins within the watershed and

2) HRUs within the sub-basins.

3.4 Weather Stations

1. To load the project weather data, click Weather Stations under the Write Input Table menu.

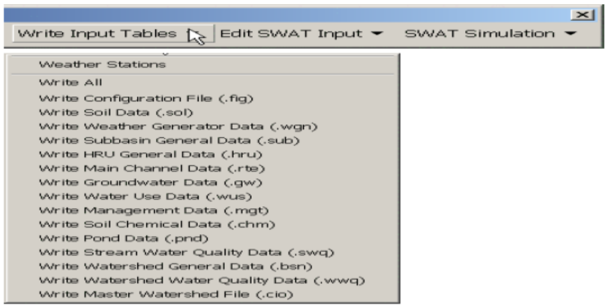
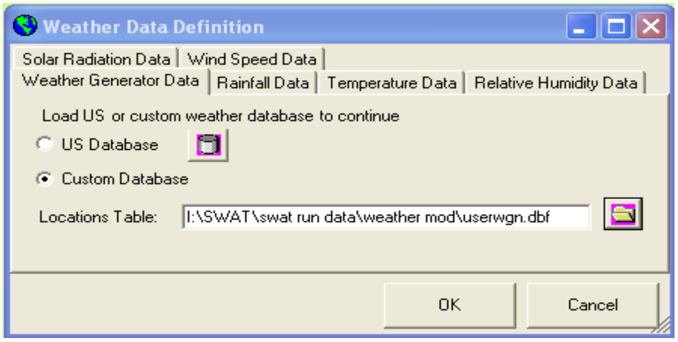


Fig. A.28 Write input table menu

2. The Weather Data Definition dialog box is displayed. The project data set contains data files with measured precipitation, temperature, humidity and wind for weather stations around the watershed.



Load US or custom weather database to continue

○ US Database

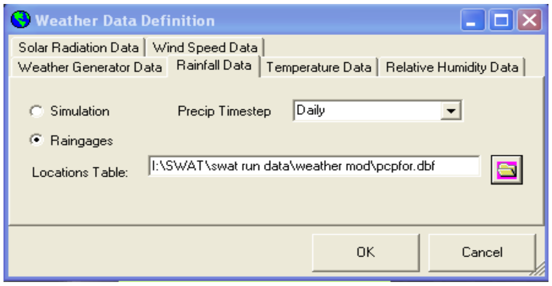
● Custom Database

Locations Table: I:\SWAT\swat run data\weather mod\userwgn.dbf

Fig. A.29 Weather data definition (custom database)

3. For a SWAT simulation using measured weather data, weather simulation information is needed to fill in missing data and to solar radiation. The project data set uses weather generator data loaded into the custom database. Click the radio button next to Custom data base. Next, click the file browse button next to the Locations Table text box. Select the name of the weather generator stations location table (userwgn.dbf) from the swat run data folder and click Add.

4. To load the table containing the locations of the rain gage stations, click Rainfall Data tab of the Weather Data Definition dialog. Click the radio button next to Raingages and choose a Precip Time step of “Daily”. Next, click the file browse button next to the Locations Table text box. Select the name of the weather generator stations location table (pcpfor.dbf) from the swat run data folder, and click Add. The path to the rain gage station file appears in the text box.



○ Simulation

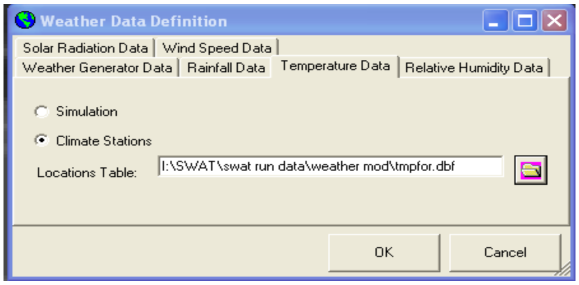
● Raingages

Precip Timestep: Daily

Locations Table: I:\SWAT\swat run data\weather mod\pcpfor.dbf

Fig. A.30 Weather data definition (Rainfall data)

5. To load the table containing the locations of the temperature gage stations, click Temperature Data tab of the Weather Data Definition dialog. Click the radio button next to Climate Stations. Next, click the file browse button next to the Locations Table text box. Select the name of the weather generator stations location table (tmpfor.dbf) from the swat run data folder, and click Add. The path to the climate station file appears in the text box.



○ Simulation

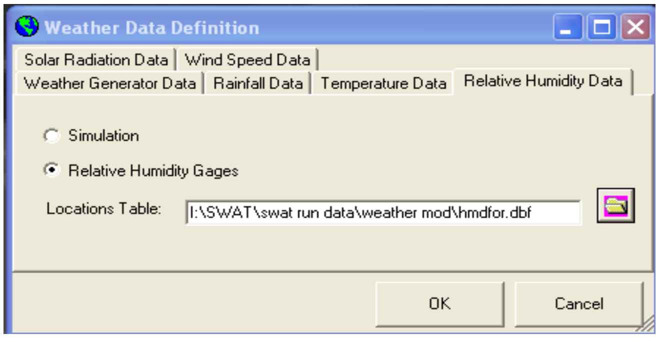
● Climate Stations

Locations Table: I:\SWAT\swat run data\weather mod\tmpfor.dbf

Fig. A.31 Weather data definition (Temperature data)

6. To load the table containing the locations of the humidity gage stations, click Humidity Data tab of the Weather Data Definition dialog. Click the radio button next to Relative Humidity Stations. Next, click the file browse button next to the Locations Table text box. Select the name of the weather generator stations location table (hmdfor.dbf)

from the swat run data folder, and click Add. The path to the relative humidity station file appears in the text box.



○ Simulation

● Relative Humidity Gages

Locations Table: I:\SWAT\swat run data\weather mod\hmdfor.dbf

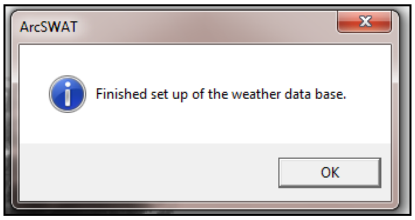
Fig. A.32 Weather data definition (relative humidity)

7. To load the table containing the locations of the wind gage stations, click Wind Data tab of the Weather Data Definition dialog. Click the radio button next to Wind Stations. Next, click the file browse button next to the Locations Table text box. Select the name of the weather generator stations location table *(*wndfor.dbf) from the swat run data folder and click Add. The path to the wind station file appears in the text box.

8. The weather data time series for solar radiation is simulated by the weather generator.

9. To generate spatial layers of the weather stations, and load the observed weather data into SWAT weather files, click the OK button at the bottom of the Weather Data Definition dialog

10. A prompt box is appeared when processing of the weather data is complete. Click OK.



Finished set up of the weather data base.

Fig. A.33 Weather data base setup window

11. The interface is also assigned the different weather station data sets to the sub-basins in the watershed.

4. Write Input Tables Menu

1. The Input menu contains the commands which generate the ArcSWAT geodatabase files used by the interface to store input values for the SWAT model. Figure A.34 displays the Write Input menu.

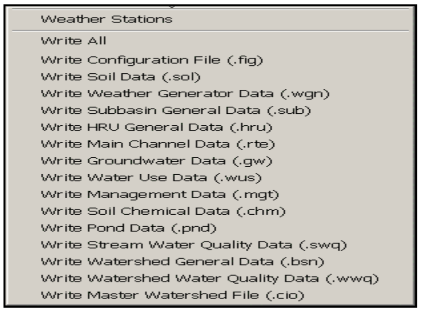


Fig. A.34 Weather stations and other input data list

2. Input files are written individually. If this method is used to write the input database files, the database files must be written (selected) in the sequence in which they are presented in the Input menu: watershed configuration file (Figure A.34), soil data, weather generator data, general sub-basin data, HRU general data, main channel data, groundwater data, water use data, management data, soil chemical data, pond data, stream water quality data, watershed general data, watershed water quality data, and master watershed file.

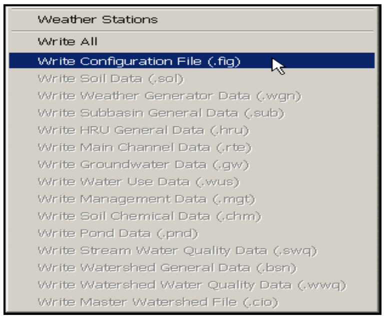


Fig. A.35 Weather station menu

3. To write SWAT input databases individually, begin by selecting the Write Configuration File (.fig) command from the Write Input Tables menu. This selection generates the watershed configuration file. When the file has been written, a message box is pop up.

Finished writing FIG table

Fig. A.36 Write different table

4. Click OK to proceed. Select all the input files individually and click OK.

5. Edit SWAT Input

1. To rewrite all the inputs we have to select Rewrite Input Files from Databases menu. The Re-Write SWAT Input Files command allows users to re-write the SWAT input files (.sub, .mgt, .hru, etc.) after the SWAT geodatabase files have been edited.

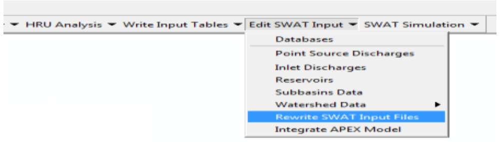


Fig. A.37 Edit SWAT input menu

2. A dialog box appeared, select the Select All button, when all input files are selected then select Write All button. All the input files are rewrited. Now select the Cancel button.

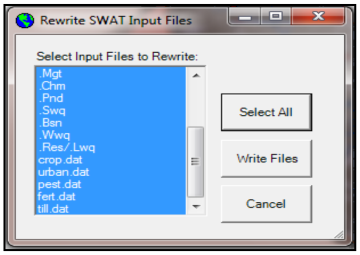
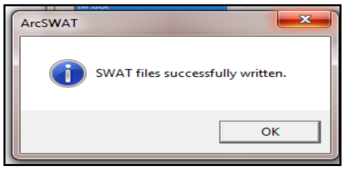


Fig. A.38 Rewrite SWAT input files

3. A prompt box appeared. Click OK.



SWAT files successfully written.

Fig. A.39 SWAT files write window

6. SWAT Simulation

1. Run Swat on the SWAT Simulation menu, click Run SWAT.

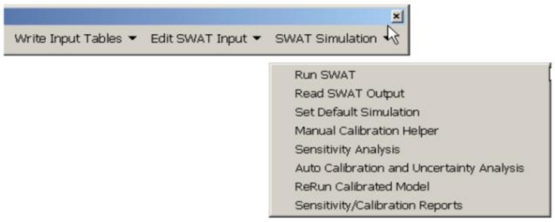
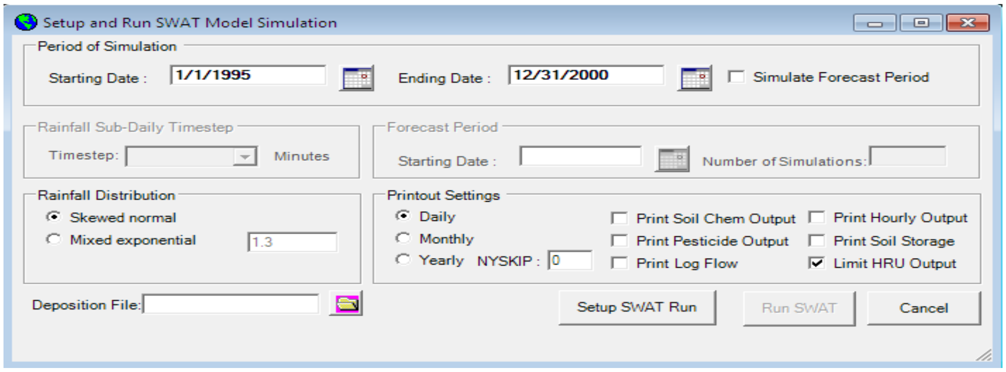


Fig. A.40 SWAT simulation menu

2. A dialog box is brought up.


Setup and Run SWAT Model Simulation

Period of Simulation
Starting Date : 1/1/1995
Ending Date : 12/31/2000
☐ Simulate Forecast Period

Rainfall Sub-Daily Timestep
Timestep: Minutes

Forecast Period
Starting Date :
Number of Simulations:

Rainfall Distribution
● Skewed normal
○ Mixed exponential 1.3

Printout Settings
● Daily
○ Monthly
○ Yearly NYSKIP : 0
☐ Print Soil Chem Output
☐ Print Pesticide Output
☐ Print Log Flow
☐ Print Hourly Output
☐ Print Soil Storage
☑ Limit HRU Output

Deposition File:

Fig. A.41 Setup and Run SWAT model simulation

3. The initial and final day of simulation are set to the first and last days of measured weather data. Leave those values set to 1/1/1995 and 31/12/2000. Set the Limit HRU Output to Daily frequency. Leave all other settings as it is.
4. Click the button labeled Setup SWAT Run to build master watershed control file and write point source, inlet and reservoir files. A prompt is indicated when setup is complete. Click the Run SWAT button.
5. When the SWAT run is finished, a message box is displayed noting that the simulation is successfully completed. Click OK.

6. Then select the option Read SWAT Output from the SWAT Simulation menu bar.

8. VITA

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