HYDROLOGICAL MODELLING OF SABARMATI RIVER USING SWAT

A MAJOR PROJECT REPORT

Submitted in partial fulfilment of the requirements for the award of the Degree of

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BONAFIDE CERTIFICATE

This is to certify that the project report entitled "HYDROLOGICAL MODELLING OF SABARMATI RIVER USING SWAT" is a record of the bonafide dissertation work carried out by me, NUPUR VERMA, towards the partial fulfilment of requirements for the award of the degree of Master of Technology in Hydraulics & Flood Control Engineering.

Also, I do hereby state that I have not submitted the matter embodied in this thesis in any other University/Institute for the award of any degree as per my knowledge and belief.

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ABSTRACT

Water resources of India have experienced wide array of changes over time. Extreme hydrological events call for adequate management measures to be taken up. The management of water resources taken up as a whole is an enormous task in itself. A watershed is considered as a unitary land unit in the development of a sustainable ecosystem. So watershed modelling has become the need of the hour. With the ever increasing pressure of population, rapid urbanization and climate changes coupled with poor management of land and water resources, the natural hydrological processes in the watershed gets altered so there is an imperative need to conduct the use of an apt and adequate modelling tool.

In this dissertation it is envisaged to undertake hydrological modelling in the Sabarmati River basin using the Soil and Water Analysis Tool (SWAT). The ArcGIS interface for the SWAT model, ArcSWAT allows the use of Geographical Information System (GIS) inputs like the Digital Elevation Model (DEM), land use maps and soil maps for the extraction and zoning of the watershed. The entire watershed was divided into 37 subbasins and 213 HRUs. The model was simulated for a period of six years with one year as a warm-up period which resulted in the simulated results. Simulation with the calibrated model with climate data for the years 2001-2005 showed an accurate and satisfying result with the coefficient of determination R^2 as 0.7629 for discharge prediction and 0.7515 for rainfall-runoff prediction from the water budget equation. The calibrated model can be used for further analysis for management of water resource and climate and land use change impact studies.

Keywords: Hydrological modelling, SWAT, ArcSWAT, GIS, Digital Elevation Model, HRUs

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ABBREVIATION NOTATION AND NOMENCLATURE

AWD	Automatic Watershed Delineation
CN	Curve Number
CWC	Central Water Commission
DEM	Digital Elevation Model
ET	Evapotranspiration
G	Soil Heat Flux
H	Sensible Heat
HRUs	Hydrological Response Units
LULC	Land Use/Land Cover
MCM	Million Cubic Metres
MUSLE	Modified Universal Soil Loss Equation
R	Runoff
R_n	Net Radiation
SCS	Soil Conservation Service
SRTM	Shuttle Radar Topography Mission
SWAT	Soil and Water Assessment Tool
TCM	Trillion Cubic Metres
WRIS	Water Resources Information System
λE	Latent Heat

CHAPTER 1

INTRODUCTION

1.1 GENERAL

Water plays an essential role in the functioning of ecosystems. In addition, humans and society rely on ecosystems to provide hydrological services and their resulting benefits (Brauman et al., 2007). These include: water supply in terms of quantity, quality and timing (for household, industry, agriculture, hydropower generation, transportation, recreational and spiritual benefits); and water hazard mitigation (reduction in the number and severity of floods, decrease in soil erosion and mitigation of landslides).

In basic terms, hydrology is defined as the study of water movement through a cycle and the transportation of contents such as sediments and pollutants in the water as it flows. In other words, hydrology could be said to be applied science concerned with the occurrence, distribution and circulation of the waters of the earth. Although the main focus of hydrology is on water and its cyclical movement through the environment, it provides for a holistic approach which may more closely investigate how water, the environment and human activities are mutually dependent and interactive.

Hydrological processes in watersheds are the continuous circulation of water on the earth through a process of precipitation, base flow, evapotranspiration, stream flow and surface runoff. The natural circulation of water, however, gets altered as watersheds experience urbanization. Permeable surfaces like the soil surface are overlain with impervious cover such as buildings, roads, and pavements that disconnect the surface processes from sub-surface processes during the urbanization process. In practical terms, it is often tedious and expensive to determine most of the parameters that interplay in hydrological process. Variables like the runoff, sediment load, evaporation; pesticides effects on plants, etc. are very difficult to measure in the field. Hydrologists, regional geographers and agricultural development planners are often faced with the tasks of determining the short and long term effects of natural variables like temperature, rainfall, solar radiation, land use and land use changes on the environment. The only feasible solution to this would be to use a reliable hydrological model.

Rainfall runoff model that is a typical hydrological modelling tool which determines the amount of runoff that leaves the watershed basin from the rainfall received by the basin. Therefore, precipitation is the most important parameter in hydrological modelling. In this study, Soil & Water Assessment Tool (SWAT) (Arnold et al., 1998) was used to calculate the runoff and the sediment load concentration due to the spatially distributed rainfall and other meteorological data depending upon the watershed topography, soil and land use conditions. SWAT model is being used widely for basin hydrology studies to simulate the runoff.

1.2 SWAT in a Nutshell

Catchment scale model:
It can predict the impact of land management practices (human activities) and climate change over time on: water, sediment and agriculture.

Model operation:

- Physically based input
- Long term simulations
- Continuous time: Daily / Hourly time step
- Computationally efficient: Semi – distributed & conceptual sub-models
- Weather generator using monthly statistics of weather data: Filling of missing weather data

1.3 Objectives and Aims of Study

The primary objectives of this thesis are:
General Objective:

- To study the water balance for the Sabarmati river basin by setting up ArcSWAT hydrological model.

Specific Objectives:

- To build the database required by ArcSWAT for GIS inputs.
- To setup ArcSWAT hydrological model for the Sabarmati river.
- To take and check simulated output from Sabarmati basin.
- Calibration of the ArcSWAT model developed with discharge flows.
- Validation of the model.

1.4 Thesis Organization

Chapter 1 introduces the reader with the introduction to the background of the study. The interdisciplinary, objectives and justification of the report are discussed.

Chapter 2 is the literature review for the project and explains in detail about hydrological modelling and the tools required since their early development stages. The usage of hydrological models is discussed.

Chapter 3 is the study area defines the watershed physiological and climatological conditions and the effects the land and soil conditions have on the watershed.

Chapter 4 is the Project Methodology which describes the entire procedure carried out for the hydrological modelling. The data requirements and acquisition; step by step use of input data in the SWAT model and running the calibrated model are discussed.

Chapter 5 provides the discussions on results. The efficiency of the model has been checked by providing graphs showing the coefficient of correlation.

Chapter 6 is the conclusion of the research work. It concludes the analysis of the results and checks the feasibility of the study.

CHAPTER 2

REVIEW OF LITERATURE

2.1 Hydrological Modelling

Hydrologic process can be defined as the natural system in which water moves between land, atmosphere and the ocean cyclically as shown in Figure 2.1. Human actions interrupt these cycles and the consequences of which now threaten the living existence of man on Earth.

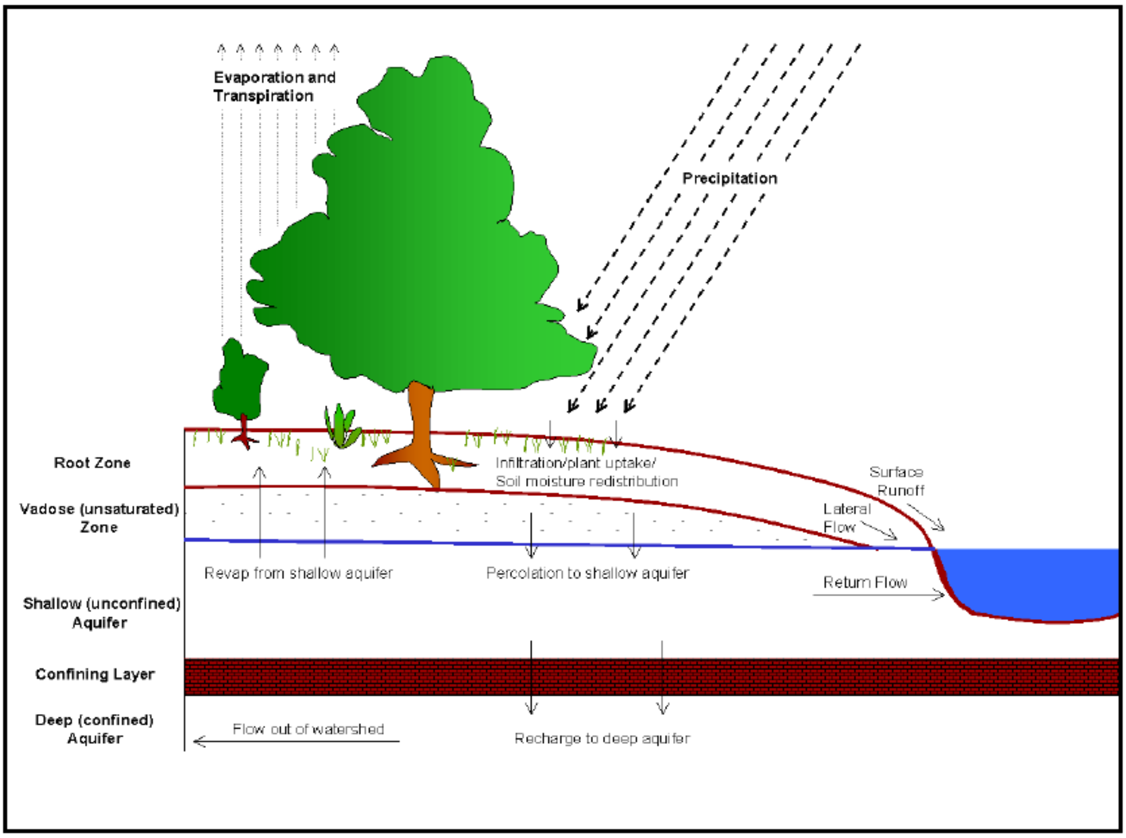

Figure 2.1 Schematic representation of the Hydrological Cycle

Hydrologic cycle is composed of several natural processes which have interactions and they can be represented or simplified using a mathematical model.

Uhlenbrook (2006) outlined the following as the processes that are represented in hydrological cycle:

- precipitation,
- interception (including utilization by ecosystems, man and irrigation),
- absorption into earth materials and uptake by plants (including percolation),
- water movement from shallow to deep aquifers,
- surface flow,
- subsurface flow and
- Water losses in the form of evaporation, transpiration and seepage

It is highly important to differentiate between surface and subsurface flow. Surface flow can be described as the flow of water through the earth surface like stream, rivers or surface-runoff, whereas sub-surface flow would be defined as the flow of water through the earth materials. These earth materials are heterogeneous; therefore the flow through them tends to follow the path of least resistance.
Mathematical models applications in water resources design, management and decision support systems have been in consideration since early sixties. Having longer years of historical records for hydrological modelling often provide a better model representation.

2.2 Hydrological Modelling Methods

Mathematical models are needed daily mainly in overcoming challenges of decision making. Rational formula modelling method is one of the earliest types of hydrological models. This is the quantitative expression of flood flow rates in relation to rainfall and watershed area of relatively small catchments. The method was based on the concept of the 'time of concentration' which means that the time required for water to reach the outlet from the most remote point of the area. **Sherman** (1932) developed the unit hydrograph concept of modelling on the basis of superposition. This superposition concept involved many assumptions such as; the catchments behave like a linear, dynamic, time variant causative system in respect to the rainfall-runoff transformation. In the 1960 and 70s, the complex dynamic systems were analysed by systems approach (**Lewarne**, 2009). The response function was obtained from the input and output data analysis and represented by mathematical expressions. The response function carried no physical significance of the system. At about this time, computers became more widely accessible, and powerful enough to significantly assist in modelling process. There are numerous hydrological models and they can be grouped by pollutants addressed, complexity of pollutant sources, whether the model is steady state or dynamic, and the time period modelled. Also important in determining the selection of model is whether it distributed (i.e. capable of predicting multiple points within a river) or lumped.

2.2.1 Physical "Deterministic" Models

These models are based on various physical theories and require large amount of computational time and data. Hence, these models are not cost effective to develop and operate. These models do not follow linear partial differential equations which describe in the hydrological processes. Analytical solutions are the only tools which are available although its development is very difficult and time consuming. Hence steps are to be needed to develop partial differential equations; include finite difference method (**Freeze**, 1971), finite element methods (**Beven**, 1977; **Ross et. al**., 1979), integral finite difference and boundary integral methods which are difficult and time consuming. Alternatively Kinematic wave theory and Simplifications in it was used. The models offer the ability to simulate the complete runoff and the effect of catchment changes which is particularly important in case of resource management. One of the major advantages of deterministic models is that these models offer the internal view of the process which enables improve understanding of the hydrological system. Système Hydrologique Europèen (SHE) is one of the well-known distributed models (**Gosain et. al., 2009**). SHE, ACRU, SWAT and VTI share the description of being semi-distributed, quasi-based daily time step models for watershed-scale modelling. It allows for spatially distributed water flow and sediment transport modelling. Processes are represented by either finite difference sub-models of partial differential equations or by derived empirical equations. They simulate the interaction between land use and climate changes as they impact on in-stream water quality, with varying consideration of groundwater interactions. Other similar international models include RORB, Xinanjiang, Tank model, ARNO, TOPMODEL, UBC, HBV, AGNPS, GWLF, HSPF and Mohid Land (**Lewarne**, 2009).

2.2.2 Stochastic Models

Stochastic hydrological models are the types of models that use mathematical concepts and statistical principles to derive results from the inputs. Examples are models that use neural networks principles, regression analysis techniques etc. (**Lewarne,** 2009). These types of models are very common in water resources forecasting where the rainfall, runoff and antecedent moisture content are related.

2.3 HYDROLOGICAL MODELLING STANDARD EQUATION

Hydrological Models like SWAT have many essential equations but the hydrological water balance equation is the fundamental equation upon which the model is based. The water balance equation is given as:

$$P = R + ET + \frac{\Delta s}{\Delta t}$$

Where:

P = Precipitation,

R = Runoff,

ET = Evapotranspiration and

$\Delta s/\Delta t$ = change in storage over time

The storage expressed in the above equation can be in many forms. **Uhlenbrook** (2006) lists the following as the form of storage in hydrological cycle:

- Atmosphere
- soil water/groundwater
- oceans
- ice caps, glaciers, snow
- Rivers, lakes
- surface storage (interception) and
- biosphere.

Uhlenbrook (2006) further stated that water balance does not stand in isolation for hydrological studies, and is used in conjunction with the surface energy balance which represents evapotranspiration processes more accurately. This is further explained by the following equation:

$$R_n = \lambda E + H + G + \frac{\Delta s}{\Delta t}$$

Where:

R_n = Net Radiation,

λE = Latent heat (the same as evapotranspiration, ET)

H = Sensible heat

G = Soil heat flux and

$\Delta s/\Delta t$ = change in storage over time

Assuming G and $\Delta s/\Delta t$ are negligible, then the equation can further be simplified as:

$$R_n = \lambda E + H$$

Several other important equations used in setting up SWAT models are identified and summarized in Table 2.1 shown below (Uhlenbrook, 2006; Watson and Burnet, 1996; Neitsch et. al., 2005; Lewarne, 2009).

Table 2.1: Equations used in Hydrological Models

Equation	**Uses**
Manning´s Roughness Coefficient	Used for Overland and Channel flow analysis to calculate the time of concentration in watersheds
Overland Flow Sediment Transport sub routine	This equation make use of the 2D total sediment load conservation equation
Penman-Monteith (ET) equation (Monteith 1965)	Simulates evapotranspiration
Richards equation	Used for calculation flow in Unsaturated zone.
Lane´s Method	Used for calculation of transmission losses through leaching channel beds

Soil Conservation Service (SCS) Curve Number(CN) Method	This is an index used in the determinations of correlation between rainfall and runoff
The Modified Universal Soil loss equation (MUSLE)	This helps in erosion study taking into account several factors like the erodibility, land cover, soil slope etc.
The Green & Ampt. equation	This method helps in calculating infiltration
Darcy´s Law and the Mass Conservation of 2D laminar flow	They are used for groundwater saturated flow.

2.4 SWAT Model

Soil and Water Assessment Tool (SWAT; **Arnold et al.**), is a river basin scale model operating on a daily time step which was developed to predict the impact of land management practices in mesoscale to macro scale basins. It is a physically based model. Major model components describe processes associated with water movement, sediment movement, soils, temperature, weather, plant growth, nutrients, pesticides and land management. The water balance is represented by several storage volumes in each of the spatial subunits. These include: canopy storage, snow, soil profile, shallow aquifer and deep aquifer.

Surface Runoff is calculated using a modification of the curve number technique. The soil profile is divided into a number of layers. The processes include evaporation, infiltration, plant uptake, lateral flow and percolation to deeper layers. Shallow aquifer is recharged by percolation from the bottom of the soil profile. The flow from the aquifer to the stream is lagged by using a recession constant. Other shallow aquifer components include evaporation, pumping withdrawal and seepage to the deep aquifer. Plant growth can only occur if the daily temperature exceeds a plant specific base temperature. Penmann – Monteith method is used to estimate the Potential evapotranspiration. Canopy evaporation is a function of potential evapotranspiration, maximum interception capacity and the ratio of actual to potential maximum leaf area index. Plant water uptake is a function of potential evapotranspiration, leaf area index and rooting depth and is limited by the soil water content.

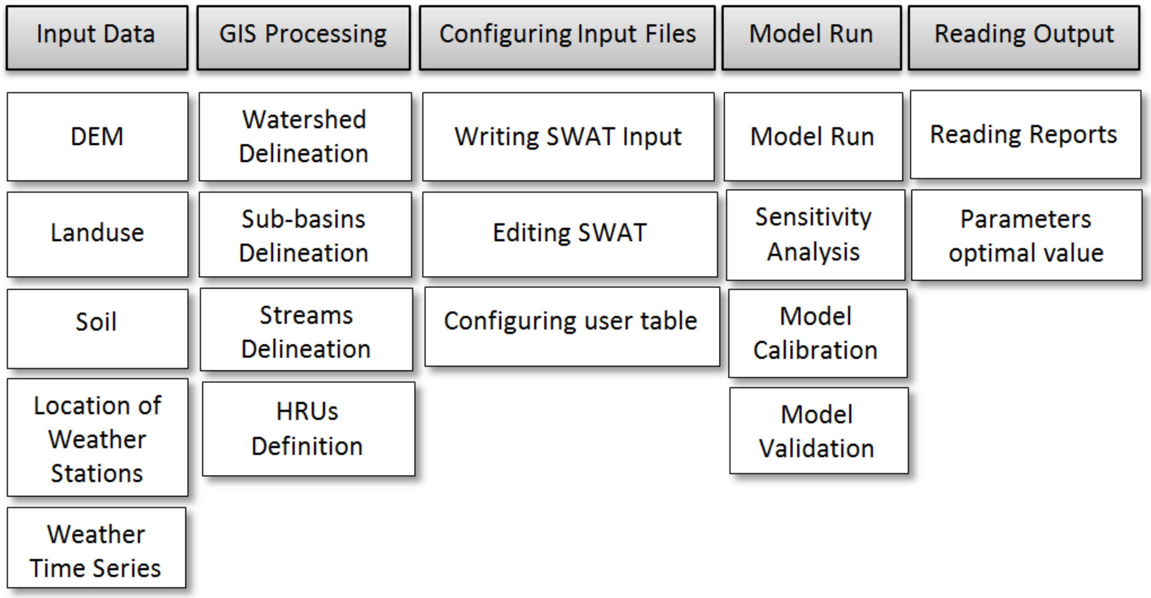

Figure 2.2: Workflow of SWAT Model

2.4.1 SWAT Developmental History and Overview

The development of SWAT is a continuation of USDA Agricultural Research Service (ARS) modelling experience that spans a period of roughly 30 years. Early origins of SWAT can be traced to previously developed USDA – ARS models including the Chemicals, Runoff, and Erosion from Agricultural Management Systems (CREAMS) model (Knisel, 1980), the Groundwater Loading Effects on Agricultural Management Systems (GLEAMS) model (Leonard et al., 1987), and the Environmental Impact Policy Climate (EPIC) model (Izaurralde et al., 2006), which was originally called the Erosion Productivity Impact Calculator (Williams, 1990). These components were first grafted into the SWRRB model (Arnold and Williams, 1987), along with other key components including a weather generator, sediment routing routine, and groundwater submodel (Arnold and Allen, 1999). The initial version of SWAT was created by interfacing SWRRB with the routing structure in the Routing Outputs to Outlet (ROTO) model (Arnold et al., 1995b). Expanded routing and pollutant transport capabilities have since been incorporated into the model, including reservoir, pond, wetland, point source, and septic tank effects as well as enhanced sediment routing routines (Arnold et al., 2010b). Additional modifications that have been incorporated into SWAT include an improved carbon cycling routine based on the CFARM model (Kemanian, 2011), alternative daily and subdaily hydrology routines including the Green-Ampt infiltration method (Green and Ampt, 1911), temporal accounting of management practice and land use changes and enhanced subsurface tile drainage, filter strips, grassed waterways, irrigation, and other improved representations of conservation and management practices (Arnold et al., 2010b). The temporal accounting routine allows users to introduce the adoption of different selected management practices or account for changes in land use through SWAT simulation run, such as the hydrologic and pollutant impacts simulated by Chiang et al. (2010) in response to temporal changes in pasture use for a 32 km^2 watershed in northwest Arkansas.

The current SWAT incorporates all of the above components as well as other routines, and also features several pre- and post-processing software tools, including the Map Window GIS interface. Extensive SWAT documentation is accessible at the SWAT website (http://swatmodel.tamu.edu), including theoretical documentation describing all equations, a user's manual describing model inputs and outputs, ArcSWAT and Map Window interface manuals, and a developer's manual.

SWAT has undergone some significant improvement since its creation in 1990s. **Neitsch et. al.** (2008) outlined some of these improvements as:

- SWAT94.2: Multiple hydrologic response units (HRUs) were incorporated.
- SWAT96.2: Auto-fertilization and auto-irrigation added as management options; canopy storage of water incorporated; etc
- SWAT98.1: Snow melt routines improved; in-stream water quality improved; nutrient cycling routines expanded; etc
- SWAT99.2: Nutrient cycling routines improved, rice/wetland routines improved, reservoir/pond/wetland nutrient removal by settling added; bank storage of water in reach added; etc
- SWAT2000: Bacteria transport routines added; Green & Ampt infiltration added; weather generator improved; etc.
- SWAT2005: Bacteria transport routines improved; weather forecast scenarios added; sub-daily precipitation generator added; etc

2.4.2 GIS – SWAT Interface Development

It was a historical achievement when GIS was coupled with SWAT for easy manipulation of input data like the land use, DEM, soil map, masking etc. GRASSSWAT was developed by Srinivasan and Arnold (1994). Later the ArcView version of SWAT was developed to help generate and inputs from ArcView 3.x GIS (Di Luzio et. al., 2004a, 2004b). There is now a recent version which has the functionality of being able to include data including soil data input from both the USDA-NRCC State Soil Geographic (STATSGO) and Soil Survey Geographic (SSURGO) database (USDANRCS, 2007a, 2007b). There is an alternative version called the "Automated Geospatial Watershed Assessment (AGWA)" which uses the SWAT 2000 modelling framework and could also use the KINEROSS2 model (**Miller et. al., 2007**).

ArcGIS versions 9.1 & 9.2 (ArcSWAT) have been developed that use geodatabase approach and a programming structure consistent with Component Object Model (COM) protocol (Olivera et. al., 2006; SWAT, 2007).

The Waterbase project of the United Nations University which has a broader aim of advancing the practice of Integrated Water Resources Management (IWRM) in developing countries came out with the MapWindow interface version of SWAT. MapWindow is open source GIS software which has several advantages. This tool was coupled with SWAT to produce "MWSWAT". The design is based on three major steps which include: watershed delineation, HRU definition and SWAT step up and run (**George et. al., 2007**).

To support SWAT simulation executions, various tools have been developed, including:

- The interactive SWAT (i_SWAT) software supports SWAT simulations using a Windows interface with an Access database;
- The Conservation Reserve Program (CRP) Decision Support System (CRPDSS) developed by Rao et. al. (2006);
- The AUTORUN system used by Kannan et. al. (2007), which facilitates repeated SWAT simulations with variations in selected parameters;

- A generic interface (iSWAT) program (Abbaspour et. al., 2007), which automates parameter selection and aggregation for iterative SWAT calibration simulations.
- The SWATPLOT tool which is a standalone software developed also by the Waterbase group in 2009.

2.4.3 SWAT Applications

SWAT has been used for a number of applications in the last decade. Many of the applications have been driven by the needs of various government agencies that require direct assessments of anthropogenic, climate change, and other influences on a wide range of water resources or exploratory assessments of model capabilities for potential future applications.

One of the first major applications performed with SWAT was within the Hydrologic Unit Model of the U.S. (HUMUS) modelling system, which was carried out to support the USDA analyses of the Resources Conservation Act Assessment of 1997 (**Gassman et. al., 2007; Arnold et. al., 1999**). The system was used to simulate the hydrologic and/or pollutant loss impacts within each of the 2,149 U.S. Geological Survey (USGS) 8 - digit Hydrologic Cataloging Unit (HCU) watersheds. Other applications in the US are reported by Mausbach and Dedrick (2004), Borah et. al. (2006), Shirmohammadi et. al. (2006), Benham et. al. (2006), etc. Gassman et. al. (2007) also did detailed survey of other applications worldwide.

SWAT has been applied widely in the European Union. **Volk et. al**. (2007) describes SWAT application approaches within the context of the European Union (EU) Water Framework Directive. There are some European Commission (EC) projects also like the Climate Hydrochemistry and Economics of Surface water Systems (CHESS) project where SWAT has been used to quantify the impact of climate change on several watershed (CHESS, 2001); EUROHARP project (EUROHARP, 2006) and TempQsim project which focused on testing the ability of SWAT and five other models to simulate intermittent stream conditions that exist in southern Europe (TempQsim, 2006).

2.5 Hydrologic Assessments

Simulation of the hydrologic balance is foundational for all SWAT watershed applications and is usually described in some form regardless of the focus of the analysis. The majority of SWAT applications also report some type of graphical and/or statistical hydrologic calibration, especially for streamflow, and many of the studies also report validation results. A wide range of statistics has been used to evaluate SWAT hydrologic predictions. By far the most widely used statistics reported for hydrologic calibration and validation are the regression correlation coefficient (R^2) and the Nash – Sutcliffe model efficiency (NSE) coefficient (Nash and Sutcliffe, 1970). The R^2 value measures how well the simulated versus observed regression line approaches an ideal match and ranges from 0 to 1, with a value of 0 indicating no correlation and a value of 1 representing that the predicted dispersion equals the measured dispersion (**Krause et al., 2005**). The regression slope and intercept also equal 1 and 0, respectively, for a perfect fit; the slope and intercept are often not reported. The NSE measures how well the simulated versus observed data match the 1:1 line (regression line with slope equal to 1) and ranges from $-\infty$ to 1. An NSE value of 1 again reflects a perfect fit between the simulated and measured data. A value of 0 or less than 0 indicates that the mean of the observed data is a better predictor than the model output.

CHAPTER 3

STUDY AREA

3.1 SABARMATI BASIN

3.1.1 Location

Sabarmati river basin is one of the 24 river basins on the west coast of India covering the States of Rajasthan and Gujarat. Sabarmati basin falls in the Mahi & Sabarmati Sub-zone 3(a). It is one of the 26 hydro-meteorological homogenous subzones in the country. The basin lies between 70° 58' to 73° 51' east longitudes and 22° 15' to 24° 47' north latitudes. The river is bounded by Aravalli hills on the north and north-east, by Rann of Kutch on the west and by Gulf of Khambhat on the south.

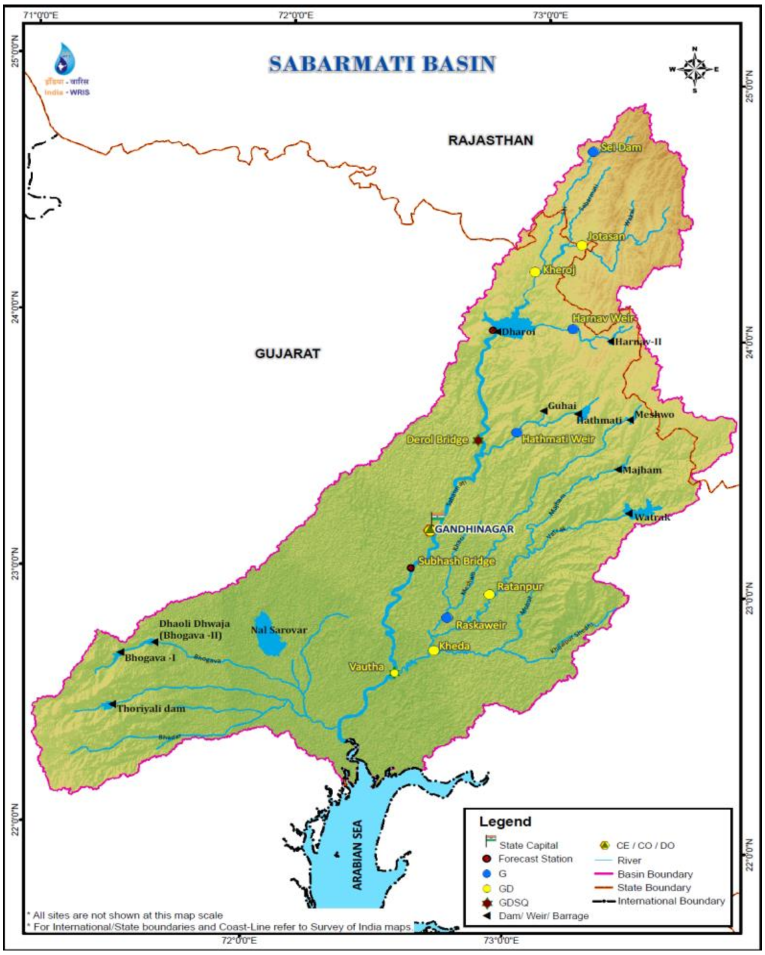

Figure 3.1: Geographical description of the basin showing sites of CWC

3.1.2 River System

The catchment area extends over 21,674 sq km with maximum length and width of 371 km and 150 km, respectively. The drainage area covered by Sabarmati is detailed in Table 2.1. The major left bank tributaries of Sabarmati are: Wakal, Harnav, Hathmati and Watrak. The major tributary along the right bank of Sabarmati is Sei. The upper reaches are drained by Wakal, Harnav and Sei while Hathmati and Watrak mostly flow in the plains.

Table 3.1The catchment area distribution of Sabarmati

Name of state	***Total catchment area in Sabarmati (in Sq. Km.)***	***%age contribution***
Gujarat	17550	80.973
Rajasthan	4124	19.027

3.1.3 Topography

The basin has typical undulating topography starting from upper reaches in the Aravalli hills to gently sloping alluvial plains in the lower reaches. The upper reaches constitute mainly draining the parts of Aravalli ranges with the elevations varying from 300 m to 600 m. The elevation of the area where Sabarmati rises is around 762 m in the Rajasthan state.

3.1.4 Rainfall

The Sabarmati subzone lies in the semi-arid zone. The normal annual isohyets of 60 cm to 80 cm cover the upper reaches of Sabarmati. The major source of rainfall is south-west monsoon during June to September. About 90% of the annual rainfall takes place during the monsoon season. The maximum mean monthly rainfall of 20cm to 30cm occurs in the month of July.

3.1.5 Temperature

The temperature in this subzone reaches extreme levels. The climate generally varies from arid in the Saurastra to semi-arid in north Gujarat to humid in coastal areas.

Table 3.2 Temperature in (°C) CWC sites

Year 2008-2009	Jotasan		Kheroj		Derol Bridge		Ratanpur		Kheda	
	Max - Min		Max - Min		Max - Min		Max - Min		Max - Min	
Max	44°	23°	45°	26°	44°	24°	44°	26°	39°	25°
Min	29°	4°	29°	10°	33°	8°	32°	9°	35°	16°

3.1.6 Soil and Land use

The Sabarmati basin constitutes of grey brown soils. The subzone is mostly constituted with arable land interspersed with forests, grasslands and shrubs. The major part of the basin is covered with agriculture accounting to 74.68% of the total area. 4.19% of the total area is covered by water bodies.

3.1.7 Water resource development

The Sabarmati subzone is well developed in terms of water resources. Most of the projects range from medium to minor. The major water projects are Sabarmati reservoir (Dharoi), Hathmati reservoir and Meshwo reservoir project.

Table 3.3 Salient features of Sabarmati basin

Average Water Resource Potential(MCM)	3810
Utilizable Surface Water Resource(MCM)	1900
Live Storage Capacity of Completed Projects (MCM)	1567
Live Storage Capacity of Projects Under Construction (MCM)	110
Total Live Storage Capacity of Projects (MCM)	1677
No. of Hydrological Observation Stations (CWC)	13
No. of Flood Forecasting Stations (CWC)	2

CHAPTER 4

PROJECT METHODOLOGY

4.1 Data Collection

The first and foremost step towards hydrological modelling is the data collection. Since there is vast amount of required, the study area was chosen accordingly for where the data was available. The entire collection of input data was either taken or digitized from the data available on the web. The input data being available on the internet helps in the research and exploration possibilities beyond management of water resources projects.

The digital elevation model is the most essential data required for the calculation of rainfall-runoff. The gridded precipitation data was taken from Indian Meteorological Department for the time period of 1971-2005. Data for the stream flow discharge was collected from India-Water Resources Information System portal for different weather stations where the observed data can be used to calibrate the model.

Table 4.1 Data required for modelling and their Sources

Data	Source
DEM	SRTM 90m (CGIAR – CSI) http://srtm.csi.cgiar.org/
Soil Map	FAO http://www.fao.org/nr/land/soils/en/
Land Use	Global Irrigated Area Map (GIAM) - IWMI
River Streamline	Streamline digitized from Google Earth
Meteorological Data	Indian Meteorological Department Gridded Precipitation (0.5^o X 0.5^o) 1971 - 2005
Discharge Data	India - Water Resources Information System

4.1.1 DEM

The relief has a major impact on the evolution of runoff processes and digital elevation models are very important in any spatially distributed hydrologic analysis.
The main factor determining the runoff of water and its accumulation in channels causing floods, the altimetry is an essential dataset in runoff modelling. All the runoff processes depend on the movement of water due to gravitation, movement that can be modelled when knowing the topographic structure of the terrain.
The digital elevation model is also important in determining the slope of the terrain and flow direction, which are later used for delineating drainage basins corresponding to a measuring gauge or needed for an analysis.
The shape of the terrain is a surface that varies continuously into space and that can be symbolized using contours in a plan. Any digital representation of the continuous variation of altitude in an area is called a digital elevation model (DEM).

Data recorded by remote sensing

Perhaps the greatest progress in hydrological modelling over the past few years has been the public availability of land surface elevation data over the Internet or in other digital format and development of advanced data processing methods.

SRTM (Shuttle Radar Topography Mission) program measured the altitude for about 80% of worldwide land area, using a radar sensor mounted on board of the space shuttle Endeavour in February 2000. The SRTM was the first set of global continuous altitude data at good spatial resolution: 1 arc-second (approximately 30 m), freely available to the U.S. and paid the rest of the world and 3 arc-seconds (approximately 90 m at the equator). The commercial data is distributed by NASA and the free data is available on the USGS website for free.

These data are available as raster data where each raster cell surface has a corresponding value of the land elevation at that point and cell size is equal to the accuracy of measurements.

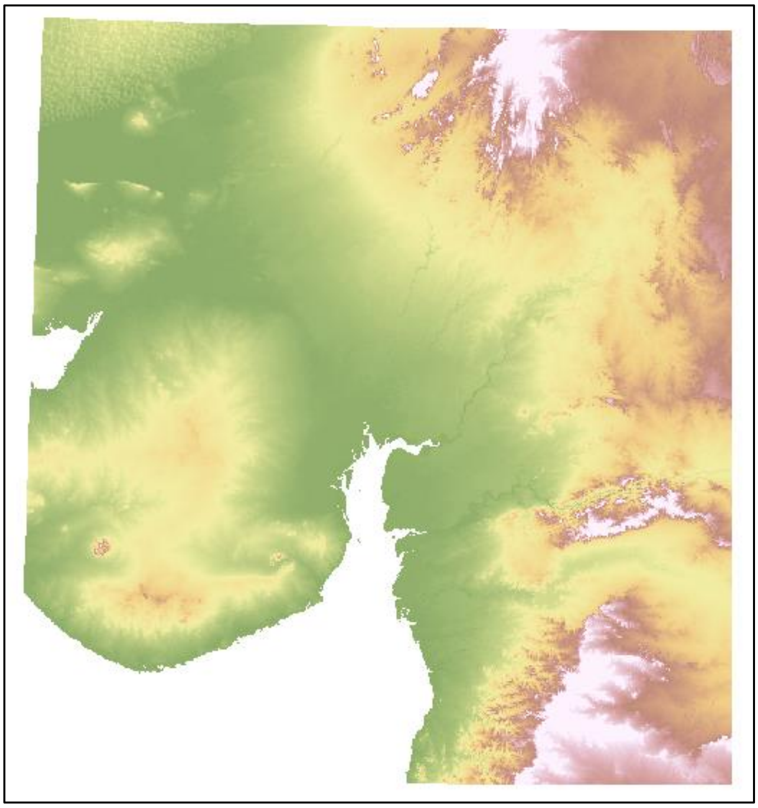

Figure 4.1: DEM Tile (51_08) for the watershed

ArcView ASCII Grid File with Latitude: Min: 20N; Max: 25N
and Longitude: Min: 70E; Max: 75E

4.1.2 Soil Data

Soil data is available as soil maps. These maps represent the soil type for the surface of the ground and some characteristics of this soil type. The soil maps were taken from FAO, Food and Agriculture organization of the United States which are made available for download by the SWAT community in their SWAT 2012 Conference, New Delhi. Soils are differentiated at a spatial resolution of 10 kilometres and divided into almost 5000 soil types.

4.1.3 Land use Data

Land use data has also been made available as land use maps by the SWAT community in their conference which can freely be downloaded from their website as SWAT Datasets. The land use has been differentiated into 24 classes with a spatial resolution of 1 kilometre (Appendix I). Leaf area index, maximum root depth and temperature for plant growth area some parameters used for classification.

4.2 DESIGN PHILOSOPHY

While setting up a SWAT project the most essential step is to project the input files to an adequate projection. The processed raster images were converted into WGS 1984 zone 43 Northern Hemishphere from Geographic Coordinate System.
To simplify the process of modelling the entire procedure is divided into four steps:

1. Watershed delineator
2. HRU Analysis
3. Write Input Tables
4. SWAT simulation

4.2.1 Watershed Delineator

The watershed delineator tool incorporated in the SWAT toolbar allows for the delineating of the watershed. It uses an automatic procedure to delineate sub-basins by calculating the flow direction and flow accumulation using the Digital Elevation Model (DEM) data. The maximum value where the flow is directed from a cell gives the direction of the stream. The threshold value for the stream defines the minimum amount of flow in the stream for which the sub-basins will be delineated.

The form for watershed delineation has five parts:

- DEM Setup
- Stream Definition
- Outlet and Inlet Definition
- Watershed Outlet(s) Selection and Definition
- Calculation of Subbasin Parameters.

ArcGIS and Spatial Analyst extension tool allows the easy delineation of the watershed by using the DEM in grid format giving each cell a specific elevation value. The option for a mask is checked to reduce the work area and make the process faster. The approximate area for the mask is drawn by taking reference from the India-WRIS portal.

The streamline for the Sabarmati River digitized from Google Earth with the help of ArcGIS is then added for stream burn-in. The digital stream network is added to the model to trace the stream path where the elevation difference from the DEM is low and the streams are difficult to trace.

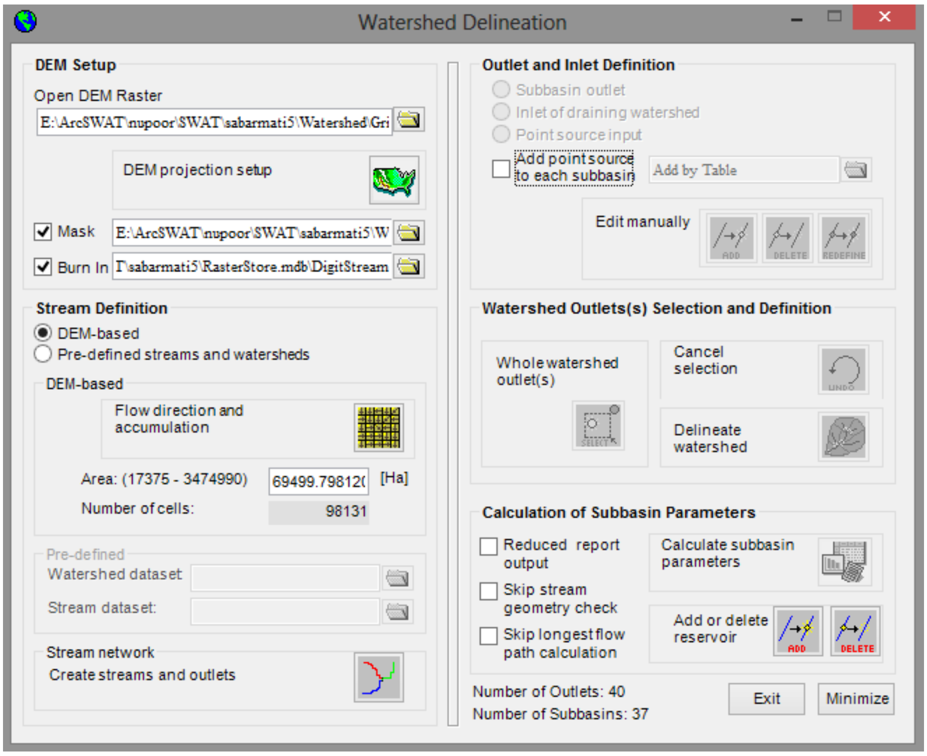

Figure 4.2 Watershed Delineation window

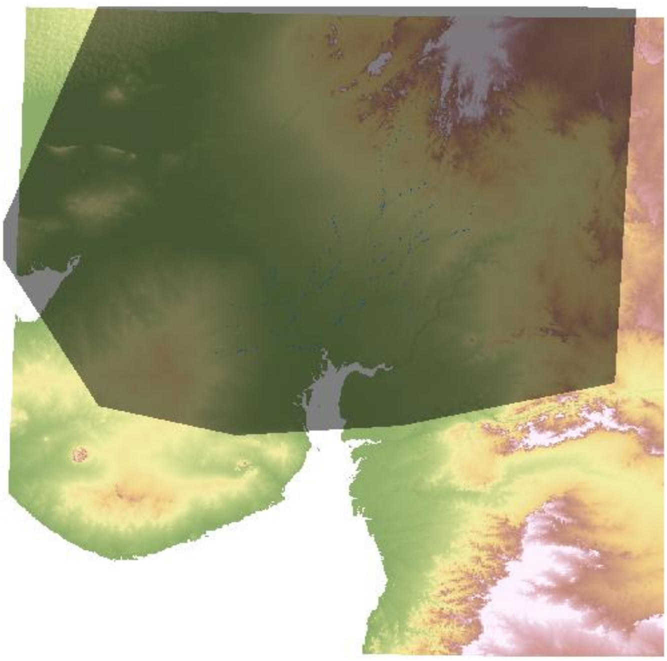

Figure 4.3 DEM with mask for the watershed

The stream definition is done for the basin by flow direction and flow accumulation principle. The threshold limit was taken as default and the stream network thus added as a layer.

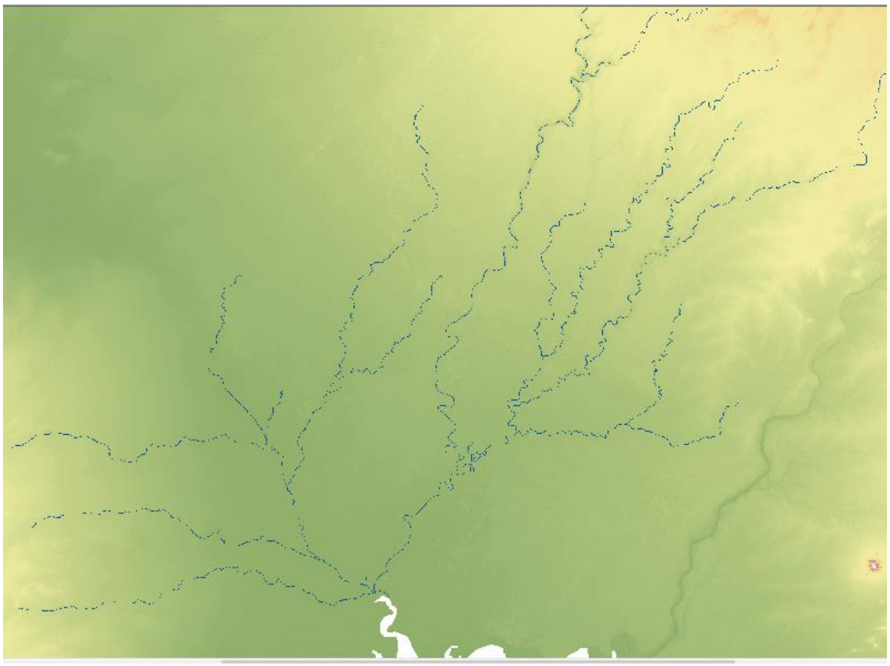

Figure 4.4 Digitized stream network

Outlet and inlet definition is carried out by selecting additional points where the discharge measurement is to be checked for calibration of the model. The manually added outlets are shown in table 5. The outlet for the entire watershed is selected at the junction of the river and the Gulf of Khambhat. The Subbasin parameters are calculated, the reservoirs are located and finally the watershed is delineated.

After the watershed delineation a detailed Topographical report is added to the project. The watershed, Reach, Monitoring Point and Outlet are added after the completion watershed delineation.

Table 4.2: Manually added outlet locations

Station	Latitude	Longitude
Jotasan	24.34469144	73.14129588
Kheda	22.74582512	72.68003328
Kheroj	24.23003922	73.0068681
Ratanpur	22.978095	72.88445027
Vautha	22.64956046	72.5340937

Steps:

- Loading the DEM
- Restricting the working space by creating a focusing mask
- Loading the digitized stream which is to be used for watershed delineation
- Pre-processing of the DEM
- Locate the inlet and outlet points
- Calculate subbasin parameters
- Mark Reservoirs

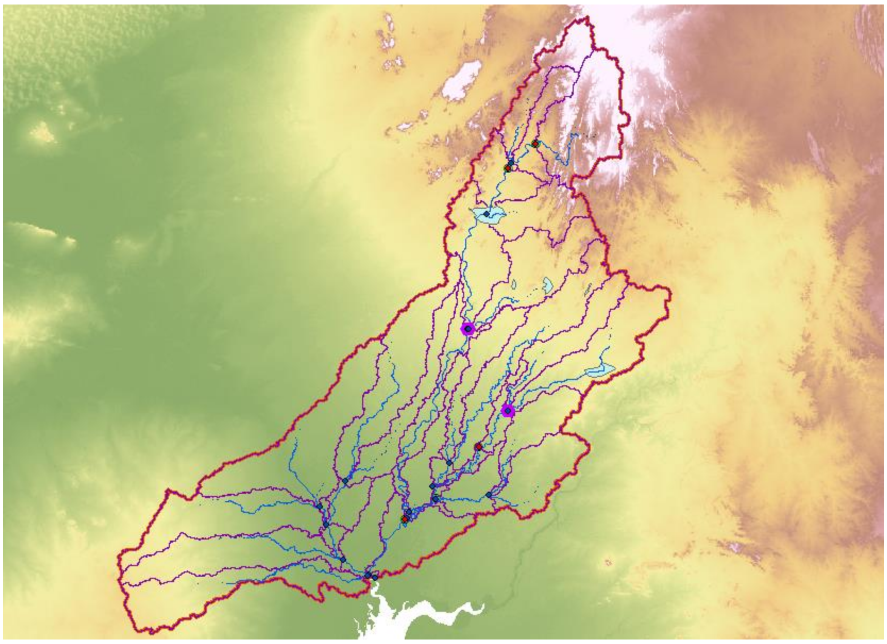

Figure 4.5 Delineated Watershed

4.2.2 HRU Creation

The basis for hydrological modelling in SWAT is the formulation of Hydrologic Response Units (HRUs). HRUs are divisions or units that behave similarly and have same land use, soil and slope characteristics. There may be several HRUs formed in a single subbasin depending upon the combination of land use, soil and slope in the watershed.

The first step for HRU Analysis is the Land Use/ Soil/ Slope Definition and Overlay. This tool allows the user to load soil and land use maps for the watershed for which the basin is reclassified into smaller units. Each land use and soil class has different properties which give different characteristic responses for the same rainfall. The land use / land cover map utilized in this study was changed into SWAT LULC map by reclassification by looking up values from the land use lookup table. These lookup tables provide a common ID (value) for a particular land use class which make the land use map for the watershed. Fig 4.7 shows the land use data definition form.

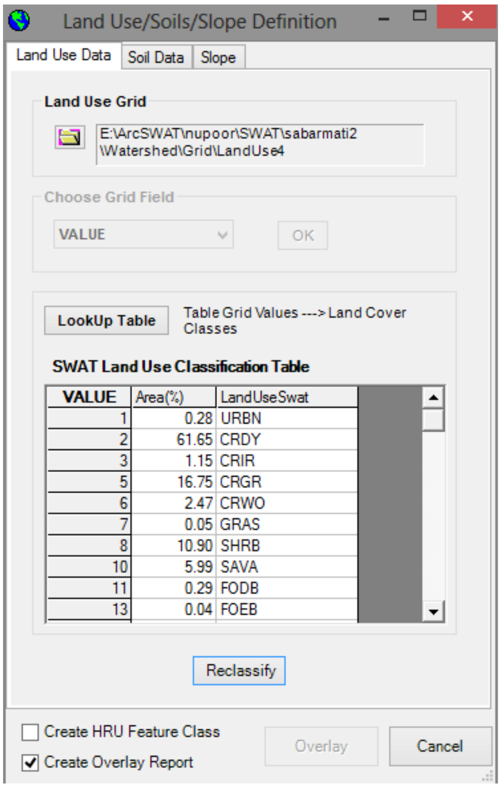

Figure 4.6 Form showing land use data being reclassified

After the land use reclassification, a similar procedure is adopted for the reclassification of soil data. The grid file for soil map and the database made for soil vales and their characteristic responses is added. Around 5000 soil attributes are recorded in the Global Soils database. The soil lookup table links the table grid vales into soil attributes which ultimately when reclassified give the soil map for the basin.

Slope Definition for the basin is the next step in HRU analysis. It is carried out by slope discretization into multiple slopes classes. The upper and lower limits for the different slope classes were given and the basin was classified according to the percentage slope. After reclassification, the Overlay button gives the land use, soil and slope maps for the basin. The basin was divided into 213 HRUs and overlay report for the HRUs was generated. The report shows the classified HRUs and the area distribution among them.

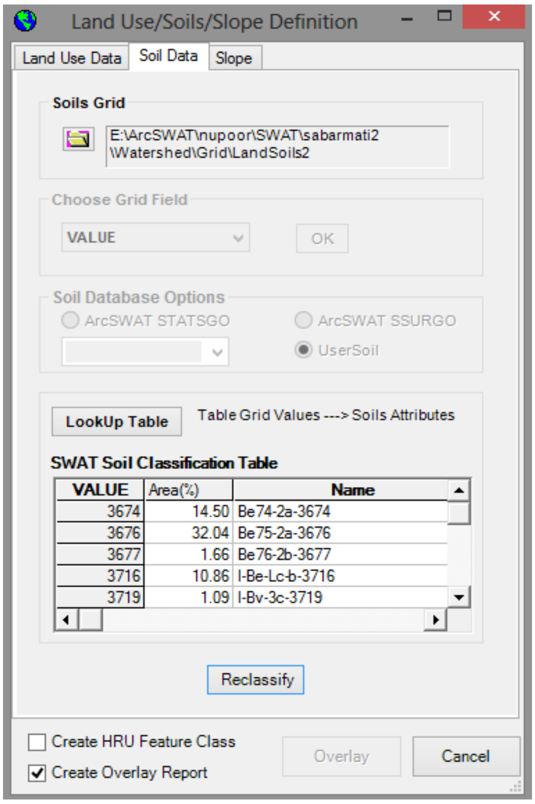

Figure 4.7 Form showing soil data being reclassified

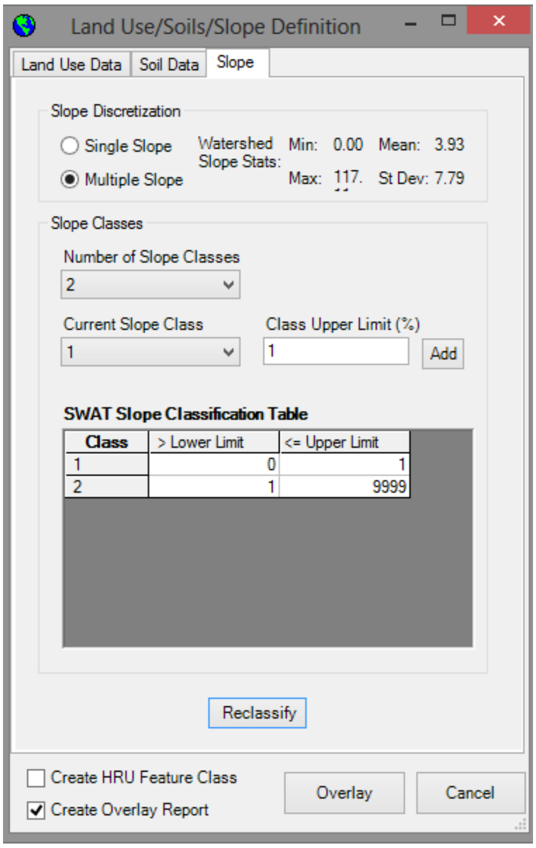

Figure 4.8 Form showing multiple slope watershed reclassification

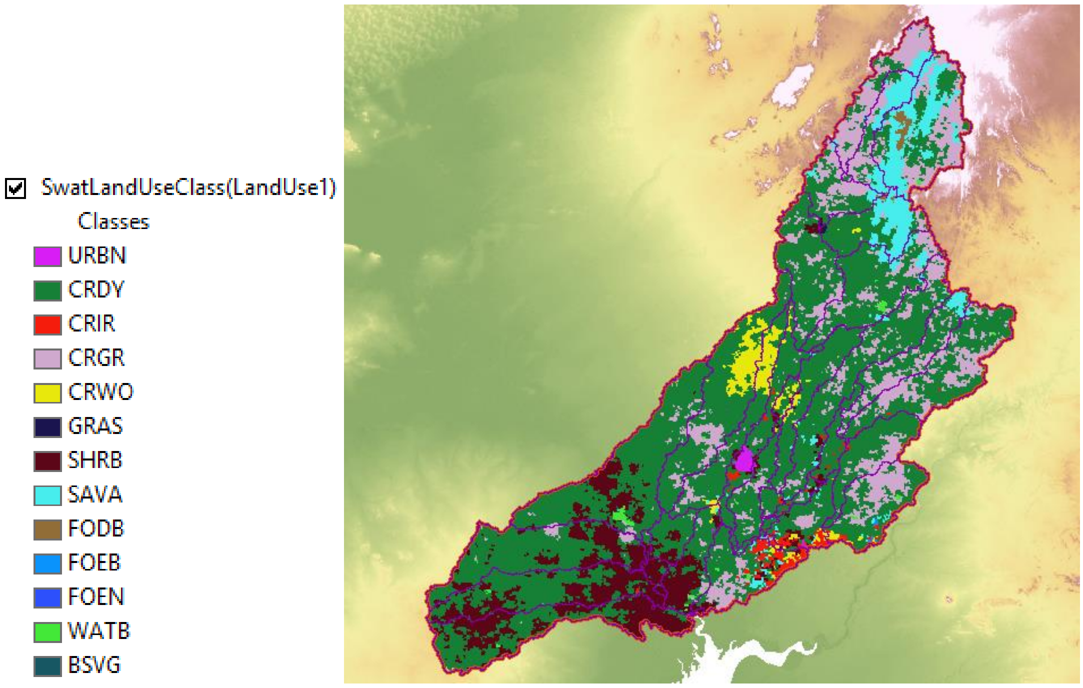

Figure 4.9 Land use projected and clipped for the watershed after classification

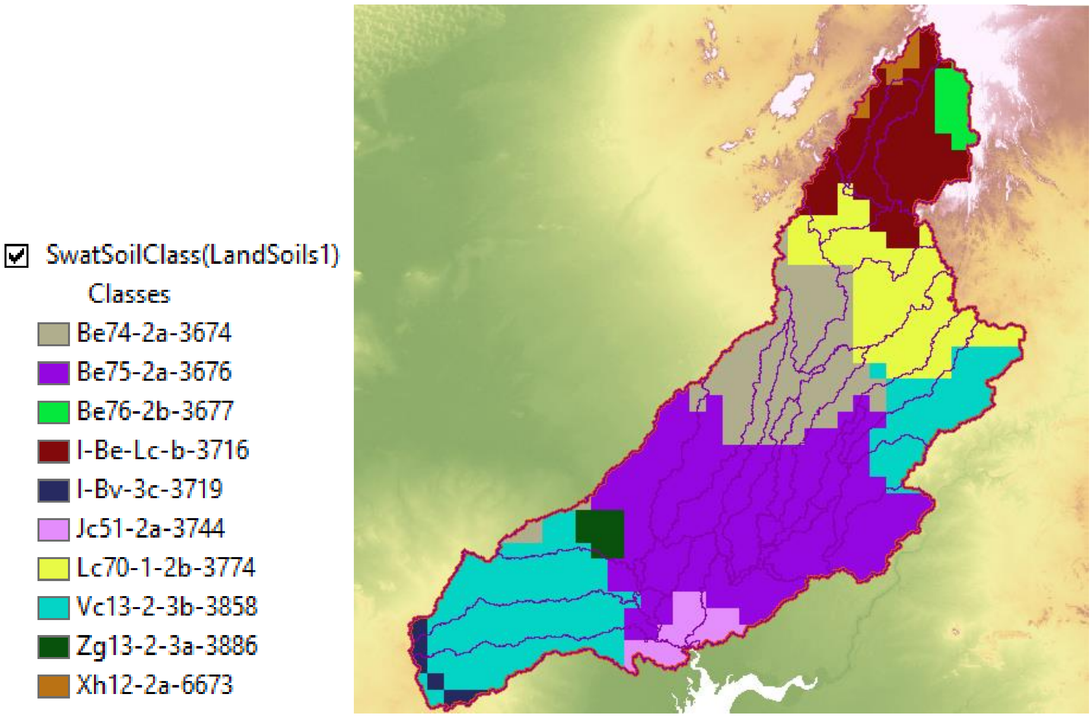

Figure 4.10 Soil Map projected and clipped for the watershed after classification

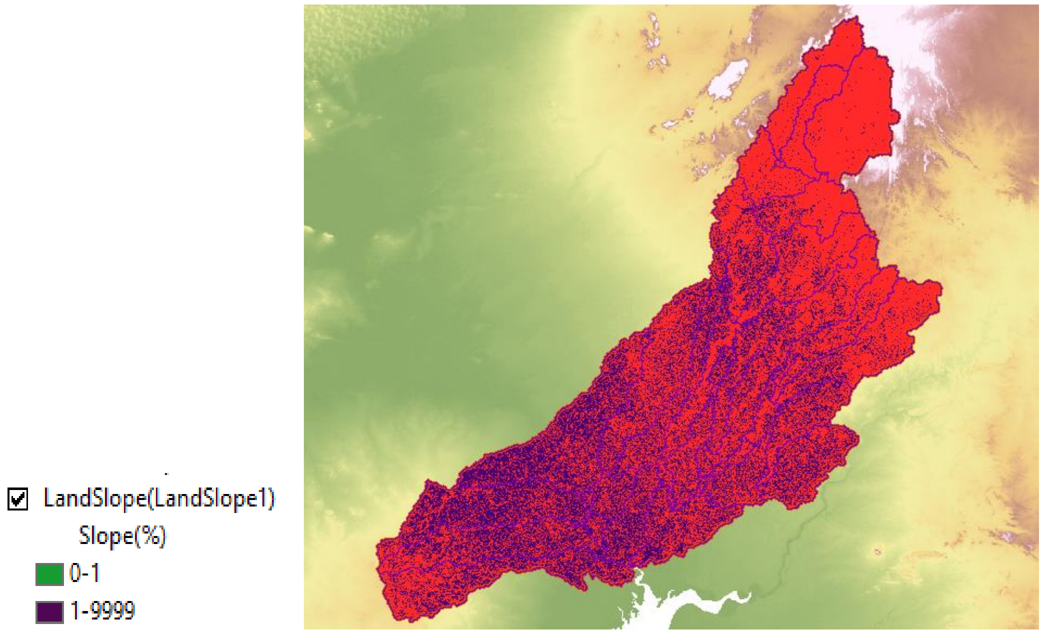

Figure 4.11 Delineated watershed after slope classification

4.2.3 Write Input Tables

This step includes reading the weather data and writing of input tables. The weather data definition for the basin is done by selecting the weather station files like rainfall data, temperature data and the weather generator file. The rainfall data definition tab is shows the rain gauge locations being uploaded. The rain gauge locations table was prepared in the SWAT acceptable format. The precipitation data in daily timestep for all the locations were in separate text files which the SWAT database automatically picked from their location.

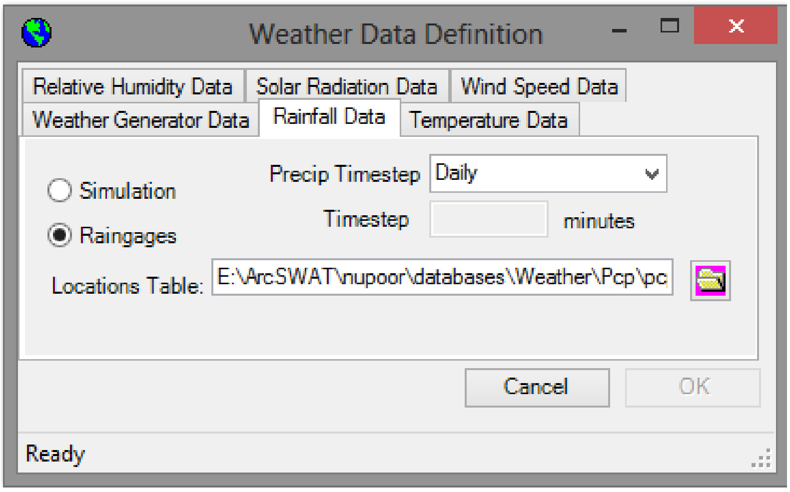

Figure 4.12: Weather data definition form

The temperature locations table was uploaded similarly in the temperature data tab. The precipitation and temperature locations were calculated from the (0.5° x 0.5°) grid locations in the basin. The locations table are shown in Appendix II.
The weather generator file was uploaded for WGEN_user which provides the missing weather data information edited into the SWAT database for the basin. For each weather type of weather data loaded, each sub-basin is linked to one gage.

The next step is the write SWAT input tables which writes the database table into the main SWAT database and the project database. The tables need to be written in a specific sequence so that some of the related tables could be written. All tables need to have a status of 'Completed' before the SWAT project can be setup and run.

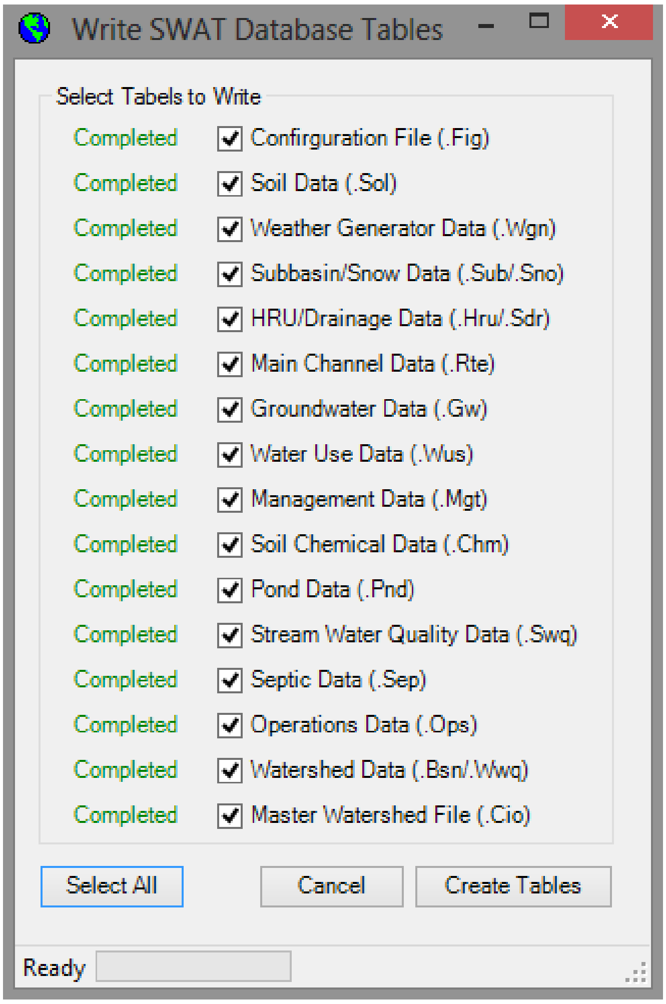

Figure 4.13: The completed write SWAT database tables form

Adding Reservoir Data

The reservoir data was added from the 'Edit SWAT Input' option. The sub-basin locations were found for the reservoirs placed in Step 1 of Watershed delineation by the identify tool. The values for the reservoir volume, hydraulic conductivity and surface area were edited for each reservoir. Some of the values were assumed keeping in mind the average values for the reservoirs with reference to the 'SWAT Theoretical Documentation'. The reservoir data taken from the India-WRIS portal is shown in Appendix III.

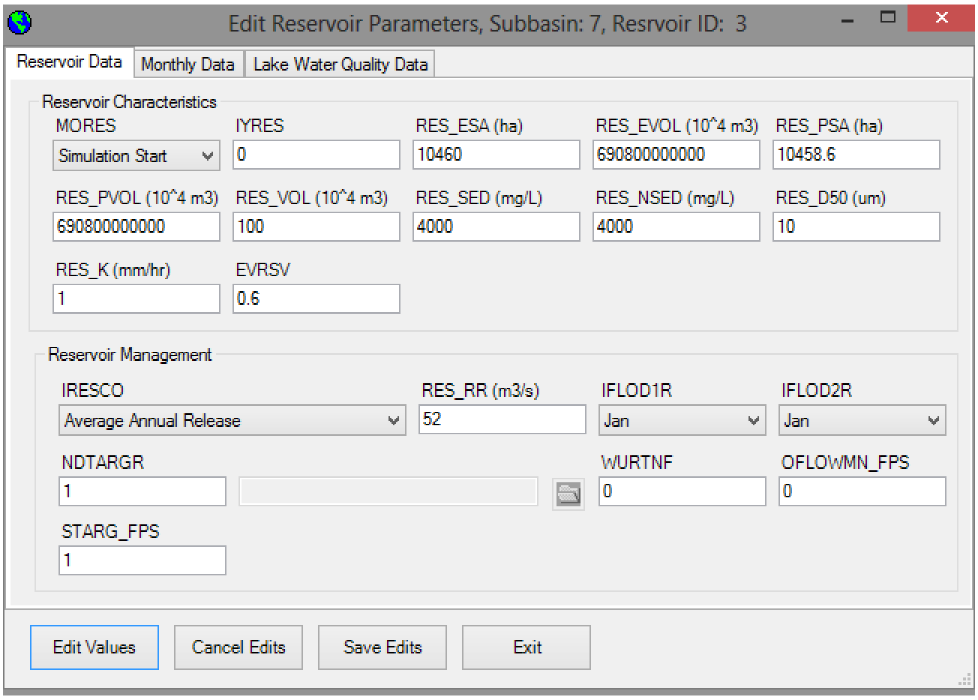

Figure 4.14 The Edit Reservoir parameters form

4.2.4 SWAT Simulation

The final step is the setup and run SWAT model simulation. The period of simulation was taken for six years from January 2000 to December 2005 for which the observed data was sufficiently available. One year of warm up period was given to the model so that it could better simulate the results. The model is run for the entire duration of six years but the warm up period is not shown in the results. The setup of SWAT Run is necessary before the final SWAT Run could be made. The setup generates the final input files for the period of simulation.

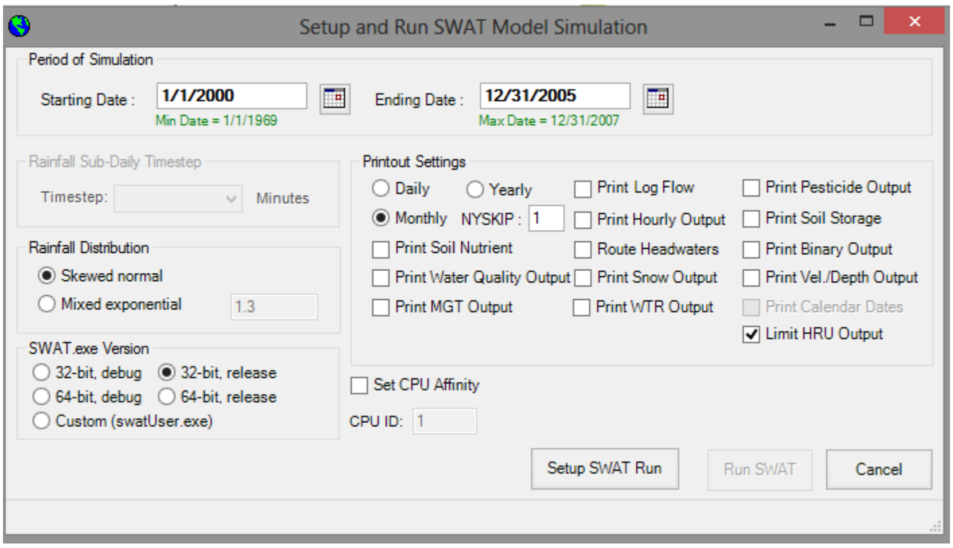

Figure 4.15 SWAT Setup and Run Form

After the successful SWAT Setup, the Run SWAT button becomes active. The final SWAT run is allowed which takes time in processing all the information.

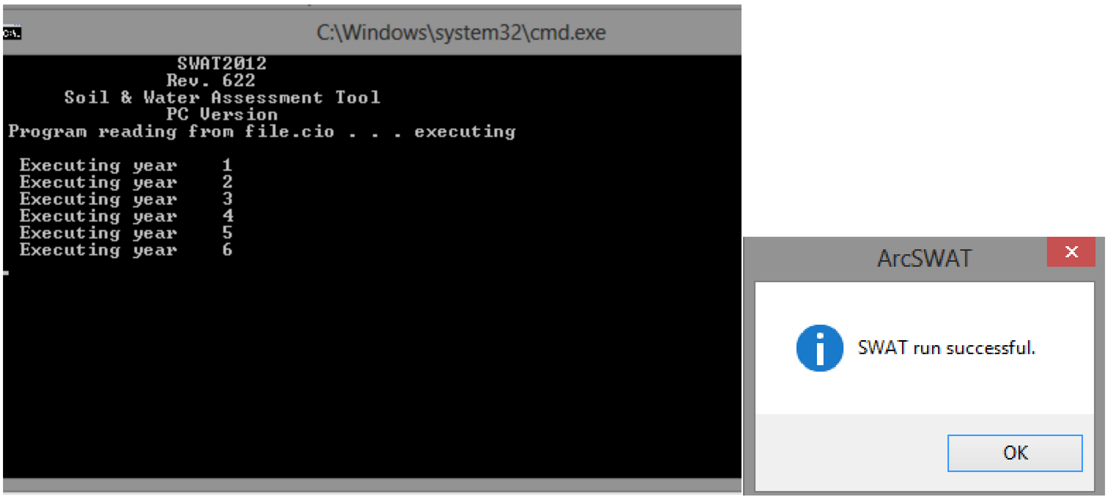

Figure 4.16 Model execution

4.3 SWAT Output

The output of the SWAT model is in the format of database files which need to be imported to the main SWAToutput.mdb file in the SWAT database. Part of the output file imported is shown in Appendix IV. These output files can be exported into a spreadsheet for further analysis and plotting. For the analysis of the entire basin flow, the sub-basin at the outlet is identified and the Flow_out from that sub-basin is plotted and checked with the observed flows of the basin.

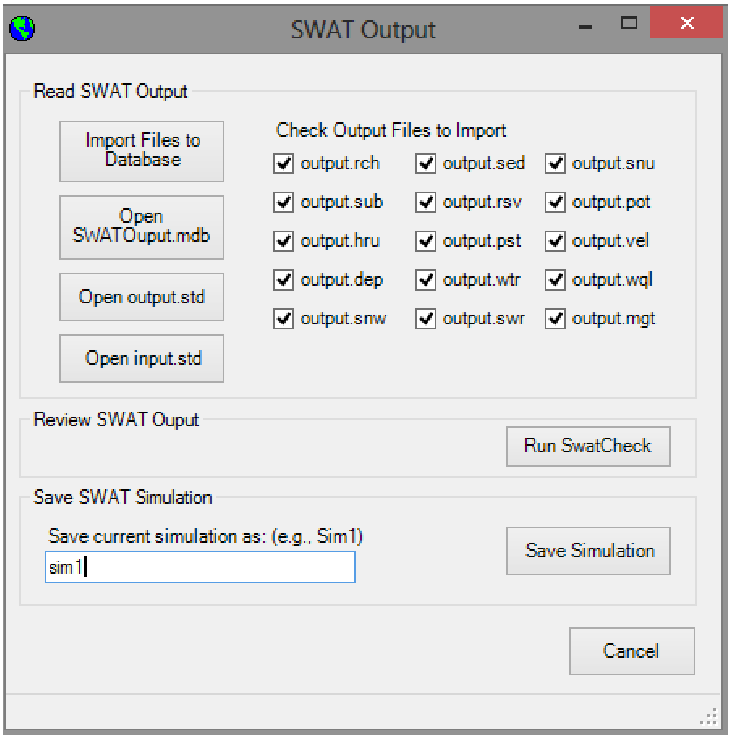

Figure 4.17 SWAT Output Form

The current simulation can be saved as Sim1 and made as the default simulation. For further adjusting of the SWAT output further simulations can be done after varying parameters and compared with the default simulation and the observed flows.

Since the observed discharge was not available at the outlet of the basin, the discharge at Vautha was taken as the study point. The sub-basin was identified for Vautha and the discharge at that particular sub-basin was compared with the observed.

4.4 Calibration and Validation of Results

The simulated results of the model were checked with the observed streamflow discharge. Due to some variation in the results, manual calibration was done for the model. SWAT Check was done for the model which showed particular areas to be concentrated upon for the calibration. The Calibration was done for some parameters which improved the results significantly.

CHAPTER 5

RESULTS

This chapter presents and analyses the results from the hydrological modelling. These results involves various derived maps and tables which give the necessary information for the watershed like the discharge and sediment at outlets and HRUs formed according to different land classes, soil classes and slope.

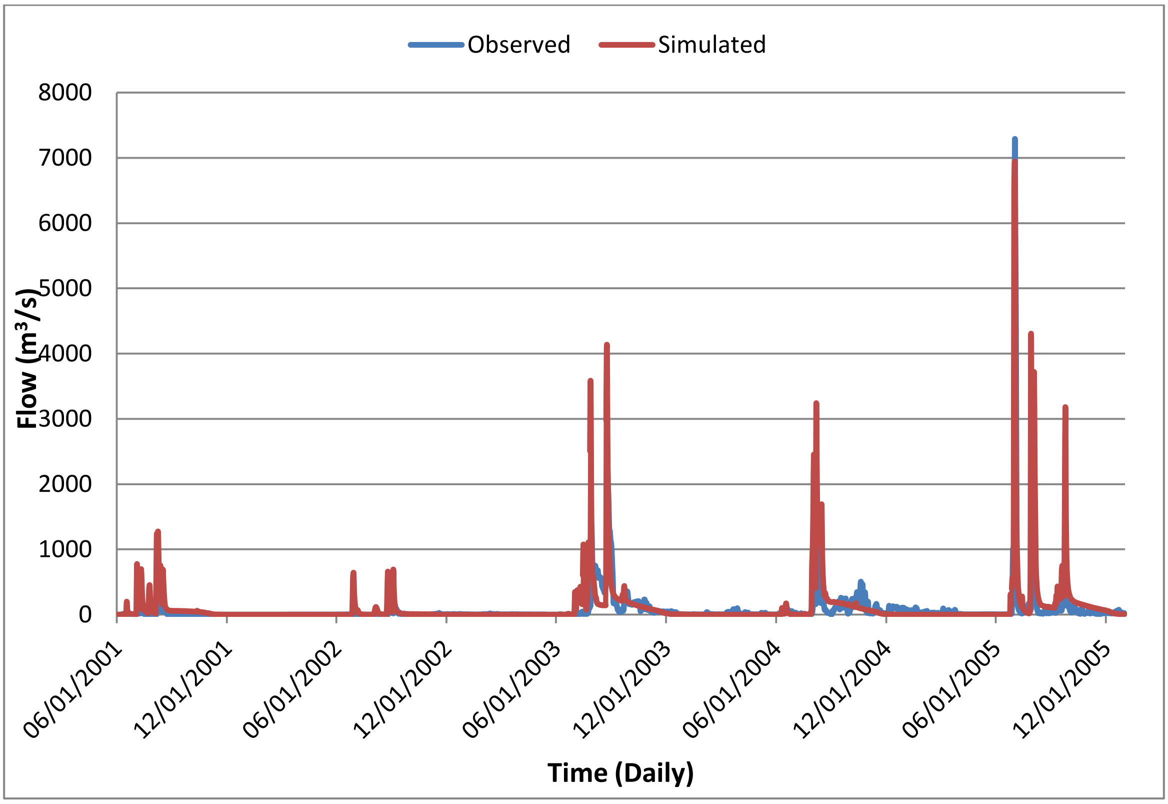

Figure 5.1 Observed and Simulated Daily Flows

The simulated flows checked with the observed discharge for the time period of six years is shown in the graph 5.1. The time step taken for initial simulations is daily so as to facilitate the model in the warm up period since the initial observed flows are less at the discharge gauging location, Vautha. The peaks of the simulated and observed flows match showing a good co-relation of the model.

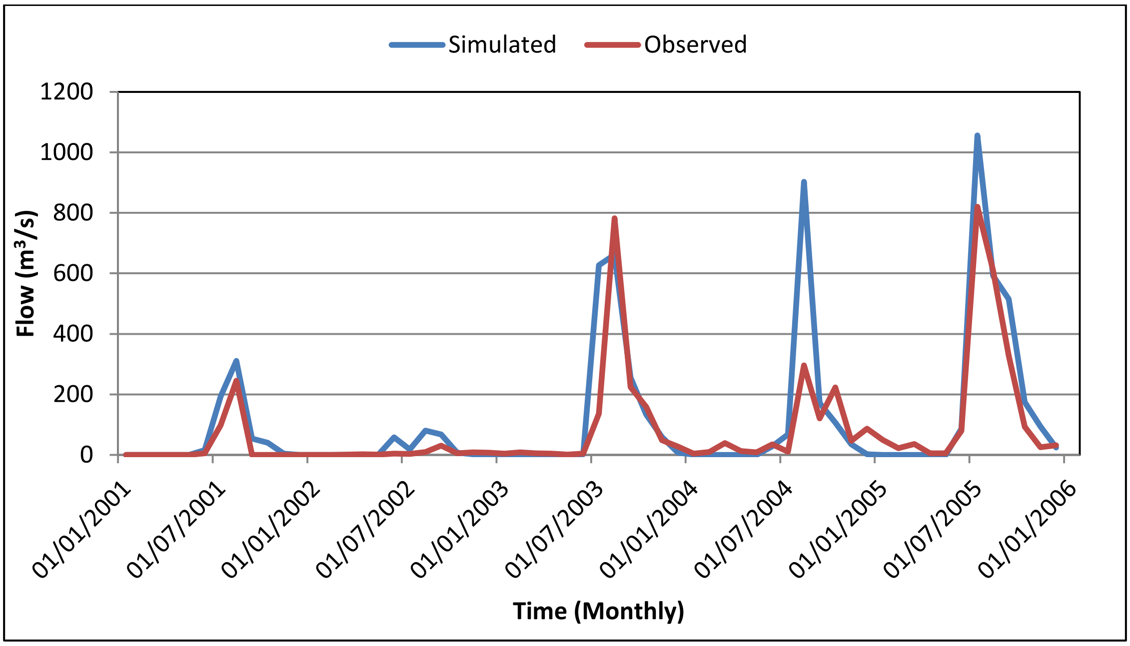

Figure 5.2 Observed and Simulated Monthly Flows

Figure 5.2 shows the observed flows at Vautha and simulated flows for the monthly time interval. The peaks near August of every year mark a mismatch in the graphs due to the reservoir operations which results in reduced peaks.

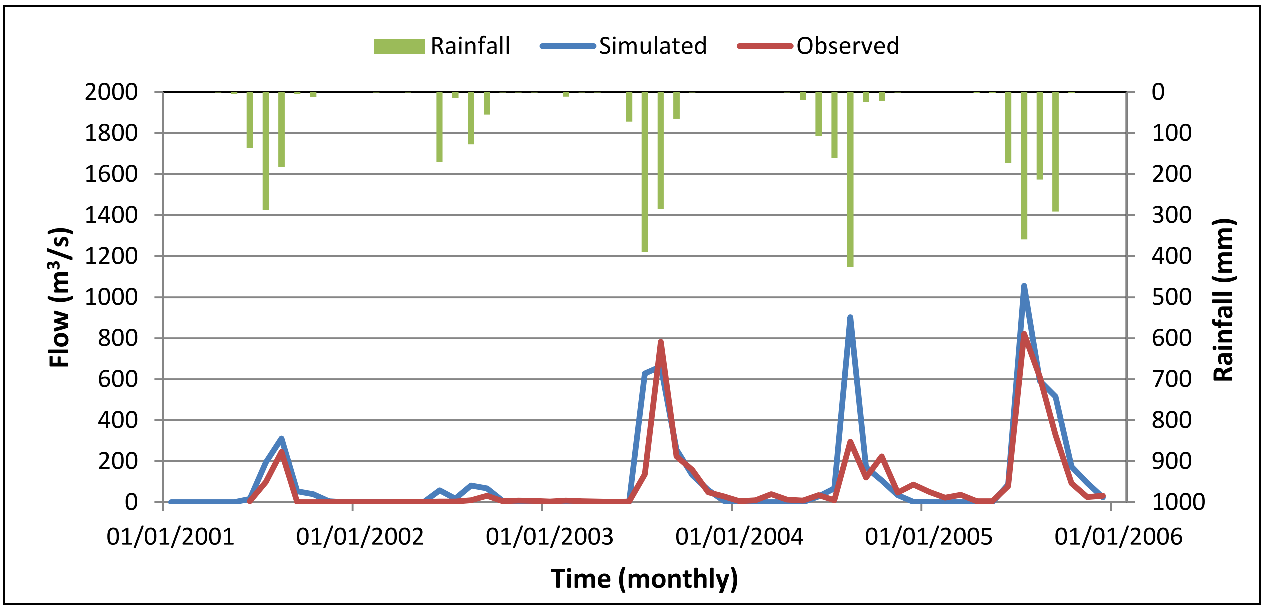

Figure 5.3 Observed and Simulated Monthly Flows in co-relation with precipitation

Figure 5.3 shows peaks for the simulated flows when the precipitation values reach maximum showing satisfying correlation with the precipitation.

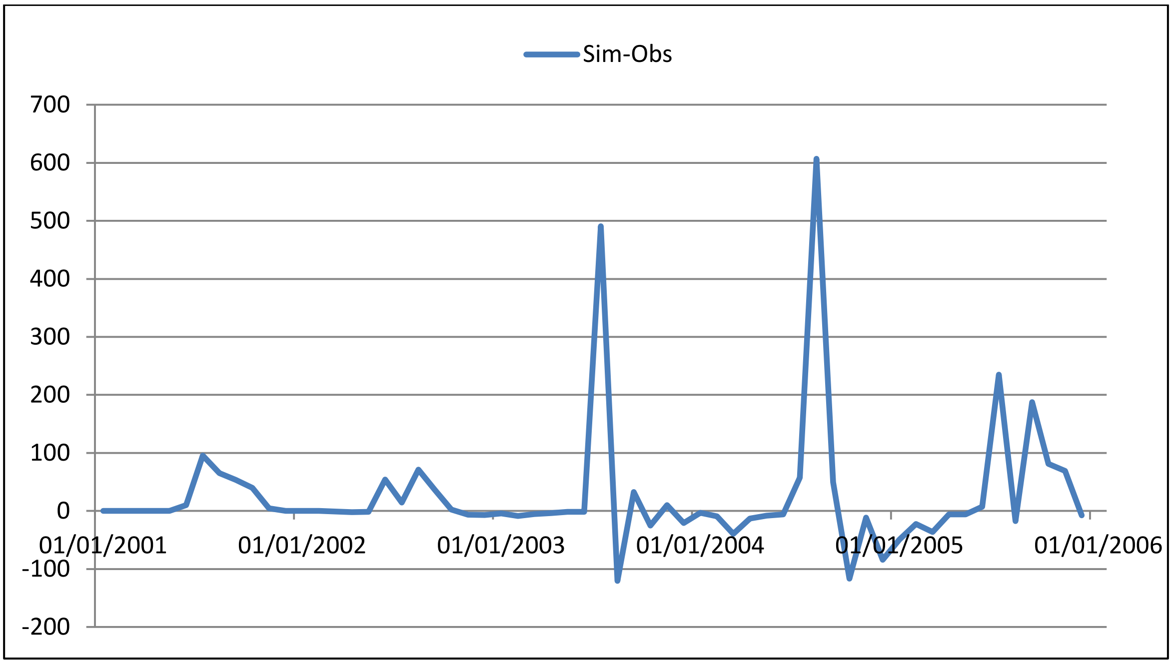

Figure 5.4 Difference between Simulated and Observed

Figure 5.4 shows that the difference between the observed and simulated flows ranges from both positive to negative indicating that the model is neither under-predicting or over-predicting flows throughout the simulation. In this condition the model cannot be predicted further.

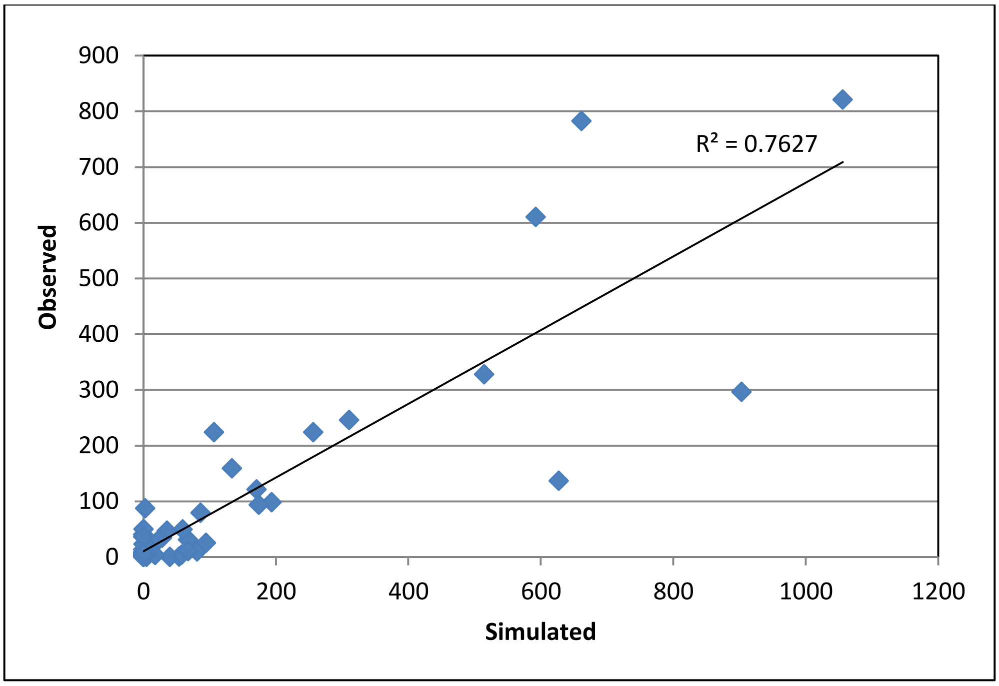

Figure 5.5 Linear Plot of the Observed and Simulated Flows

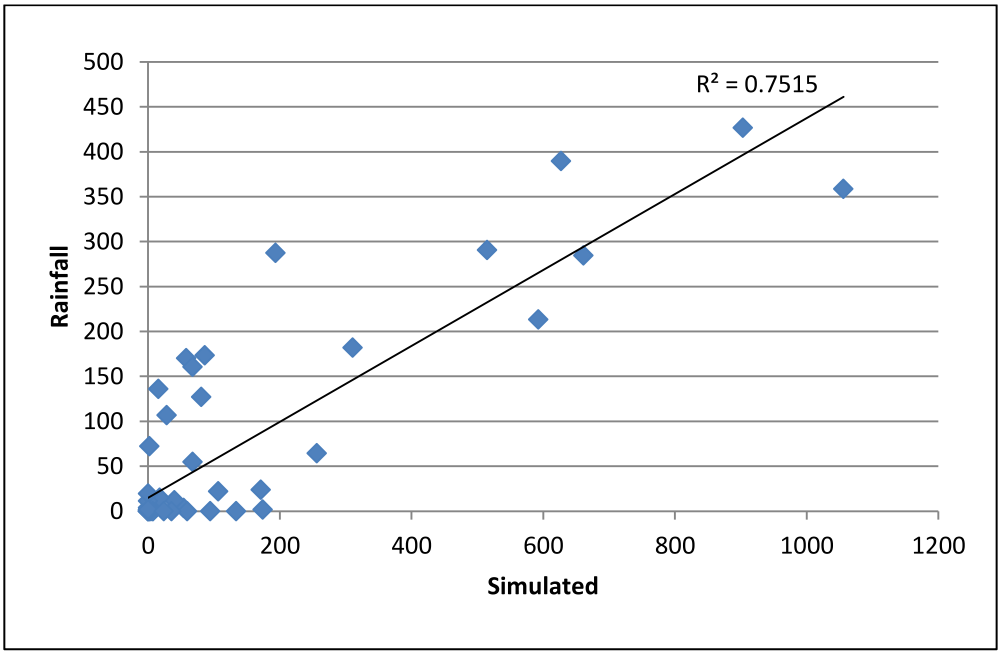

Figure 5.6 Linear Plot of the Rainfall and Simulated Flow

CHAPTER 6

CONCLUSIONS

The primary aim of this study was the hydrological modelling of Sabarmati river basin using SWAT 2012 version and examine the water balance for the region. The study checked the feasibility of the SWAT model in calculating the discharges for the region. The following points can be concluded from the study:

- The coefficient of determination for the model was found to be satisfactory (R^2 0.7515) for the determination of the discharge in case of rainfall and simulated flows and the value improved in the correlation with the observed and simulated flows (R^2 0.7627).
- The peaks for both the observed and simulated flows gained height in correlation with the precipitation showing that the model predicts flood conditions at exact times.
- The varying observed flows with precipitation and those with simulated flows show that the difference in flows are encountered due to reservoir operations at that time.
- The model was calibrated for the basin characteristics to improve the results which could have been further improved for future work by procurement of exact reservoir and basin data so that the model can also be used for future prediction of flows.

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APPENDIX I

LAND USE CLASSIFICATION TABLE

OBJECTID	CPNM	CROPNAME
2.00000	CRDY	DRYLAND CROPLAND AND PASTURE
3.00000	CRIR	IRRIGATED CROPLAND AND PASTURE
4.00000	MIXC	MIXED DRYLAND/IRRIGATED CROPL
5.00000	CRGR	CROPLAND/GRASSLAND MOSAIC
6.00000	CRWO	CROPLAND/WOODLAND MOSAIC
7.00000	GRAS	GRASSLAND
8.00000	SHRB	SHRUBLAND
9.00000	MIGS	MIXED GRASSLAND/SHRUBLAND
10.00000	SAVA	SAVANNA
11.00000	FODB	DECIDUOUS BROADLEAF FOREST
12.00000	FODN	DECIDUOUS NEEDLELEAF FOREST
13.00000	FOEB	EVERGREEN BROADLEAF FOREST
14.00000	FOEN	EVERGREEN NEEDLELEAF FOREST
15.00000	FOMI	MIXED FOREST
16.00000	WATB	WATER BODIES
17.00000	WEHB	HERBACEOUS WETLAND
18.00000	WEWO	WOODED WETLAND
19.00000	BSVG	BAREN OR SPARSLY VEGETATED
20.00000	TUHB	HERBACEOUS TUNDRA
21.00000	TUWO	WOODED TUNDRA
22.00000	TUMI	MIXED TUNDRA
23.00000	TUBG	BARE GROUND TUNDRA
24.00000	ICES	SNOW OR ICE

APPENDIX II

PRECIPITATION AND TEMPERATURE STATION LOCATIONS

pcploc1.txt - Notepad

File Edit Format View Help

```
ID,NAME,LAT,LONG,ELEVATION
1,705220 pcp,22.00,70.50,0
2,705225 pcp,22.50,70.50,0
3,705230 pcp,23.00,70.50,0
4,705235 pcp,23.50,70.50,0
5,705240 pcp,24.00,70.50,0
6,705245 pcp,24.50,70.50,0
7,705250 pcp,25.00,70.50,0
8,705255 pcp,25.50,70.50,0
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APPENDIX III

RESERVOIR DATA

Name of the Dam	Hathmati Dam
Nearest City	Bhiloda
District	Sabar Kantha
State	Gujarat
Basin Name	Sabarmati
River	Hatmati
Dam Type	Earthen
Dam Status	Completed
Purpose	Irrigation
Completion Year	1989
Length of Dam (m)	993
Dam Height (m)	23.62
Design flood (cumec)	2944
Type of Spillway	Ogee
Length of spillway (m)	241
Type of Spillway gates	UNGATED
Crest Level of spillway	178.36
Total Volume content of dam (TCM)	1189
Spillway capacity (cumec)	2943
Seismic Zone	Seismic Zone-III

Name of the Dam	Watrak Dam
Nearest City	Bayad
District	Sabar Kantha
State	Gujarat
Basin Name	Sabarmati
River	Watrak
Dam Type	Earthen
Dam Status	Completed
Purpose	Irrigation
Completion Year	1983
Length of Dam (m)	325
Dam Height (m)	43.31
Design flood (cumec)	12798
Type of Spillway	Ogee
Length of spillway (m)	89
Type of Spillway gates	RADIAL
Number of Spillway gates	6
Size of Spillway Gates (m X m)	12.50 x 8.23
Crest Level of spillway	128
Commencement year	1971
Total Volume content of dam (TCM)	2096
Seismic Zone	Seismic Zone-III

Name of the Dam	Guhai Dam
Nearest City	Idar
District	Sabar Kantha
State	Gujarat
Basin Name	Sabarmati
River	Guhai
Dam Status	Completed
Purpose	Irrigation
Completion Year	1990
Length of Dam (m)	3380
Dam Height (m)	43.07
Design flood (cumec)	5851
Type of Spillway	Ogee
Length of spillway (m)	89.33
Type of Spillway gates	RADIAL
Number of Spillway gates	6
Size of Spillway Gates (m X m)	14*94 10.67
Crest Level of spillway	164.77
Total Volume content of dam (TCM)	1961.43
Spillway capacity (cumec)	5787
Seismic Zone	Seismic Zone-III

Name of the Dam	Sabarmati Dam
Nearest City	Idar
District	Sabar Kantha
State	Gujarat
Basin Name	Sabarmati
River	Sabarmati
Dam Type	Earthen / Gravity / Masonry
Dam Status	Completed
Purpose	Irrigation,Water Storage
Completion Year	1982
Length of Dam (m)	1207
Dam Height (m)	46
Design flood (cumec)	14158
Type of Spillway	Ogee
Length of spillway (m)	219
Type of Spillway gates	RADIAL
Number of Spillway gates	12
Size of Spillway Gates (m X m)	14.95 x 10.67
Crest Level of spillway	178.92
Commencement year	1971
Total Volume content of dam (TCM)	6908
Spillway capacity (cumec)	21662
Seismic Zone	Seismic Zone-III

APPENDIX IV

OUTPUT TABLE FILTERED FOR SUB BASIN 1

SUB	YEAR	MON	AREAkm2	FLOW_INcms	FLOW_OUTcms	EVAPcms
1	2001	1	872.8	0.1941	0.1317	0.06263
1	2001	2	872.8	0.1476	0.04728	0.103
1	2001	3	872.8	0.1044	0.002374	0.1029
1	2001	4	872.8	0.07579	0	0.07579
1	2001	5	872.8	0.05689	0.0006473	0.05624
1	2001	6	872.8	6.195	6.071	0.1217
1	2001	7	872.8	34.14	34.09	0.05586
1	2001	8	872.8	41.74	41.64	0.09979
1	2001	9	872.8	9.612	9.49	0.1216
1	2001	10	872.8	9.397	9.314	0.07988
1	2001	11	872.8	0.6114	0.5384	0.07095
1	2001	12	872.8	0.2368	0.1811	0.0577
1	2002	1	872.8	0.1693	0.1061	0.0638
1	2002	2	872.8	0.1281	0.03756	0.09262
1	2002	3	872.8	0.09045	0.001173	0.09036
1	2002	4	872.8	0.06552	0	0.06552
1	2002	5	872.8	0.04757	0	0.04757
1	2002	6	872.8	9.784	9.711	0.07317
1	2002	7	872.8	0.3132	0.1774	0.1342
1	2002	8	872.8	3.543	3.457	0.0846
1	2002	9	872.8	1.093	0.9881	0.1051
1	2002	10	872.8	0.1017	0.01596	0.08803
1	2002	11	872.8	0.05395	0	0.05395
1	2002	12	872.8	0.03257	0	0.03257
1	2003	1	872.8	0.0206	0	0.0206

SUB	YEAR	MON	AREAkm2	FLOW_INcms	FLOW_OUTcms	EVAPcms
1	2003	2	872.8	0.216	0.1831	0.03286
1	2003	3	872.8	0.02857	0	0.02857
1	2003	4	872.8	0.01388	0	0.01388
1	2003	5	872.8	0.008043	0	0.008043
1	2003	6	872.8	1.643	1.587	0.05626
1	2003	7	872.8	58.49	58.4	0.08438
1	2003	8	872.8	42.98	42.9	0.08011
1	2003	9	872.8	8.545	8.437	0.1079
1	2003	10	872.8	6.879	6.789	0.08948
1	2003	11	872.8	3.311	3.233	0.07214
1	2003	12	872.8	0.51	0.4469	0.06291
1	2004	1	872.8	0.2283	0.1682	0.06242
1	2004	2	872.8	0.1665	0.06959	0.09906
1	2004	3	872.8	0.1217	0.009252	0.1138
1	2004	4	872.8	0.08837	0.0001426	0.08823
1	2004	5	872.8	0.06905	0.0004665	0.06858
1	2004	6	872.8	0.05629	0.0004102	0.05588
1	2004	7	872.8	0.05795	0.002269	0.05359
1	2004	8	872.8	30.57	30.49	0.07839
1	2004	9	872.8	6.004	5.897	0.112
1	2004	10	872.8	2.542	2.453	0.0835
1	2004	11	872.8	0.1757	0.1031	0.0751
1	2004	12	872.8	0.1122	0.05125	0.06134
1	2005	1	872.8	0.07692	0.01633	0.06276
1	2005	2	872.8	0.05655	0	0.05655
1	2005	3	872.8	0.03902	0	0.03902
1	2005	4	872.8	0.0277	0	0.0277
1	2005	5	872.8	0.01976	0	0.01976

SUB	YEAR	MON	AREAkm2	FLOW_INcms	FLOW_OUTcms	EVAPcms
1	2005	6	872.8	0.05531	0.02451	0.0237
1	2005	7	872.8	54.63	54.52	0.1199
1	2005	8	872.8	96.69	96.55	0.1346
1	2005	9	872.8	74.2	74.1	0.1067
1	2005	10	872.8	7.855	7.766	0.08878
1	2005	11	872.8	4.96	4.886	0.07405
1	2005	12	872.8	0.8347	0.7688	0.06084