WATERSHED SIMULATION
USING GIS INTEGRATED PHYSICALLY BASED MODEL

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PROJECT REPORT

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Department of Land and Water Resources and Conservation Engineering
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KERALA, INDIA

2009

DECLARATION

We here by declare that this project report entitled **"Watershed Simulation using GIS Integrated Physically Based Model"** is a bonafide record of project work done by us during the course of project and that the report has not previously formed the basis for the award to us of any degree, diploma, associate ship, fellowship, or other similar title of any other university or society.

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Date : -01-2009

CERTIFICATE

Certified that this project report entitled **“Watershed Simulation using GIS Integrated Physically Based Model”** is a record of project work done jointly by **Divya Gopinath, Kripa, I.V, Pooja, P and Shalini, M. Chandran** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, associate ship, fellowship to them.

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At this moment we remember affectionately our dear **parents** and all our **friends** who have aided us in every way to make our way a success.

Above all we bow our heads before the **God Almighty** for bestowing His innumerable blessings upon us.

Divya Gopinath
Kripa, I.V
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Shalini,M. Chandran

Dedicated to

God Almighty,

Loving Parents

and Teachers

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SYMBOLS AND ABBREVIATIONS

AMC	-	Antecedent Moisture Condition
ARS	-	Agricultural Research Station
AVSWAT	-	Arc View Soil and Water Assessment Tool
CN	-	Curve Number
cm	-	centimeter
COD	-	Coefficient of Determination
CWC	-	Central Water Commission
DEM	-	Digital Elevation Model
Dept	-	Department
dGEN	-	daily weather generator algorithm
ET	-	Evapotranspiration
et al	-	and others
etc	-	et cetra
FCC	-	False Colour Composite
Fig	-	Figure
GIS	-	Geographic Information System
GPS	-	Global Positioning System
GRASS	-	Geographic Resources Analysis Support System
HRU’s	-	Hydrologic Response Units
ha	-	hectare
HSG	-	Hydrologic Soil Group
ILWIS	-	Integrated Land and Water Information System
IRS	-	Indian Remote sensing Satellite
K.C.A.E.T	-	Kelappaji College of Agricultural Engineering and Technology
km^2	-	square kilometre
LANDSAT-TM	-	LAND Satellite- Thematic Mapper

LISS - Linear Imaging and Self Scanning

m - metre

m^2 - square metre

mm - millimetre

NBSS&LUP - National Bureau of Soil Survey & Land Use Planning

NRCS - National Resource Conservation Service

NRSA - National Remote Sensing Agency

SCS - Soil Conservation Service

SOI - Survey of India

SWAT - Soil and Water Assessment Tool

Sol_awc - Soil available water content

Sol_cbn - Soil carbon

SPOT - Systeme Pour l’Observation de la Terre

USDA - United States Department of Agriculture

UTM - Universal Transverse Mercator

WEPP - Water Erosion Prediction Project

r^2 - Coefficient of Determination

< - less than

> - greater than

% - percent

^{0} - degree

’ - minute

INTRODUCTION

Chapter I
INTRODUCTION

Natural resources are the pillars of nature's life support system. Among this, Land and Water are the most important natural resources that are essential for the existence of life and are the two variable factors for which management has become most essential. Fast paced and multi-faceted development and ever increasing population has created tremendous pressure on these resources to provide various requirements for a modern life. To meet these requirements, the limited natural resources are being over-exploited resulting in widespread eco-system degradation.

The objective of improving the productivity, profitability and prosperity of the agricultural sector on an ecologically sustainable basis can be attained only when conservation, development and management of the land and water resources are assured. Watershed is an ideal unit for carrying out scientific resources management for ensuring continuous benefit on sustainable basis. Integrated watershed management is a pre-requisite not only for land, water and biomass management of degraded areas but also for conservation of productive lands so that biodiversity and genetic riches are protected for future generations.

A watershed is a basin-like landform defined by highpoints and ridgelines that descend into lower elevations, valleys and streams. It is a natural integrator of all the hydrological phenomena pertaining to an area bounded by a natural divide and is a logical unit for planning the optimal development of soil, water and biomass resources. Area development programs, these days, are carried out on watershed basis knowing the importance of watershed concept in natural resource management and development. Natural resource management is the precursor to any socio-economic development activity. The strength of the watershed development programme will largely determine the growth in agriculture.

Watershed models are very effective tool for planning watershed development activities. The term watershed modelling has a broad connotation. It generally refers to the simulation of the processes that takes place in the watershed. The aim of watershed modelling is to gain better understanding of hydrologic phenomena operating within the watershed area and how changes in watershed may affect these phenomena. Watershed models are broadly classified into two: empirically and physically based. Empirical models are black box models and they try to fit a relationship between input and output variables without looking into the governing physical laws. On the other hand, physically based models try to incorporate the physics based processes governing the input output relationship. For the understanding of the hydrological process taking place in a watershed, physically based models has to be employed.

1.1 GEOGRAPHIC INFORMATION SYSTEM

The use of GIS in today's water resources modelling is inevitable. As data becomes available electronically, more and more computer modelling is being done in place of traditional paper based approaches. GIS is an information system that is designed to work with data referenced by spatial or geographic coordinates. It is that chain of operations that takes us from planning the observation and collection of data, to store and analysis of the data, to the use of the derived information in some decision making process. GIS has played an important role in resources management, environment monitoring, land use and planning activities (Chagarlamudi, P and Plunkett, G.W., 1991).

1.2 REMOTE SENSING

Remote sensing technology has been playing an important role in effective and timely mapping of georesources. It is defined as collecting and interpreting information about a target without being in physical contact with the object. Aircrafts and satellites are the common platforms for remote sensing observations. It is commonly restricted to methods that employ electromagnetic energy such as heat, light and radio waves as a means of detecting. Remote sensing data having high resolution available from IRS, LANDSAT-TM and SPOT have been improved and computer based image processing system have become comparatively less expensive and more effective. Remote sensing integrated with GIS, involving application of digital computers to the storage, manipulation, analysis, interpretation and effective communication of the information associated with georesources and collateral aspects have provided scope for multiple representation of data for variety of uses (Reddy,D.V, 1991).

1.3 APPLICATION OF GIS IN WATERSHED MODELLING

Application of GIS is attaining increasing interest in watershed modelling. The geographic information systems are able to capture, store, manipulate, analyze and visualize the diverse sets of georeferenced data. Distributed hydrologic model requires lot of data. Therefore, integration of hydrologic models and GIS is quite essential. The integration involves three components: spatial data construction, integration of spatial model layers, GIS and model interface (Singh, 1997). The GIS can help in design, calibration, modification and comparison of watershed models. This integration is spreading throughout the world and is expected to accelerate in the times to come. There are many challenges in the use of GIS for conceptualizing and modelling complex hydrologic processes. The GIS technology is suitable for efficient management of large and complex database. Spatial statistics and grid design capabilities of GIS can improve the efficiency of watershed modelling. The GIS database for watershed modelling comprises details of land use, water use, soils, hydrologic characteristics, drainage network etc. A digital representation of watershed characteristics by GIS is used in watershed modelling.

1.4 OVERVIEW OF SWAT MODEL

SWAT is a basin scale, continuous time model that operates on a daily time step. The model has been developed by United States Department of Agriculture (USDA) and has undergone many capability expansions. It is designed to predict the impact of management on water, sediment and agricultural chemical yields in gauged and ungauged watersheds. The model is physically based, computationally efficient and capable of continuous simulation over long time periods. Major model components include weather, hydrology, sediments and nutrients. In SWAT, a watershed is divided into multiple sub-watersheds. These are then further subdivided into hydrologic response units (HRUs) that consist of homogeneous land use, management and soil characteristics. The HRUs represent percentages of the sub-watershed area and are not identified spatially within a SWAT simulation (Gassman et al., 2007). The capability of SWAT model is particularly limited in terms of dealing with groundwater flow, due to its lumped nature.

GIS can assist the decision maker in dealing with complex management and planning problems within a watershed, providing geo-processing function and flexible problem solving environments to support the decision research process. Use of these technologies will definitely promote the aforementioned goal of pursuing Development through the ‘Eco-friendly’ route. Hence, the present study is an attempt to utilize the advances in information technology for natural resource management with the given below specific objectives.

1.5 MAIN OBJECTIVES OF THE STUDY ARE:

Kadalundi river basin at Karathodu gauging station lying in Malappuram district has been taken for this study with the following specific objectives:

1. To model the physical characteristics of the watershed
2. To assess the hydrological processes taking place in the watershed.
3. To assess the impact of the scenario changes on the watershed processes.

REVIEW OF LITERATURE

Chapter II

REVIEW OF LITERATURE

2.1 Runoff

Runoff is the draining or flowing off of water, resulting from precipitation from a catchment area. Runoff consists of precipitation that neither evaporates, transpires nor penetrates the surface to become groundwater. It represents the output from the catchment in a given unit of time.

2.1.1 Estimation of runoff

The calculation of runoff volume (watershed yield) is of great importance in all water resources and land development studies. The various methods adopted for the estimation of runoff volume are the correlation of runoff and rainfall, empirical equations and watershed simulations.

2.1.2 Surface runoff

Surface runoff occurs when rainfall exceeds a soil's maximum saturation level and all surface depression storage is filled to capacity. The rate of runoff flow depends on the ratio of rain intensity to the infiltration rate. When water is initially applied to a dry soil, the infiltration rate is usually very high. However, it will decrease as the soil becomes wetter. When the application rate is higher than the infiltration rate, surface depressions begin to fill. If the application rate continues to be higher than the infiltration rate once all surface depressions have filled, surface runoff will commence.

2.1.3 Estimation of surface runoff

Accurate estimation of surface runoff is difficult as it depends on many factors. The following methods evolved after field experience and observation are usually used for estimation of surface runoff from a watershed. Rational method for the estimation of peak runoff rate, Soil Conservation Service method, Soil Conservation Service Curve number method and Cook’s method are the most commonly used methods.

SWAT provides two methods for estimating surface runoff: the SCS Curve number procedure (SCS, 1972) and the Green and Ampt infiltration method (1911).

2.1.4 Equations governing hydrology

The important equations to predict hydrology from the watershed is given below.

2.1.4.1 Water Balance Equation

The hydrologic cycle is simulated by the water balance equation:

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

Where, SW_t = final soil water content; SW_0 = initial soil water content; R = daily rainfall; Q = daily surface runoff; ET = daily evapotranspitration; P = daily percolation and QR = daily lateral flow.

2.1.4.2 Soil Conservation Service - Curve number method

The model was developed to provide a consistent basis for estimating the amounts of runoff under varying land use and soil types (Rallison and Miller, 1981).

The SCS Curve number equation is (SCS, 1972):

$$Q = \frac{(R - 0.2s)^2}{R + 0.8s} \quad \text{for R } \phi \text{ } 0.2\text{s}$$

$$Q = 0.0 \quad \text{for R } \pi \text{ } 0.2\text{s}$$

Where, Q = daily surface runoff (mm); R = daily rainfall (mm); S = retention parameter (mm) and CN = Curve Number. The retention parameter varies spatially due to changes in soils, landuse, management and slope and temporally due to changes in soil water content. The retention parameter is defined as:

$$\text{s} = 254\left(\frac{100}{CN} - 1\right)$$

Soil Hydrologic Groups

The U.S. Natural Resource Conservation Service (NRCS) classifies soils into four hydrologic group based on infiltration characteristics of the soils. NRCS Soil Survey Staff (1996) defines a hydrologic group as a group of soils having similar runoff potential under similar storm and cover conditions. Soil properties that influence runoff potential are those that impact the minimum rate of infiltration for a bare soil after prolonged wetting and when not frozen. These properties are depth to seasonally high water table, saturated hydraulic conductivity and depth to a very slowly permeable layer. Soil may be placed in one of four groups, A, B, C and D, or three dual classes, A/D, B/D and C/D. Definitions of the classes are:

> **Hydrologic Soil Group - A: (Low runoff potential).** The soils have a high infiltration rate even when thoroughly wetted. They chiefly consist of deep, well drained to excessively drained sands or gravels. They have high rate of water transmission.
>
> **Hydrologic Soil Group - B:** The soils have moderate infiltration rate when thoroughly wetted. They chiefly are moderately deep to deep, moderately well-drained to well drained soils that have moderately fine to moderate coarse textures. They have a moderate rate of water transmission.
>
> **Hydrologic Soil Group - C**: The soils have a slow infiltration rate when thoroughly wetted. They chiefly have a layer that impedes downward movement of water or have moderately fine to fine texture. They have a slow rate of water transmission.
>
> **Hydrologic Soil Group - D**: **(High runoff potential).** The soils have a very slow infiltration rate when thoroughly wetted. They chiefly consist of clay soil that have a high swelling potential, soils that have a permanent water table , soils that have a clay pan or clay layer at or near the surface, and shallow soil over nearly impervious material. They have a very slow rate of water transmission.

Dual hydrologic groups are given for certain wet soils that can be adequately drained. The first letter applies to the drained condition, the second to the undrained. Only soils that are rated D in their natural condition are assigned to dual classes.

2.1.4.3 Antecedent Moisture Condition (AMC)

SCS defines three antecedent moisture conditions: I-dry (wilting point), II-average moisture and III- wet (field capacity). The moisture condition I curve number is the lowest value the daily curve number can assume in dry conditions. The curve numbers for moisture conditions I and III are calculated with equations:

$$CN_1 = \frac{20(100 - CN_2)}{(100 - CN_2 + e^{(2.533 - 0.0636(100 - CN_2))})}$$

$$CN_3 = CN_2 . e^{(0.00673(100 - CN_2))}$$

Where CN_1 is the moisture condition I curve number, CN_2 is the moisture condition II curve numbers and CN_3 is the moisture condition III curve number.

Bingner, R. L (1996) studied about runoff simulated from Goodwin Creek watershed (GCW) in northern Mississippi using SWAT and was simulated for 10 years. GCW contains 14 in stream measuring stations for runoff. Each sub basin was described using the GRASS geographic information system, integrated with SWAT, to determine input parameters. Storm event rainfall was measured individually from one rain gauge for each sub basin. Results showed that simulations using SWAT predicted the relative trends of runoff on a daily and annual basis from multiple sub basins, except for a completely wooded sub basin.

King, K. W *et al.* (1999) studied about comparison of Green-Ampt and curve number methods on Goodwin creek watershed using SWAT. Two methods of simulating excess rainfall were compared on a large basin with multiple rain gauges. Eight years of measured climatic data were used in the study. Simulated and measured stream flows at the watershed outlet were evaluated. Results were not calibrated. Monthly model efficiencies were 0.84 for CN and 0.69 for Green-Ampt. The use of a sub-daily routing technique allowed for very good correlation between measured and simulated hydrographs.

Schumann, A. H *et al.* (2000) conducted a study on application of geographic information system for conceptual rainfall -runoff modelling. In this paper, an approach was presented on how statistical descriptions of distributed catchments characteristics could be used to consider spatial heterogeneity within conceptual models. Three semi-distributed modules were presented. The three components were combined to a hydrological model including feedback components between surface flow and infiltration and between subsurface return flow and surface flow in saturated areas. In the second part, it was shown how the application of this model to different catchments within a region can benefit from boundary conditions for optimization, which were derived from GIS considering the variations of catchment's characteristics.

Assefa, M. Melesse and Shiha, S. F (2002) conducted a study on spatially distributed storm runoff depth estimation using Landsat images and GIS. The US Department of Agriculture, Natural Resources Conservation Service Curve Number (USDA-NRCS-CN) method was used in this study for determining the runoff depth. Runoff curve number was determined based on the factors of hydrologic soil group, land use, land treatment, and hydrologic conditions. GIS and remote sensing were used to provide quantitative measurements of drainage basin morphology for input into runoff models so as to estimate runoff response. The study was conducted on the Kissimmee River basin in south Florida. Spatially distributed runoff curve numbers and runoff depth were determined for the watershed for different land use classes. Results of the study showed that land use changes determined from Landsat images were useful in studying the runoff response of the basin.

Hao FangHua *et al.* (2004) made a study on the runoff and sediment yield simulation in a large basin using GIS and a distributed hydrological model. A GIS-based distributed SWAT (Soil and Water Assessment Tool) model was used to simulate the runoff and sediment yield in the upper basin of the Luohe River, a tributary of the Yellow River in China. In the process of calibration, the automated digital filter technique was used to separate the surface runoff and base flow. The surface runoff, base flow, total runoff and the sediment yield were calibrated. The simulated results demonstrated that the GIS-based SWAT model could be successfully used to simulate long-term runoff and sediment yield.

Ashish Pandey *et al*. (2006) conducted a study on runoff and sediment yield modelling from a small agricultural watershed in India using the Water Erosion Prediction Project (WEPP). The WEPP model was calibrated and validated for a small hilly watershed (Karso) of India. Sensitivity analysis of the model was carried out for the input parameters. The analysis showed that the sediment yield was highly sensitive to interrill erodibility and effective hydraulic conductivity, whereas, runoff was sensitive to effective hydraulic conductivity only. Initially, the model was calibrated using data from the 1996 monsoon season and subsequently its performance was evaluated by estimating the daily runoff and sediment yield using the monsoon season data of different years. Performance of the WEPP model for simulation of sediment yield was also evaluated. High value of coefficient of determination (0.81–0.95), Nash–Sutcliffe simulation model efficiency (0.78–0.92) and percent deviation values (4.43–19.30) for sediment yield indicated that the WEPP model could be successfully used in the upper Damodar Valley, India.

Garbrecht, J. D *et al.* (2006) studied on monthly runoff predictions based on rainfall forecasts in a small Oklahoma watershed. Conditions under which monthly rainfall forecasts translate into monthly runoff predictions that could support water resources planning and management activities were investigated. Runoff response to rainfall forecasts was simulated using the hydrologic model SWAT. Eighteen scenarios were examined that represented combinations of wet, average, and dry antecedent rainfall conditions, with wet, normal, and dry forecasted rainfall. Results suggested that for the climatic and physiographic conditions under consideration, rainfall forecasts could offer potential application opportunities in surface water resources but only under certain conditions.

Kamble, A. K *et al.* (2006) estimated the surface runoff from micro watershed using Soil and Water Assessment Tool (SWAT) model and was tested on daily and monthly basis for estimating the runoff from a micro watershed in Chattisgarh, India. The model was calibrated and validated for the monsoon season of the years 1994 and 1995 using observed daily rainfall and temperature data for the respective years. The Manning's roughness coefficient values for both channel and overland flows were calibrated for the micro watershed. Graphical and statistical methods of model testing revealed that the daily (r^2=0.91) and monthly (r^2=0.86) observed and simulated values of surface runoff matched quite well for the entire calibration period. Model validation results also indicated that the magnitude and temporal variation of simulated surface runoff matched closely with the observed surface runoff for daily (r^2=0.97) and monthly (r^2=0.99) values. On the basis of results obtained through this study, it can be concluded that SWAT model can simulate daily and monthly surface runoff satisfactorily from a micro watershed.

Kannan, N *et al.* (2007) studied about sensitivity analysis and identification of the best evapotranspiration and runoff options for hydrological modelling on a small catchment of 141.5 ha in the Unilever Colworth estate, in Bedfordshire, England for the period September 1999 to May 2002 inclusive using both daily and sub-daily rainfall data. The paper describes simple and efficient approaches for sensitivity analysis, calibration and identification of the best methodology within a modelling framework. The Hargreaves and Penman-Montieth methods of evapotranspiration estimation and the NRCS Curve Number (CN) and Green and Ampt infiltration methods for runoff estimation techniques were used, in four different combinations, to identify the combination of methodologies that best reproduced the observed data.

Zachary, M. Easton *et al.* (2007) studied about re-conceptualizing the Soil and Water Assessment Tool (SWAT) model to predict runoff from Variable Source Areas (VSA). In the study, SWAT model was re-conceptualized to distribute overland flow in ways consistent with VSA hydrology by modifying how the CN and available water content were defined. The new modelling approach was called SWAT-VSA. Both SWAT and SWAT-VSA were applied to a sub-watershed in the Cannonsville basin in upstate New York to compare model predictions of integrated and distributed responses, including surface runoff, shallowly perched water table depth, and stream phosphorus loads against direct measures. Event runoff was predicted similarly well for SWAT-VSA and SWAT. This had important consequences for using models to evaluate and guide watershed management.

Maski, D *et al.* (2008) studied modelling runoff and sediment yields from combined in-field crop practices using the Soil and Water Assessment Tool. The study evaluated the impact of conventional-till and no-till management practices with surface or deep-banded fertilizer application in sorghum-soybean rotation on runoff and sediment-yield predictions using the SWAT model. The model was calibrated using USDA Natural Resources Conservation Service runoff curve number for antecedent moisture condition II (CNII), saturated hydraulic conductivity, and available water capacity parameters for runoff and USLE cropping factor (Cmin) for sediment-yield predictions for three field plots (0.39 to 1.46 ha [0.96 to 3.6 ac]) with different combinations of practices and validated for three field plots (0.40 to 0.56 ha [1.0 to 1.4 ac]) over a period of 2000 to 2004. Surface runoff calibration required CNII values greater than the recommended baseline values. No-till treatments required slightly greater curve number values than the till treatment, and this difference was similar to that associated with increasing the soil hydrologic group by one classification. Generally the model under predicted the sediment yield for all management practices. Baseline Cmin values were adequate for treatments with soil disturbance, either by tillage or fertilizer deep-banding, but best-fit Cmin values for field conditions without soil disturbance (no-till with surface-broadcast fertilizer) were 2.5 to 3 times greater than baseline values. These results indicate current model limitations in modelling undisturbed (no-till) field management conditions, and caution that models calibrated for fields or watersheds predominated by tilled soil conditions may not function equally well in testing management scenarios without tillage.

Rokhsare Rostamian *et al.* (2008) conducted a study on application of SWAT model for estimating runoff and sediment 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). 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. Runoff and sediment data from four hydrometric stations in each basin were used for calibration and validation. The P factor for Beheshtabad stations ranged from 0.31 to 0.86, while those for Vanak stations were between 0.71 and 0.80. The D factor for Beheshtabad ranged from 0.3 to 1.1, and for Vanak it was 0.77–1.16. These measures indicated a fair model calibration and accounting of uncertainties. The predicted runoff values were quite similar to those for discharge.

2.1.5 Lateral flow

Lateral flow, or interflow, is streamflow contribution which originates below the surface but above the zone where rocks are saturated with water.

Lateral flow is predicted by:

$$q_{lat} = 0.024\frac{(2SSC\sin\alpha)}{\theta_d L}$$

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); L = flow length (m); α = slope of the land and Θ_d = drainable porosity.

2.1.6 Base flow

Base flow, or return flow, is the volume of streamflow originating from the groundwater. SWAT partitions groundwater into two aquifer systems: a shallow, unconfined aquifer which contributes return flow to streams within the watershed and a deep, confined aquifer which contributes return flow to streams outside the watershed.

Base flow is estimated by:

$$Q_{\text{gwj}} = Q_{\text{gwj}-1}.e^{(-\alpha_{gw}.\Delta t)} + w_{rchrg}.(1-e^{(-\alpha_{gw}.\Delta t)})$$

Where Q_{gwj-1}= ground water flow into the main channel on day j; α_{gw}= base flow recession constant and Δt= time step.

2.2 GIS in Watershed modelling

Geographic Information system (GIS) is defined as an information system that is used to input, store, retrieve, manipulate, analyze and output geographically referenced data or geospatial data, in order to support decision making for planning and management of land use, natural resources, environment, transportation, urban facilities, and other administrative records. The use of GIS in today's water resources modelling is inevitable. As data becomes available electronically, more and more computer modelling is being done in place of traditional paper based approaches. GIS is an information system that is designed to work with data referenced by spatial or geographic coordinates. It is that chain of operations that takes us from planning the observation and collection of data, to store and analysis of the data, to the use of the derived information in some decision making process. GIS has played an important role in resources management, environment monitoring, land use and planning activities (Chagarlamudi, P and Plunkett, G.W., 1991).

Conan, C. G *et al.* (2003), came forward with a long-term hydrological modelling of the Upper Guadiana river basin (Spain). The ability of the model to represent the impact of groundwater withdrawals on the hydrological behaviour of the basin has been demonstrated, an analysis of alternative scenarios has demonstrated the usefulness of the model for decision-making and the relevance of growing vines under semi-arid conditions instead of high water consumption crops to reduce water demand.

Perotto Baldiviezo, H. L *et al.* (2003) studied about GIS- based spatial analysis and modeling for landslide hazard assessement in steep lands, southern Honduras. The objective of the study was to develop and test a heuristic approach for predicting spatial distribution of landslide hazard. Four variables: slope, aspect, stream proximity, and land cover type, generated from available topography and remote sensing data, were used in the model. Results of GIS analyses showed that the likelihood of landslide was significantly influenced by slope and land cover. As slope increased, the percentage of land affected by landslides, when the soils were saturated, increased sharply on land used for crop production, indicating that agricultural activity and the associated removal of deep-rooted permanent vegetation increased the landslide hazard on steep sites. Consequently, sites covered by shrub fallow and forests had relatively low incidence of landslides regardless of the topographic features. The model was effective in predicting landslide hazard and generating landslide hazard maps.

Pandey, V. K *et al.* (2005) conducted a study on modelling of an agricultural watershed using Remote Sensing and Geographic Information System. In this study, the Soil and Water Assessment Tool (SWAT2000) model was tested on daily, monthly and seasonal basis and applied to the Banikdih agricultural watershed, for the development of management scenarios for the prioritised sub-watersheds. Calibration and validation results revealed that the model was predicting the daily, monthly and seasonal surface runoff and sediment yield satisfactorily.

Srinivasan, R *et al.* (2005) conducted a study on effect of GIS data quality on small watershed stream flow and sediment simulations. Simulations of total runoff and fine sediment yield in Goodwin Creek watershed were carried out using a hydrological model-GIS system. The system includes Soil and Water Assessment Tool (SWAT) model version 2000 and AVSWAT version 1.0. The objective of the study was to assess the impact of GIS input variation on the uncalibrated water runoff and sediment yield outputs and compare them with the respective observed data. The implicated issues are significant wherever multiple choices of GIS input are available. Land use-land cover maps had a significant effect on both runoff and sediment yield prediction. Soil maps showed a limited influence on model results.

Selvi, V *et al.* (2006) studied about utilities and limitations of remote sensing and GIS applications in micro-watershed planning with an experience through the image map obtained on 1:12,500 scale of Kuruthukuli watershed in Kundah basin of the Nilgiris district, Tamil Nadu. The geocoded image was subjected to visual interpretation. Slope map was generated from SOI toposheets (1:50,000) in GIS environment (ARC/INFO) and other thematic maps on land use, soils and cropping patterns were prepared in GIS after field verification. On the basis of these thematic maps together with information obtained from field visits and Participatory Rural Appraisal (PRA) exercises, watershed management plan was prepared for KG-4-1 watershed. Crucial factors apart from land use categories, which are needed for land use planning, like irrigation status, cropping status and land management conditions could not be obtained from the image map of

KG-4-1 watershed processed at 1:12,500 scale. It was concluded that, GIS was an ideal system to support watershed planning which is an integrative process, especially with the help of topological overlays of different thematic layers.

Wu, K and Xu J. Y (2006) evaluated the applicability of the SWAT model for coastal watersheds of Amite, Tickfaw, and Tangipahoa River watersheds in southeastern Louisiana. The model was calibrated with daily discharge from 1976 to 1977 and validated from 1979 to 1999 for the Amite and Tangipahoa and with daily discharge from 1979 to 1989 for the Tickfaw. Deviation of mean discharge and the Nash-Sutcliffe model efficiency were used to evaluate model behaviour. The study found that Manning's roughness coefficient for the main channel, SCS curve number, and soil evaporation compensation factor were the most sensitive parameters for these coastal watersheds. The SWAT model demonstrated an excellent performance, with Nash-Sutcliffe efficiencies of 0.935, 0.940, and 0.960 for calibrations of the Amite, Tickfaw, and Tangipahoa watersheds, respectively, and of 0.851, 0.811, and 0.867 for validations. The modelling results demonstrated that SWAT is capable of simulating hydrologic processes for medium scale to large scale coastal lowland watersheds in Louisiana.

2.3 Application of SWAT in Watershed modelling

SWAT can be used to simulate a single watershed or a system of multiple hydrologically connected watersheds. Each watershed is first divided into subbasins and then into hydrologic response units (HRUs) based on the land use and soil distributions.

Srinivasan, R. S *et al.* (1998) prepared a hydrologic model of the United States watershed with the Soil and Water Assessment Tool. The paper describes the Hydrologic Unit Model for the United States (HUMUS): a decision support system designed for making national and river basin scale resource assessments. The HUMUS system was applied and validated against flow sediment at three scales.

Saleh, A *et al.* (2000) studied about application of SWAT for the Upper North Bosque River Watershed (UNBRW) of north central Texas. SWAT was validated for the baseline condition within UNBRW. The baseline condition within UNBRW was simulated from 1988 through 1996; model output was compared to flow, sediment, and nutrient measurements for 11 stream sites within the watershed for the period of October 1993 to July 1995 for SWAT model validation. The Nash-Sutcliffe coefficient evaluating model efficiency of SWAT for predicting average monthly flow, sediment, and nutrient loading over the validation period ranged from 0.65 to 0.99, indicating reasonable predicted values.

Spruill, C. A *et al.* (2000) simulated the daily and monthly stream discharge from small watersheds using the SWAT model. The Soil and Water Assessment Tool (SWAT) was evaluated and parameter sensitivities were determined while modelling daily stream flow in a small central Kentucky watershed over a two-year period. Stream flow data from 1996 were used to calibrate the model and stream flow data from 1995 were used for evaluation. The model adequately predicted the trends in daily stream flow during this period although Nash-Sutcliffe and r^2 values were –0.04 and 0.19 for 1995 and 1996, respectively. The model poorly predicted the timing of some peak flow values and recession rates during the last half of 1995. The Nash-Sutcliffe and r^2 for monthly total flows was 0.58 for 1995 and 0.89 for 1996. The parameters included drainage area, slope length, channel length, saturated hydraulic conductivity, and available water capacity. Overall, the results indicated that the SWAT model can be an effective tool for describing monthly runoff from small watersheds in central Kentucky.

Kamble, A. M (2003) made a study on estimation of sediment yield from Baronda micro watershed in Chattisgarh using SWAT model, and was tested on daily and monthly basis. The model was calibrated and validated for the monsoon season of the years 1994 and 1995 using observed daily rainfall and temperature data for the respective years. The Mannings roughness coefficient values for both channel and overland flow were calibrated for the study. Graphical and statistical methods of tests revealed that the observed and simulated daily and monthly sediment yield for the calibration period have been matched quite well that validation results have indicated that the magnitude and temporal variation of simulated sediment yield matched closely with observed sediment yield.

Van Liew, M. W. and Garbrecht, J (2003) studied about hydrologic simulation of the Little Washita River experimental watershed using SWAT. Precipitation and stream flow data from three nested sub watersheds within the watershed in southwestern Oklahoma were used to evaluate the capabilities of the Soil and Water Assessment Tool (SWAT) to predict stream flow under varying climatic conditions. Eight years of precipitation and stream flow data were used to calibrate parameters in the model, and 15 years of data were used for model validation. Calibration of the model involved a multistep approach. A preliminary calibration was conducted to estimate model parameters so that measured versus simulated yearly and monthly runoff were in agreement for the respective calibration periods. Calibration on a daily basis resulted in higher base flows and lower peak runoff rates than were obtained in the preliminary calibration. Test results showed that once the model was calibrated for wet climatic conditions, it did a good job in predicting stream flow responses over wet, average, and dry climatic conditions selected for model validation. Monthly coefficients of efficiencies were 0.65, 0.86, and 0.45 for the dry, average, and wet validation periods, respectively.

Bosch, D. D *et al.* (2004) evaluated the SWAT model on a coastal plain agricultural watershed. Comparisons were made between water balance results obtained using high and low spatial resolution data as well as those obtained using default initial parameters versus those modified for existing groundwater conditions. In general, all scenarios simulated general trends in the observed flow data. However, for the years with lower precipitation, the total water yields simulated with the low spatial resolution data and the default initial conditions were over predicted by up to 27% of the annual precipitation input.

Huang, Q and Zhang, W (2004) explained about the application of GIS-based distributed SWAT hydrological modelling on high altitude, cold, semi-arid catchments of Heihe river basin, China. Corresponding to different topography, soil types, and land use/cover classifications over the 10009 km^2 catchments, SWAT-GIS delineated the watershed based on 120m resolution DEM into 157 simulation sub watersheds, each watershed was thought a unique Hydrological Response Unit (HRU). Numerical experimental simulations on the catchments suggested that the shallow storage recession factor (base flow recession factor), the altitudinal range discrimination was very essential for the simulation of base flow and snow-melting process. Through adjustment of the parameterization, satisfied simulation results were obtained with the accuracy of 0.88 for Nash-Sutcliffe coefficient, 0.91 for correlation coefficient over the 11 years continuous simulations on monthly discharges.

Bouraoui, F *et al.* (2005) explained about the application of the SWAT model on the Medjerda river basin (Tunisia) to study the potential impact of land management scenarios. The model was able to represent the hydrological cycle even though some discrepancies were observed, probably due to a lack of sufficient rainfall data, and due to the lack of representation of reservoirs. It was predicted that converting all agricultural land to irrigated crop introduced significant changes on nitrate concentration in surface water. It was also predicted that drastic reduction in the load of ammonium and phosphorus could be achieved by collecting and treating wastewater from major urban areas.

Jayakrishnan, R *et al.* (2005) conducted a study about advances in the application of the SWAT model for water resources management. The paper describes some recent advances made in the application of SWAT and the SWAT-GIS interface for water resources management. Four case studies were presented. The study demonstrated the usefulness of radar rainfall data in distributed hydrologic studies and the potential of SWAT for application in flood analysis and prediction.

Lisbeth Adalid Urribarri Molina (2005) demonstrated about the validation of the SWAT hydrologic model with Arc View interphase in the Chama river high basin, State Merida, Venezuela. The main purpose of the research was to verify the model behaviour, in relation to the water production and hydric system. A seven-year period (1980-1986) was employed to perform this simulation, in order to achieve simulated flows and compare them with the observed data at Ejido. The SWAT model (version 2000) was tested together with the AVSWAT interface and the results were compiled. Therefore, the validation of this model was meaningful, complying with the established hypothesis.

Qi, C and Grunwald, S (2005) studied about GIS-based hydrologic modelling in the Sandusky watershed using SWAT. The objective was to conduct a spatially distributed calibration and validation of water flow using the Soil and Water Assessment

Tool (SWAT). They used measured stream flow data obtained from U.S. Geological Survey (USGS) gauge stations from water years 1998 and 1999 for calibration and from water years 2000 and 2001 for validation. The surface water simulations at all monitoring stations were better than the groundwater simulations. Overall, simulations of water flow in the Sandusky watershed and sub watersheds were satisfactory except for winter rainfall-runoff events. The study showed the importance of spatially distributed calibration and validation.

Santhi, C *et al.* (2005) conducted a study on the GIS-based regional planning tool for irrigation demand assessment and savings using SWAT. The objective of the study was to improve the capabilities of a basin-scale hydrologic simulation model for regional planning of irrigated agriculture. In this study, a Geographical Information System (GIS) based hydrological model, Soil and Water Assessment Tool (SWAT), was configured as a regional planning tool with a canal irrigation capability for estimating irrigation demand. The tool was capable of simulating hydrological processes associated with soil-plant-water interactions and capable of capturing the spatial and temporal variability of the major factors, which were important in regional planning. It was validated for crop evapotranspiration and canal conveyance efficiency and applied to analyzing the demand and potential water savings of alternative water conservation measures. Results indicated that on-farm management measures might be as beneficial as improving canal conveyance systems.

Kannan, N *et al.* (2006) conducted a study on hydrological modelling of a small catchment using SWAT-2000 for ensuring correct flow partitioning for contaminant modelling. The performance of the SWAT-2000 model was evaluated using stream flow at the outlet of Colworth catchment (Bedfordshire, UK). Initial results from SWAT-2000 identified some necessary modifications in the model source code for correct simulation of processes driving water balance. After modification of the code, hydrological simulation, crop growth and evapotranspiration (ET) patterns were realistic when compared with empirical data. Acceptable model performance was obtained in final model runs, with reasonable runoff partitioning into overland flow, tile drainage and base flow.

Mishra, A *et al.* (2006) evaluated the SWAT model for assessing sediment control structures in a small watershed in India. The Soil and Water Assessment Tool (SWAT) model was used to assess sediment transport from Banha watershed located in Jharkhand. Calibration (1996) and validation (1997-2001) of surface runoff and sediment yield were performed with SWAT on both a daily and monthly basis by comparing model estimates versus measured data. The calibration r^2 and Nash-Sutcliffe modelling efficiency (NSE) statistics were found to range between 0.70 to 0.99 for surface runoff and 0.82 to 0.98 for sediment loss. The corresponding validation period statistics ranged from 0.60 to 0.92 for surface runoff and 0.58 to 0.89 for sediment loss. Following calibration and validation, the SWAT model was executed with and without check dams to test its capability in visualizing the impacts of sediment control structures in the watershed. The model estimates showed that sediment loss from the watershed could be reduced more than 64% by adopting check dams as a barrier for sediment. The results also revealed the potential for using SWAT to assess sediment transport from specific sub watersheds within a watershed and to prioritize the silting of sediment control structures within a watershed to obtain the most effective reduction of sediment losses to surface water.

Schuol, J and Abbaspour, K. C (2006) conducted a study using monthly weather statistics to generate daily data in a SWAT model application to West Africa. In this study they developed a daily weather generator algorithm (dGen) that uses the currently available 0.5° monthly weather statistics from the Climatic Research Unit (CRU). They tested dGen in two ways. Firstly, a direct comparison of the measured and generated precipitation and maximum–minimum temperatures was done by looking at some long term statistics in a few stations in West Africa. Secondly, “Soil and Water Assessment Tool” (SWAT) with dGen-generated and measured daily weather data was run to simulate 25 years of annual and monthly river discharges at some gauging stations. The simulated river discharges were then compared with the measured ones. It was seen that using the dGen-simulated daily weather data resulted in a much better match with the measured discharge data than the measured daily weather data in combination with the SWAT internal weather generator WXGEN. WXGEN is used in SWAT to fill missing data using monthly statistics, which must be calculated from the existing daily data.

Gassman, P. W *et al.* (2007) conducted a study on the Soil and Water Assessment Tool, its historical development, applications, and future research directions. The Soil and Water Assessment Tool (SWAT) model is a continuation of nearly 30 years of modelling efforts conducted by the USDA Agricultural Research Service (ARS). Most of the important works done in this regard according to relevant application categories are such as stream flow calibration and related hydrologic analyses, climate change impacts on hydrology, pollutant load assessments, comparisons with other models, and sensitivity analyses and calibration techniques.

Jha, M. K *et al.* (2007) studied about water quality modelling for the Raccoon River watershed using SWAT. An integrated modelling framework had been constructed for Raccoon River watershed that consists of the SWAT (Soil and Water Assessment Tool) model, the interactive SWAT (i_SWAT) software package, the Load Estimator (LOADEST) computer program, and other supporting software and databases. The study presented the calibration and validation of SWAT for the stream flow, sediment losses, and nutrient loadings in the watershed, and an assessment of land use and management practice shifts in controlling pollution. Stream flow, sediment yield and nitrate loadings were calibrated for the period 1981-1992 and validated for the period 1993-2003. A set of land use change scenarios depicting conversion of cropland into land set-aside resulted in large reductions of sediment yield at the watershed outlet.

Karim, C *et al.* (2007) undertook a study on hydrologic modelling and water quality in the pre-alpine/alpine Thur watershed using SWAT. The program SWAT (Soil and Water Assessment Tool) was used to simulate all related processes affecting water quantity, sediment, and nutrient loads in the catchment. The main objectives were to test the performance of SWAT and the feasibility of using this model as a simulator of flow and transport processes at a watershed scale. Two measures were used to assess the goodness of calibration: (1) the percentage of data bracketed by the 95% prediction uncertainty calculated at the 2.5 and 97.5 percentiles of the cumulative distribution of the simulated variables, and (2) the d-factor, which is the ratio of the average distance between the above percentiles and the standard deviation of the corresponding measured variable. These statistics showed excellent results for discharge and nitrate and quite good results for sediment and total phosphorous.

Nam Won Kilm *et al.* (2007) studied on the development and application of the integrated SWAT-MODFLOW model. In this paper, a method was proposed whereby the characteristics of the hydrologic response units (HRU's) in the SWAT model were exchanged with cells in the MODFLOW model. By using this HRU–cell conversion interface, the distributed groundwater recharge rate and the groundwater evapotranspiration was effectively simulated. By considering the interaction between the stream network and the aquifer to reflect boundary flow, the linkage was completed. For this purpose, the RIVER package in the MODFLOW model was used for river– aquifer interaction. This combined modeling was applied to the Musimcheon Basin in Korea. The application demonstrated that an integrated SWAT–MODFLOW was capable of simulating a spatio-temporal distribution of groundwater recharge rates, aquifer evapotranspiration and groundwater levels. It also enabled an interaction between the saturated aquifer and channel reaches. This interaction played an important role in the generation of groundwater discharge in the basin, especially during the low flow period.

Sudheer, K. P *et al.* (2007) assessed the impact of time-scale of the calibration objective function on the performance of watershed models. The major objective of the study was to evaluate the impact of the calibration time-scale on model predictive ability. The study considered the Soil and Water Assessment Tool for the analysis, and it was calibrated at two time-scales, viz. monthly and daily for the War Eagle Creek watershed in the USA. The results demonstrated that the model's performance at the smaller time-scale (such as daily) could not be ensured by calibrating them at a larger time-scale (such as monthly). The results implied that evaluation of models should be conducted considering their behaviour in various aspects of simulation, such as predictive uncertainty, hydrograph characteristics, ability to preserve statistical properties of the historic flow series, etc.

Wu, K and Johnston, C. A (2007) conducted a study about the hydrologic comparison between a forested and a wetland/lake dominated watershed using SWAT. The objective of the study was to determine the applicability of SWAT for modelling stream flow in two watersheds of the Ontonagon River basin of northern Michigan. Model calibration and validation were satisfactory, as determined by deviation of discharge D and Nash-Sutcliffe coefficient values E that compared simulated monthly mean discharge versus measured monthly mean discharge. Differences in seasonal pattern of long term monthly stream flow were found, with the forest-dominated watershed having a higher peak flow during April but a lower flow during the remainder of the year in comparison to the wetland and lake-dominated watershed. The results suggested that a greater proportion of wetland and lake area increases the capacity of a watershed to impound surface runoff and to delay storm and snow melting events.

Alejandra Stehr *et al.* (2008) studied about the hydrologic modelling with SWAT under conditions of limited data availability. The work presented attempts to set the basis for future modelling applications within the Biobío basin by analysing the applicability of a readily available modelling tool, the SWAT model, to one of its sub-basins. Modelling results showed that the model performed well in most parts of the study basin. The SWAT model application for the Vergara basin confirmed that SWAT was a useful tool and already ensured to make a preliminary assessment of the potential impacts of land-use and climate changes on basin hydrology.

Immerzeel, W. W *et al*. (2008) studied on integrating remote sensing and a process-based hydrological model to evaluate water use and productivity in a south Indian catchment. Water use and crop water productivity were assessed in the Upper Bhima catchment in southern India using an innovative integration of remotely sensed evapotranspiration and a process-based hydrological model .This dataset was then used in the calibration of the Soil and Water Assessment Tool (SWAT). This hydrological model was calibrated by changing 34 parameters to minimize the difference between simulated and observed actual evapotranspiration. It was found that evapotranspiration is the largest water loss in the catchment.

Pandey, V.K., *et al.* (2008) evaluated an effective management plan for an agricultural watershed using AVSWAT model, remote sensing and GIS. Effort was made to identify the critical sub-watersheds for the development of best management plan for a small watershed of Eastern India. A total of 180 combinations of various management treatments including crops (rice, maize ground nut and soybean), tillage (zero, conservation, field cultivator, mould board plough and conventional practices) and fertilizer levels (existing half of recommended and recommended) were evaluated. The investigation revealed that rice cannot be replaced by other crops such as groundnut, maize, mungbean, sorghum and soybean since comparatively these crops resulted in higher sediment yield. Sediment yield decreased in the case of zero tillage, conservation tillage, field cultivator, moldboard plough, and conservation tillage as compared to conventional tillage. It can be concluded that the sediment yield was found to be the highest in the case of disk plough followed by moldboard plough, field cultivator, conventional tillage, field cultivator and least in zero tillage practices.

Rossi, C. G *et al.* (2008) came forward with the hydrologic calibration and validation of the Soil and Water Assessment Tool for the Leon River watershed. The 2005 version of SWAT (SWAT2005) was calibrated and verified using hydrologic data from the watershed. Runoff was simulated well ($0.65 < \text{ENS} \leq 0.75$ [good]) to very well ($\text{ENS} > 0.75$ [very good]) based on the Nash-Sutcliffe efficiency (ENS) value. Average stream flow simulations agreed well with observed values during the calibration phase ($\text{PBIAS} < \pm 10$ [very good]), but the validation period agreement ($\text{PBIAS} \geq \pm 25$ [unsatisfactory]) was less than desired because one of the five validated stream gauges fell into the unsatisfactory range.

Wang, X *et al.* (2008) studied about using the hydrologic equivalent wetland concept within SWAT to estimate stream flow in watersheds with numerous wetlands. The objectives of the study were to demonstrate how to incorporate wetlands into a SWAT model using a “hydrologic equivalent wetland” (HEW) concept and to use the SWAT model to simulate the stream flows in the Otter Tail River watershed in northwestern Minnesota. The SWAT model incorporating the HEW assumption had an acceptable or satisfactory performance in simulating the stream flows for an evaluation period from 1 December 1969 to 31 May 1975 at daily, monthly, seasonal, and annual time steps ($\text{Ej } 2 > 0.36$, $\text{PVk} > 0.75$). The study indicated that the HEW concept was superior in incorporating wetlands into SWAT for the study area.

Wang, X *et al.* (2008) studied about the simulation of an agricultural watershed using an improved curve number method in SWAT. The objectives of this study were to propose a modified curve number (MCN) method and to assess the MCN method relative to the existing SWAT method with an Ia/S value either equal to 0.2 or 0.05. A SWAT model implementing the MCN method was evaluated along with the models implementing the existing SWAT method with Ia/S values of 0.2 and 0.05. The evaluation was conducted in the Forest River watershed located in northeastern North Dakota. The results revealed that the total stream flows predicted by the three models were comparable. However, the MCN approach resulted in the most accurate prediction of the stream flow components (i.e., base flow versus direct flow) as well as water yields.

Yanchun Gao and Di Long (2008) studied about the intercomparison of remote sensing-based models for estimation of evapotranspiration and accuracy assessment based on SWAT. An intercomparison of daily actual evapotranspiration (ET) estimated from the single-source models (SEBAL and SEBS) and the two-source models (P-TSEB and S-TSEB) using remotely sensed data was performed. The ET estimates from the two methodologies were shown to be comparable, indicating that S-TSEB had the highest accuracy with relative errors of 2±2% and 5 ±6% with reference to SWAT-based ET. The performance of P-TSEB largely depended on the meteorological and underlying surface conditions, both exerting significant influences on the extent of coupling between vegetation and soil.

MATERIALS & METHODS

Chapter III

MATERIALS AND METHODS

3.1 Study Area

Kadalundi riverbasin of Kadalundi River has been selected for the study. It lies mainly in Malappuram district of Kerala. Latitude/ Longitude range of the basin is 10°56' to 11°11' North Latitude and 75°49' to 76°25' East Longitude.

Total geographic area of the watershed is 804 km^2. Topography varies from moderately sloping to steep sloping and the elevation ranges from 6m to1500m. Climate is humid tropic. Major soil series of the area are Vijayapuram, Pallippadi, Chelikkiuzhi, Anayadi and Pullangod. Important vegetations of the area comprise coconut, arecanut, rubber, paddy and forest.

3.2 Base Maps and Softwares used

1. Toposheets from Survey of India (SOI) bearing numbers 49 M/16, 49 N/13, 58 A/8, 58 B/1 and 58 B/5 prepared in 1: 50000 scale.
2. Soil map of National Bureau of Soil Survey and Land Use Planning (NBSS & LUP) prepared in 1:500000 scale.
3. Daily rainfall and temperature data from the Meteorological Observatory of Cashew Research Station, Anakayam.

- ILWIS 3.3 developed by ITC, Netherlands for the generation of GIS maps and attribute data.
- SWAT Watershed model developed by USDA ARS.

3.3 Preparation of thematic layers in GIS

3.3.1 Drainage Map

Drainage network of the study area is digitized from the concerned toposheets of the study area using on screen digitization capability of the ILWIS software. Segment map of drainage network was prepared. Universal Transverse Mercator (UTM) projections corresponding to zone 43 was used as the coordinate system for all the thematic maps. Drainage map of the Kadalundi watershed is shown in the Fig.3.1.

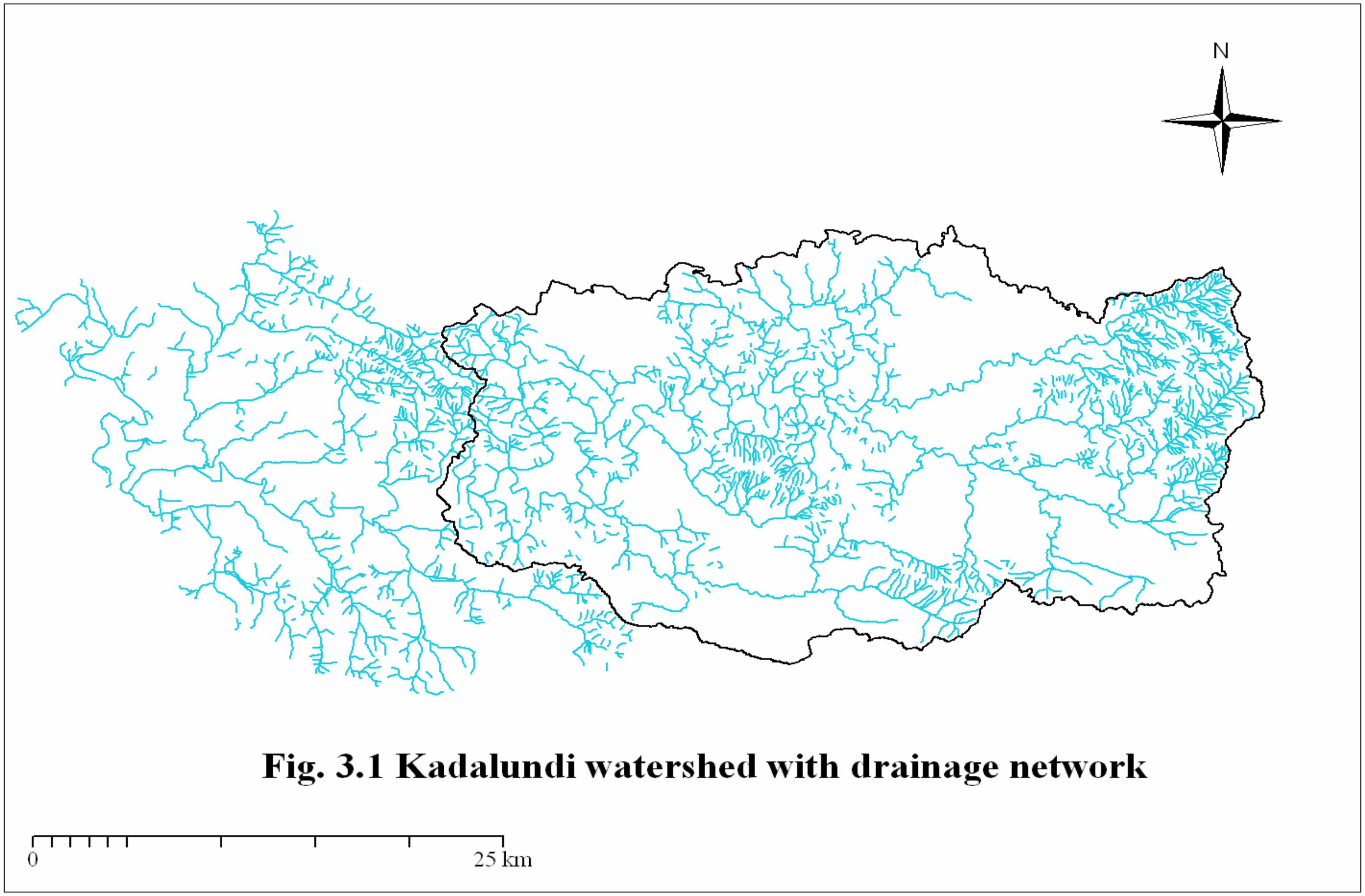


Fig. 3.1 Kadalundi watershed with drainage network

3.3.2 Digital Elevation Model (DEM)

Contour lines given in the toposheets were digitised to get the contour map for the study area. While digitising the contours, the contour lines lying at the outer premises of the river basin boundary were also included to make the interpolation of the contour values possible at the time of DEM generation. Corrections were applied to remove the errors caused due to self overlap, dead ends and intersections. After the error corrections, the segment contour map was rasterised using the segment to raster feature of ILWIS.

Next to this, a point elevation map was prepared for the entire study area. The point elevation data given in the toposheet was used to obtain the point map. The point map was then rasterised to get a raster point map. Using the raster contour segment map and raster point map DEM was prepared by giving the appropriate map calculation formula.

3.3.3 Soil Map

An analog soil map collected from NBSSC was scanned and the digital map was imported to ILWIS environment using the "File- import" option of the software. Then the boundaries of the different soil group of the map were digitized and a segment soil map was generated. A point map was then prepared giving labels to individual soil types. Using the segment soil maps and the label points, a polygon map of the soil was prepared.

3.3.4 Landuse Map

The land use map was prepared from satellite imagery of IRS 1C, LISS-III collected. A False Colour Composite (FCC) of the imagery was made in ILWIS and it was georeferenced. A sample set for the supervised classification of the imagery was prepared. The sample set was classified to get the land use map. Extensive ground truthing were carried out to verify the result of supervised classification. GPS was used in the field survey.

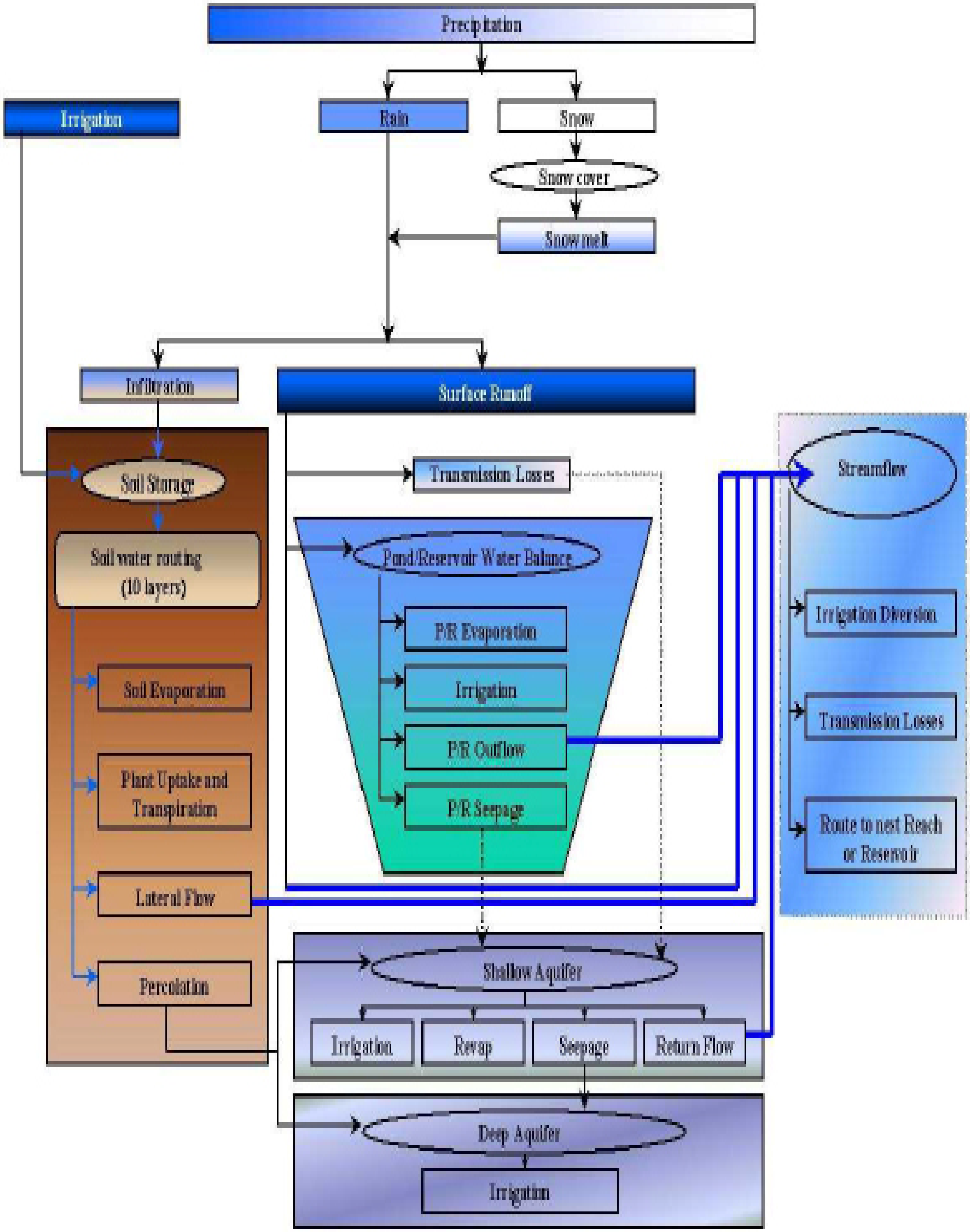


Fig. 3.2. The flow chart showing the pathway available for water movement in SWAT

3.4 SWAT themes and attributes

The following themes and attributes were used in the building of SWAT for the study area.

3.4.1 ArcInfo-ArcView GRID—Digital Elevation Model (DEM)

The interface allows the DEM to use integer or real numbers for elevation values. The units used to define the map resolution and the elevations are not required to be identical. The DEM prepared in ILWIS was exported to ArcView grid format

3.4.2 ArcInfo-ArcView GRID or Shape—Land Cover/Land Use

The category specified in the land cover/land use map prepared in ILWIS has been reclassified into SWAT land cover/plant types. The reclassification is done by creating a look up table that identifies the 4-letter SWAT code for the different categories of land cover/land use on the map. The land use look up table is used to specify the SWAT land cover/plant code or SWAT urban land type code to be modeled for each category in the land use map grid. This table is formatted as a dBase table. The first row of the land use look up table must contain the field names. The remaining rows will hold the required data.

Field name	Field format	Definition
VALUE	String	Number of map category
LANDUSE	String 4 chars	Corresponding SWAT land use or urban code

3.4.3 ArcInfo-ArcView GRID or Shape—Soil

The soil map prepared in the ILWIS was converted to Arc View format. A soil look up table is prepared and it is used to specify the type of soil to be modeled for each category in the soil map grid. The first row of the soil look up table must contain the field names. The remaining rows will hold the required data.

Field name	Field format	Definition
VALUE	String	Number of map category
NAME	String(30 chars max)	Name of the soil. The name entered into this field must correspond with the name of the soil in the user soils database

3.4.4 Precipitation Gauge Location Table (dBASE)

The precipitation gauge location table is used to specify the location of rain gauges. The table format is given below.

Field name	Field format	Definition
ID	Integer	Gauge identification number
NAME	String max 8 char	Corresponding table name string
XPR	Floating point	X coordinate in the defined projection
YPR	Floating point	Y coordinate in the defined projection
ELEVATION	Integer	Elevation of rain gage (m)

3.4.5 Precipitation Data Table (dBASE)

The precipitation data table is used to store the daily precipitation for an individual rain gauge. This table is required if the rain gauge option is chosen for rainfall in the weather data dialog box. There will be one precipitation data table for every location listed in the rain gauge location table. The name of the precipitation data table is "name.dbf" or “name.txt” where name is the character string entered for NAME in the rain gauge location table. This table is formatted as a dBase table.

Field name	Field format	Definition
DATE	Date(yyyymmdd)	Day of precipitation
PCP	Floating point(f5.1)	Amount of precipitation(mm)

3.4.6 Temperature Data Table (dBASE)

The temperature data table is used to store the daily maximum and minimum temperatures for a weather station. This table is required if the climate station option is chosen for temperature in the weather data dialog box. The name of the temperature data table is "name.dbf" or “name.txt” where name is the character string entered for NAME in the temperature gauge location table. This table is formatted as a dBase table.

Field name	Field format	Definition
DATE	Date(yyyymmdd)	Day of measure
MAX	Floating point(f5.1)	Daily maximum temperature (°C)
MIN	Floating point(f5.1)	Daily minimum temperature (°C)

3.5 SWAT Model Building

3.5.1 Watershed Delineation

The watershed delineation carries out advanced GIS functions to aid in segmenting watersheds into several hydrologically connected sub-watersheds for use in watershed modeling. The delineation process requires a Digital Elevation Model (DEM) in ArcInfo grid format.

Key Procedures involved are:

1. The DEM is first loaded to the Arc-View - SWAT interface.
2. The digitized stream network is then loaded for the delineation to be accurate.
3. Preprocessing of the DEM is then done.
4. The minimum sub-watershed area (critical source area) is then specified.
5. The stream network points are then reviewed and edited.
6. The calculation of the subbasin parameters are then done in SWAT.

3.5.2 Land Use/Soil Characterization

Land Use and Soil Characterization for a watershed are performed using two commands in the AVSWAT menu of the Watershed View. This tool allows loading land use and soil themes into the current project and determines the land use/soil class combinations and distributions for the delineated watershed and each respective sub-watershed. The themes can be either grid or shape format.

Once the land use and soil themes have been imported and linked to the SWAT databases, the criteria are specified to determine the HRU distribution.

Key Procedures involved for land use/ soil overlay are:

1. The land use theme is defined.
2. The land use theme is then reclassified.
3. Similarly, the soil theme is also defined and reclassified.
4. The land use and soil themes are then overlaid.

3.5.3 HRU Distribution

Once the land use and soil data layers have been imported, the distribution of hydrologic response units (HRU's) within the watershed is determined. One or more unique land use/soil combinations (hydrologic response units or HRU's) can be created for each sub basin. Subdividing the watershed into areas having unique land use and soil combinations enables the model to reflect differences in evapotranspiration and other hydrologic conditions for different land covers/crops and soils. Runoff is predicted separately for each HRU and routed to obtain the total runoff for the watershed. This increases the accuracy of load predictions and provides a much better physical description of the water balance. It involves selecting multiple HRU's per sub watershed. Then for these multiple HRU's, the land use and soil threshold levels are defined.

3.5.4 Weather Data Import

Weather data to be used in a watershed simulation is imported once the HRU distribution has been defined. Weather station locations are loaded into the current project and weather data namely, rainfall and temperature data's of the sub-watersheds are assigned. A -99.0 value is given to fill in skipped daily data and to fill in measured climate records so that all records have the same starting and ending date. The starting date used for measured climate data is the earliest starting date listed in the record while the ending date is the latest ending date listed in the record. The –99.0 value is used to call the weather generator to generate a value to replace the missing data during run time. Other data's like wind speed, solar radiation and relative humidity data's are successfully simulated accordingly.

3.5.5 Creation of Input

The items contained in the Input menu allow one to build database files containing the information needed to generate default input for SWAT. Several commands are listed on the Input menu. These commands are enabled in sequence (the next command is enabled only after the steps associated with the previous command are completed) and need to be processed only once for a project. When all of the default inputs have been generated, the SWAT can be simulated and is made to run.

3.5.6 SWAT Output

The Simulation menu allows finalizing the set up of input for the SWAT model and run the SWAT model; it reads the results of the simulation and builds dBASE tables and applies a calibration tool and performs load calculations. Only the ASCII output files in spreadsheet format are loaded into dBASE tables.

Some of the SWAT output files viewed in the study includes Sub basin Output File (.sub) and Main Channel Output File (.rch).

3.5.7 SWAT Calibration

The model built for the study area was calibrated using the observed daily river flow collected from Central Water Commission for the period from year 1996 to 2004. The calibration was done on annual, monthly and ten daily basis. The efficiency of simulation before and after calibration was tested by Nash Sutcliffe efficiency and Coefficient of Determination.

RESULTS & DISCUSSION

Chapter IV
RESULTS AND DISCUSSION

4.1 Digital Elevation Model (DEM)

A Digital Elevation Model of Kadalundi sub-basin of Kadalundi river is prepared with a resolution of 25 m. The DEM has been classified for different elevation ranges and the classified map showing different elevation ranges are shown in Fig. 4.1. Elevation ranges from 6m to 1500m with average elevation at 109.362m. The classified map shows that 26% of the total area is below 45m elevation; 60 % is between 50m and 200m and 8.6 % is between 200m and 1000m and 0.74 % is between 1000m and 1500m.

Table 4.1 Physical Properties of Different Soil Series

SL. NO.	SOIL SERIES	CLAY (%)	SILT (%)	SAND (%)	SOL_CBN (%)	SOL_AWC (mm)	AREA (ha)
1.	Anayadi	27.8	8.5	63.7	0.89	103.7	7486.06
2.	Chelikkuzhi	33.7	8.0	58.3	2.18	105.2	18932.03
3.	Pallippadi	27.0	9.0	64.0	0.99	93.9	3738.17
4.	Pullangod	35.0	13.5	51.5	2.16	71.9	5631.17
5.	Vijayapuram	24.7	9.5	65.8	1.01	58.8	44678.27

Table 4.2 Area under Different Landuses

SL.NO.	LANDUSE	AREA (ha)
1.	Water(WATR)	300.78
2.	Forest-deciduous(FRSD)	4413.98
3.	Forest –evergreen(FRSE)	6131.04
4.	Rice(RICE)	28043.56
5.	Orchard(ORCD)	41576.32

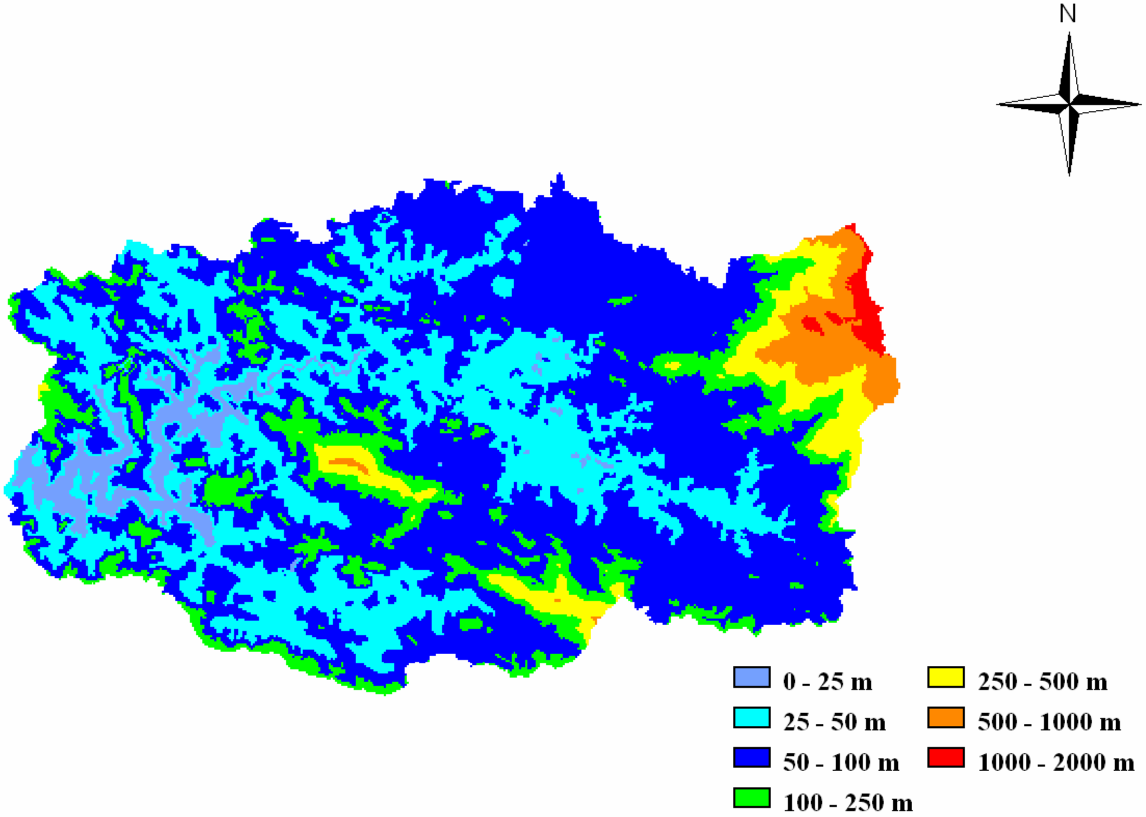


Fig.4.1 Classified DEM of kadalundi river basin

4.2 Model Simulation and Calibration

SWAT model has been simulated and calibrated on annual and monthly basis and the model gives very promising results. The watershed has been divided into 25 sub basins and a total of 84 HRU's has been identified. It is shown in Fig. 4.2. The soil map of the Kadalundi watershed was prepared as shown in the Fig. 4.3. The various soil series are marked in the map. The Landuse map of the Kadalundi watershed is also shown in Fig.4.4 indicating all the landuses classified in the watershed.

Twelve years (1996-2007) daily rainfall and river flow have been used in the model calibration. Annual Average river flow for the period 1998 to 2005 simulated by the precalibrated model is shown in Fig. 4.5. The time series curve for annual simulation and their respective Nash Sutcliffe efficiency and Coefficient of Determination is shown in the Fig 4.6 and Table 4.3, respectively. Time series curve shows close resemblance for the simulated and observed river flow. Nash Sutcliffe efficiency values are -0.23 and -0.83 for the pre and post calibrated periods, respectively. The results suggest that the model can well be used to predict the average annual discharge values.

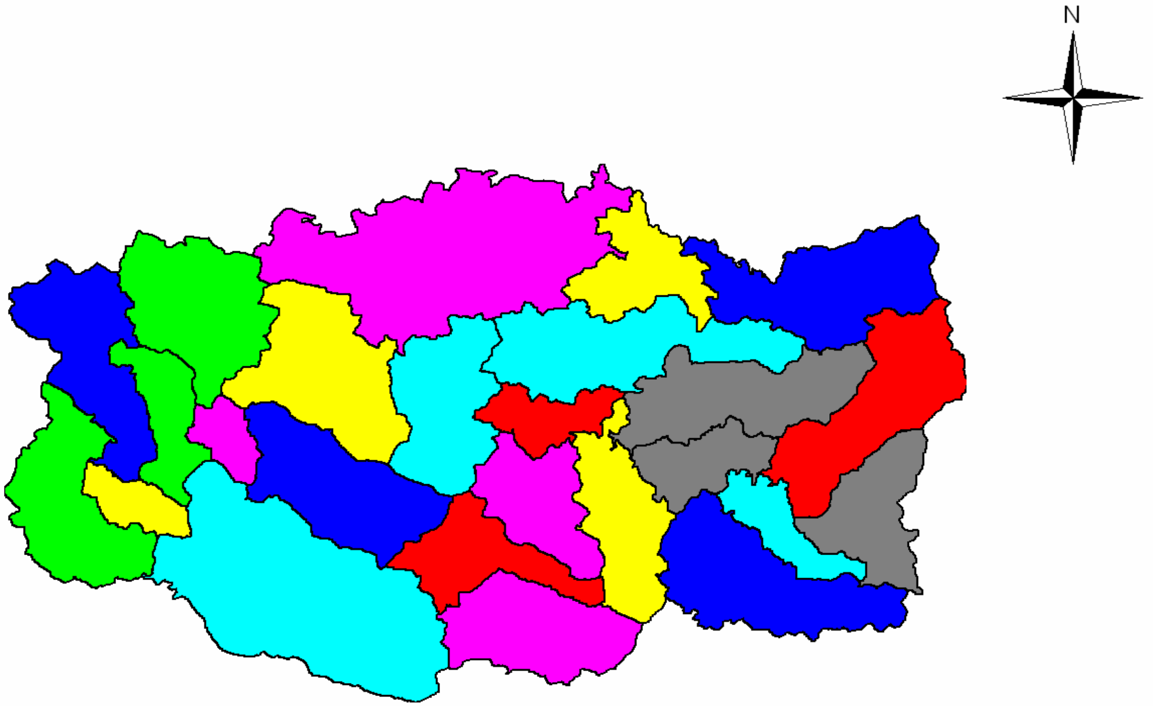


Fig.4.2. Kadalundi Watershed with sub basins

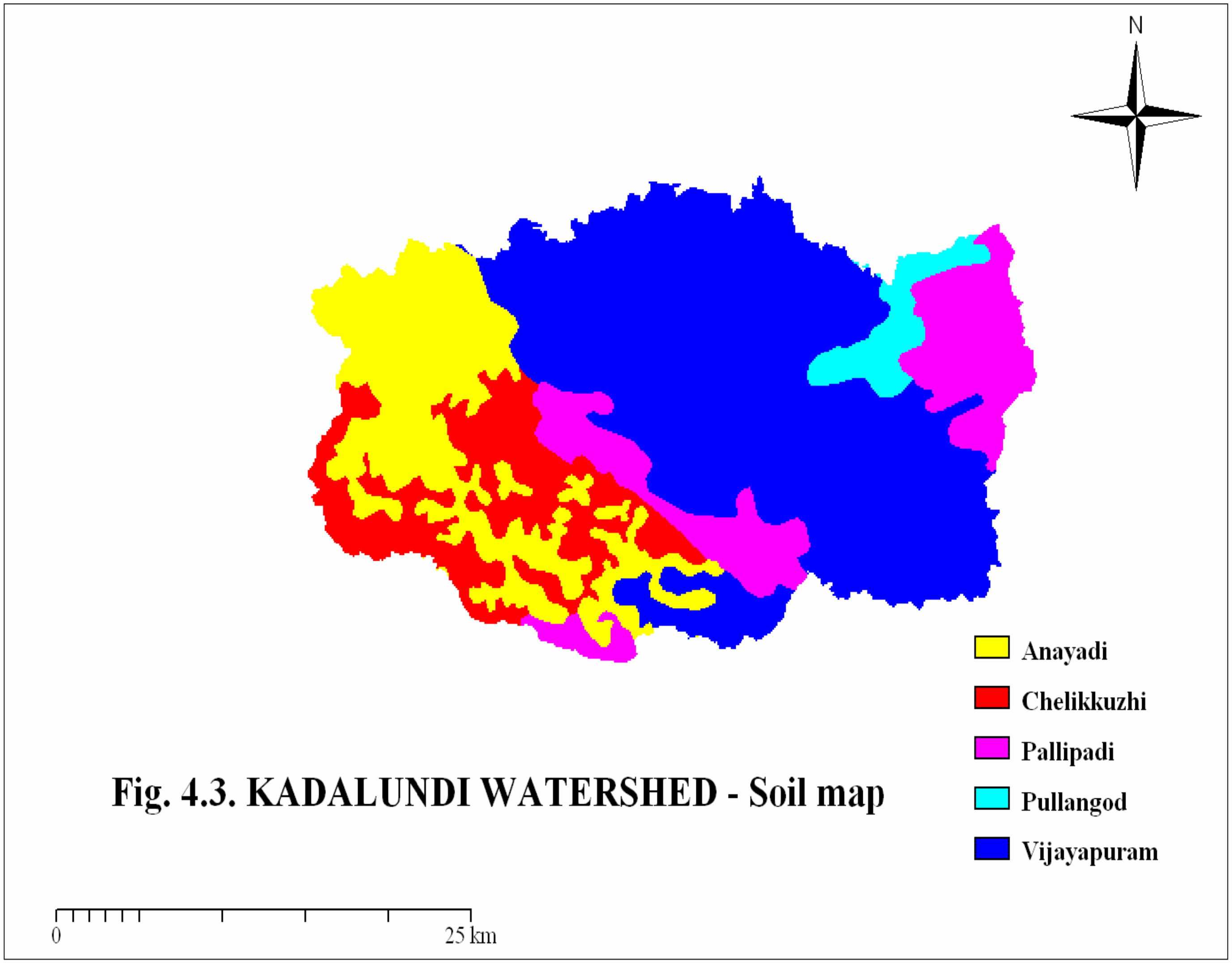


Fig. 4.3. KADALUNDI WATERSHED - Soil map

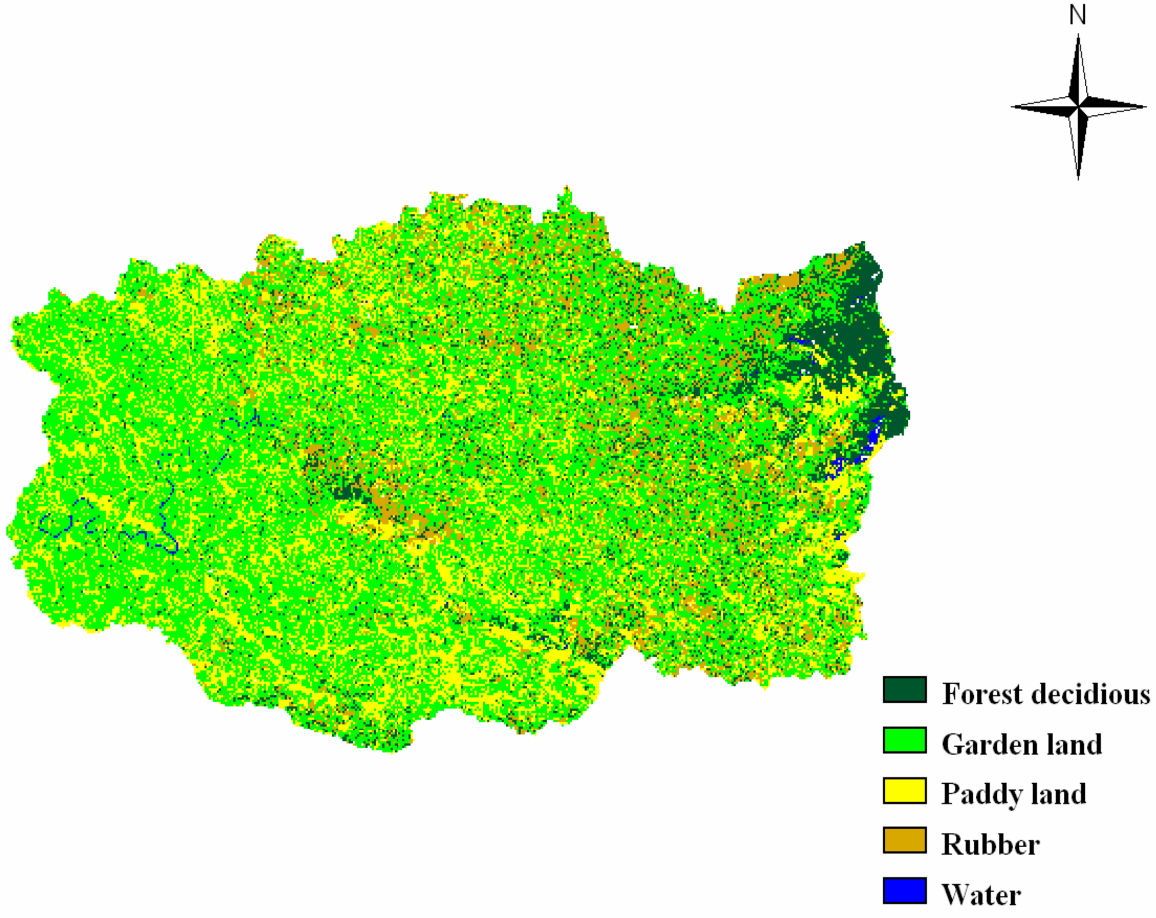


Fig. 4.4. KADALUNDI WATERSHED - Landuse map

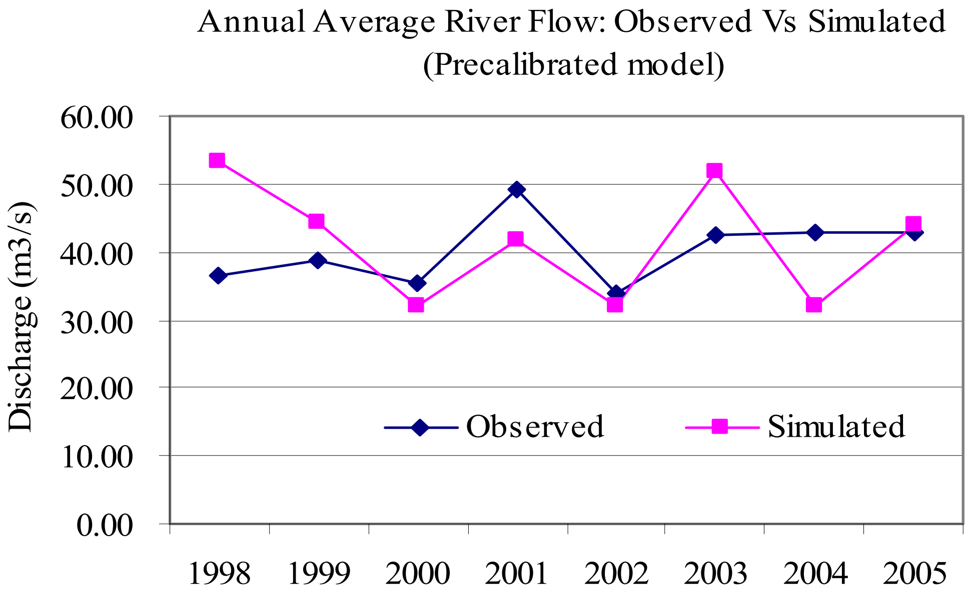


Fig. 4.5. Annual Average river flow- Observed Vs Simulated by the Precalibrated model

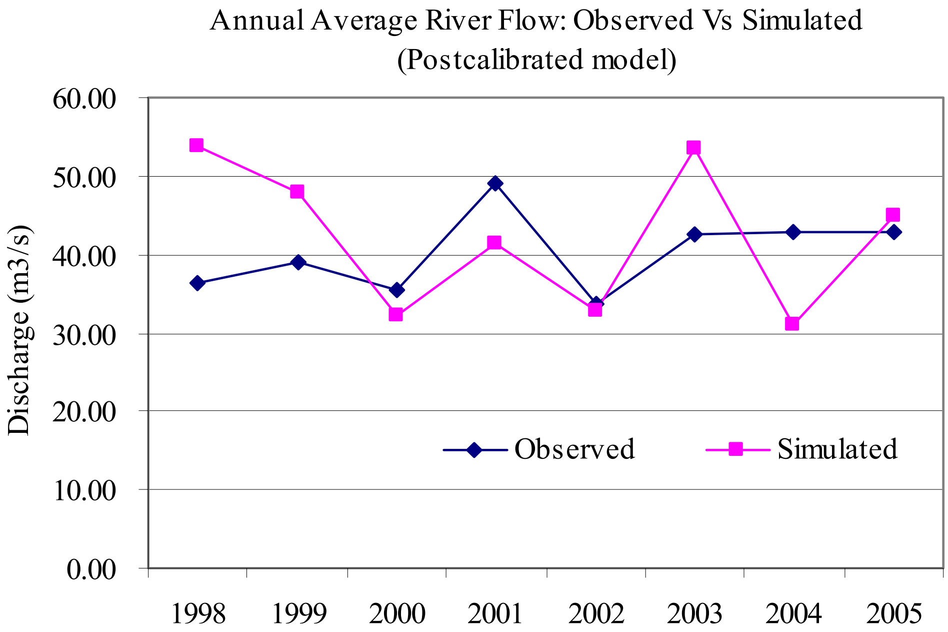


Fig. 4.6. Annual Average river flow- Observed Vs Simulated by the Postcalibrated model

Table 4.3 Descriptive Statistics of Average Annual River Flow

Statistics	Precalibrated model		Postcalibrated model	
	Observed flow (m3/s)	Simulated flow(m3/s)	Observed flow (m3/s)	Simulated flow(m3/s)
Mean	39.96	40.37	39.96	41.56
SD	9.64	6.60	9.64	6.60
Nash Sutcliffe Efficiency		-0.23		-0.83
Coefficient of Determination		0.10		0.10

The observed and simulated values of Monthly Average River flow for precalibrated and postcalibrated model is shown in Fig. 4.7 to 4.10 and the respective statistics in Table 4.4. It is found that the model under predicts some of the peak discharge values. This matches with the results reported for similar studies with SWAT. In general, the model prediction is better for the monsoon months compared to the summer period. The Nash Sutcliffe efficiency values for the pre and post calibrated models are 0.74 and 0.79 respectively.

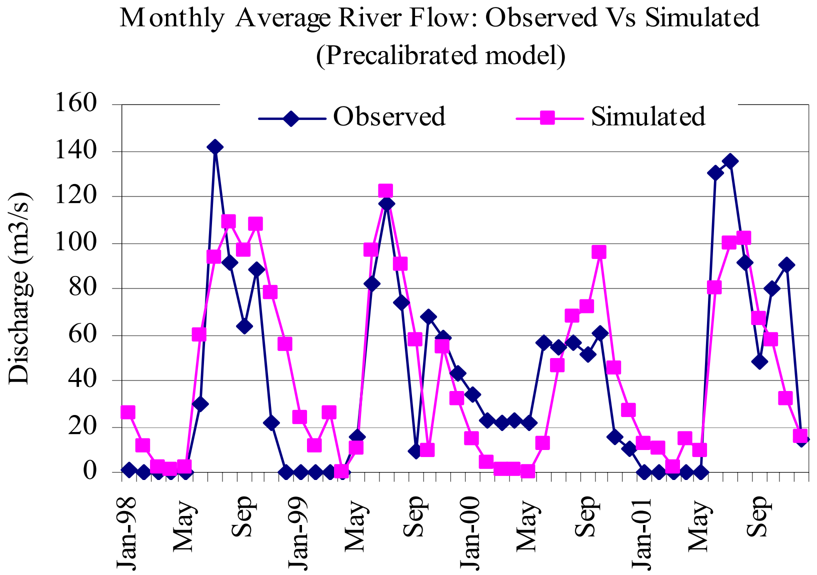


Fig. 4.7. Monthly Average River Flow- Precalibrated model

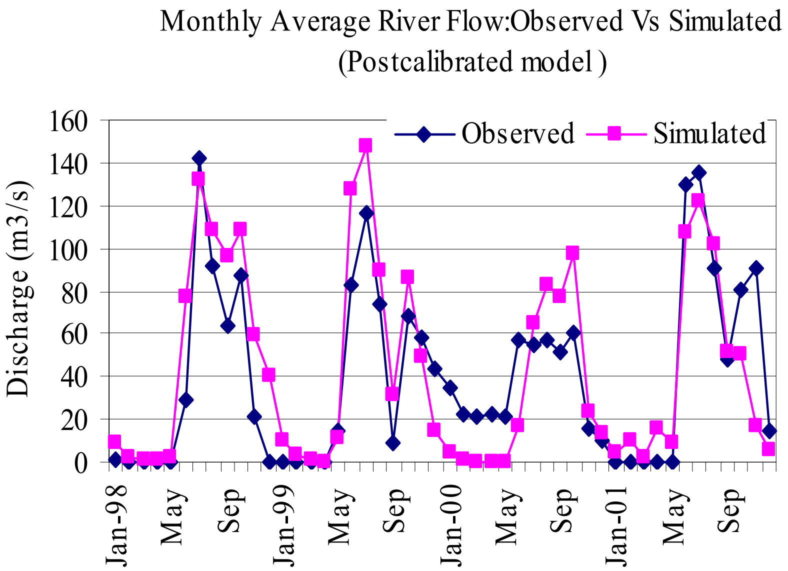


Fig. 4.8. **Monthly Average River Flow- Postcalibrated model**

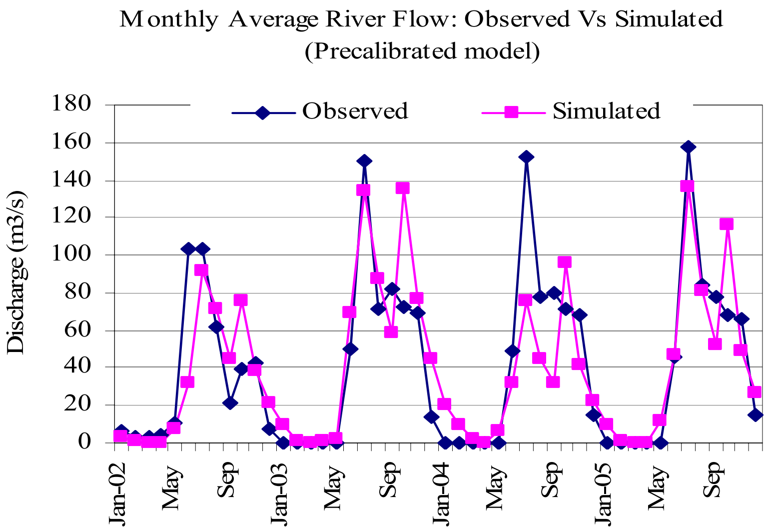


Fig. 4.9. Monthly Average River Flow- Precalibrated model

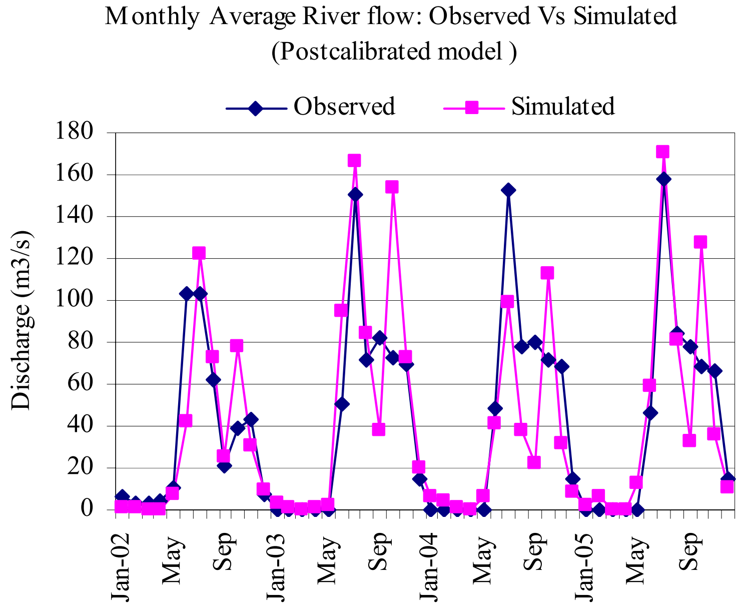


Fig. 4.10. Monthly Average River Flow- Postcalibrated model

Table 4.4: Descriptive statistics of Average Monthly Flow

Statistics	Pre-calibration period		Post-calibration period	
	Observed flow (m3/s)	Simulated flow (m3/s)	Observed flow (m3/s)	Simulated flow (m3/s)
Mean	37.65	50.92	37.65	50.43
SD	69.99	40.65	69.99	49.21
Nash Sutcliffe Efficiency		0.74		0.79
Coefficient of Determination		0.81		0.90

Ten days Average River Flow is very important for most of the river basin water management decisions. Most of the water requirements like drinking, irrigation, industrial etc. are worked out on a ten days basis and the water availability can be compared with the demand to find the surplus or shortages. Hence, the simulation values are compared with the observed values on a ten days time step to check the predictive ability of the model. The time series curve for the observed and simulated ten day average river flow values for the precalibrated model is shown in Fig. 4.11 and 4.12.

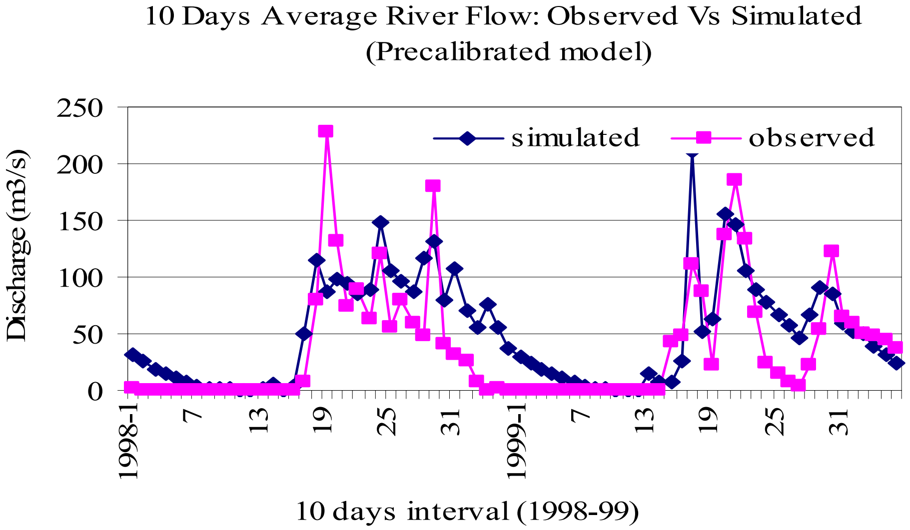


Fig. 4.11. Ten days Average River Flow- Precalibrated model

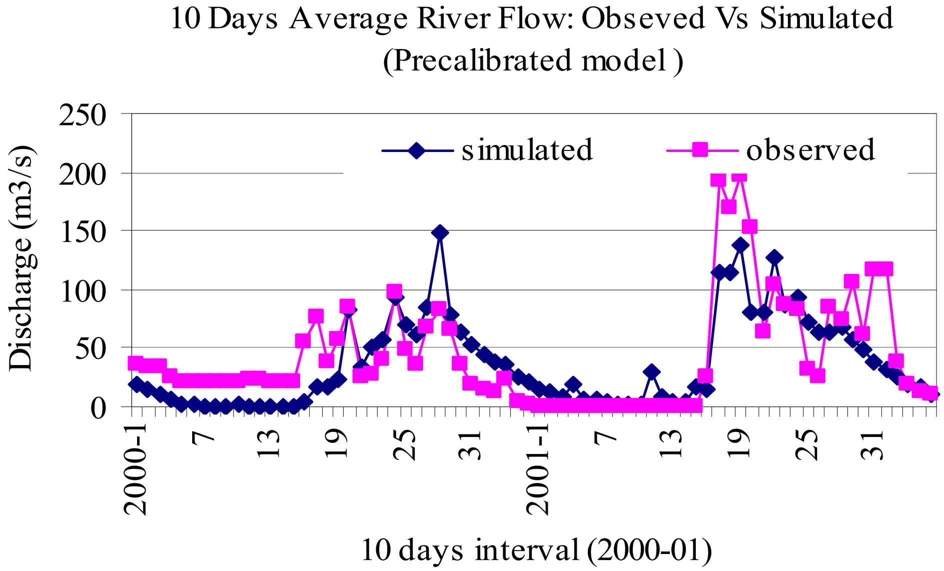


Fig. 4.12. Ten days Average River Flow- Precalibrated model

The summer lean flow is one of the major problems of the rivers of Kerala. Most of the rivers go dry in summer season. Hence, water conservation measures need to be under taken. Though there are dissimilarities in the case of some of the months, the simulated value follows the observed values more closely for the post calibration model. This depicts that the model is good for discharge value prediction for the lean period.

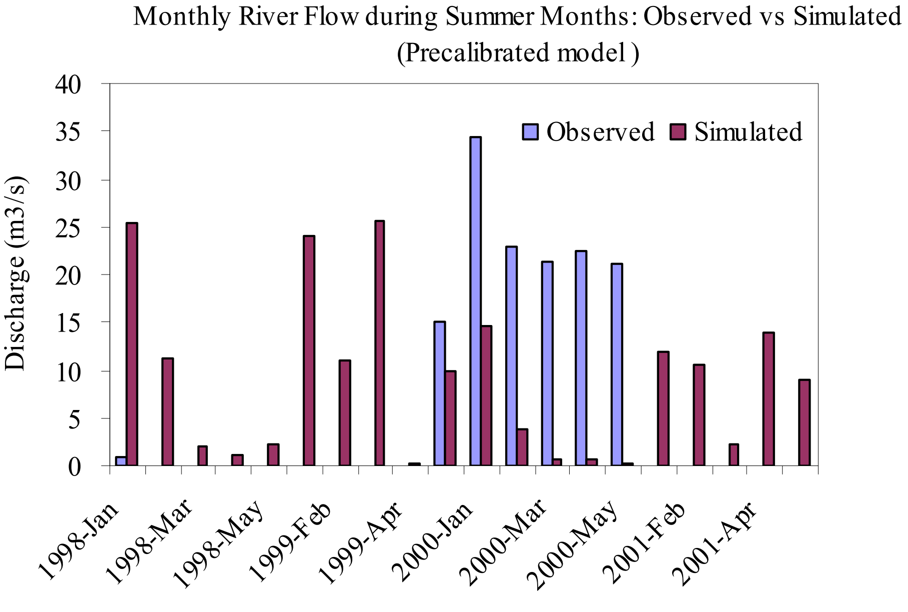


Fig. 4.13. Monthly River Flow during summer months- Precalibrated model

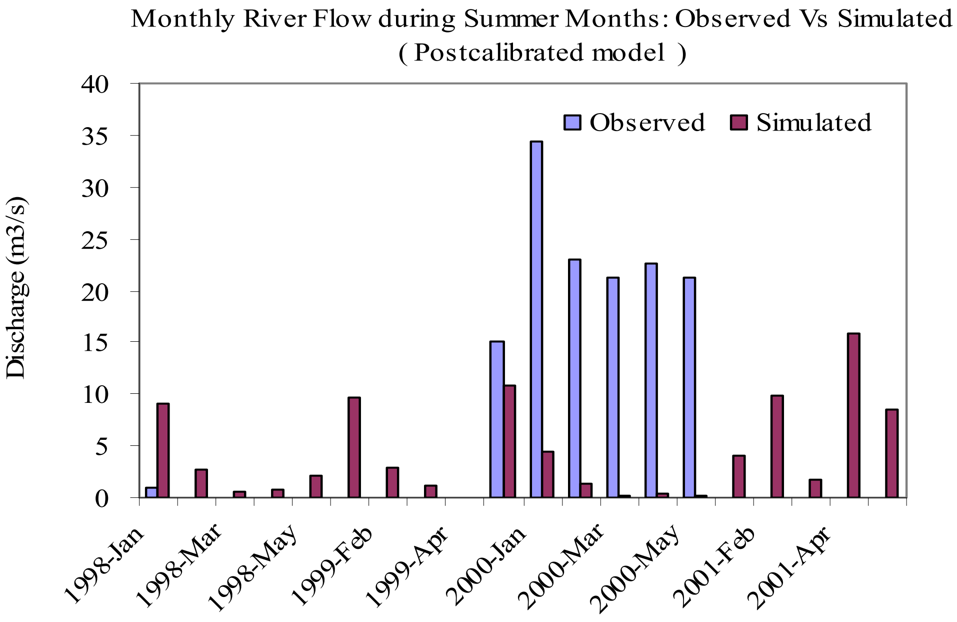


Fig. 4.14. Monthly River Flow during summer months- Postcalibrated model

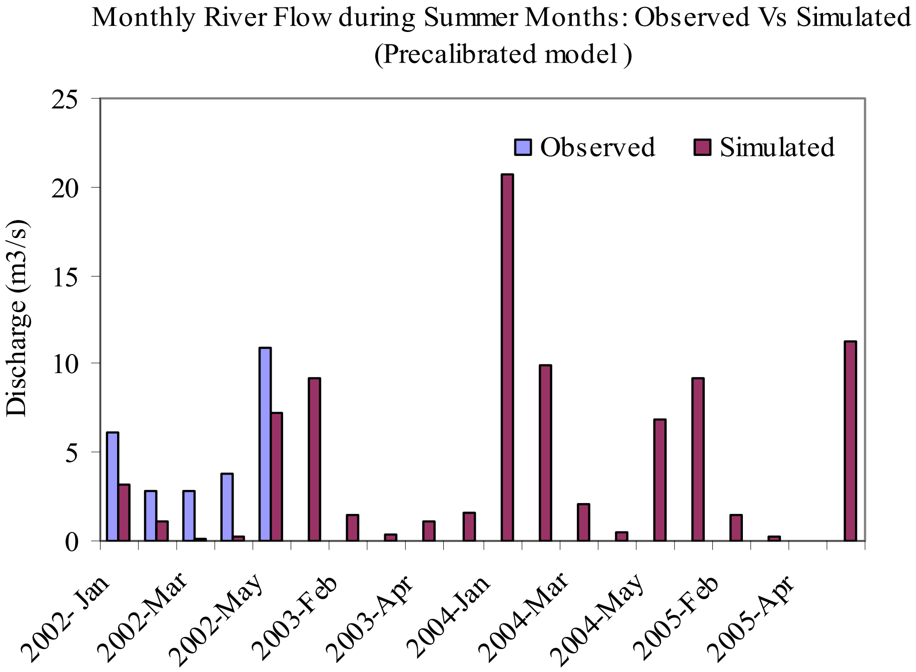


Fig.4.15. Monthly River Flow during summer months- Precalibrated model

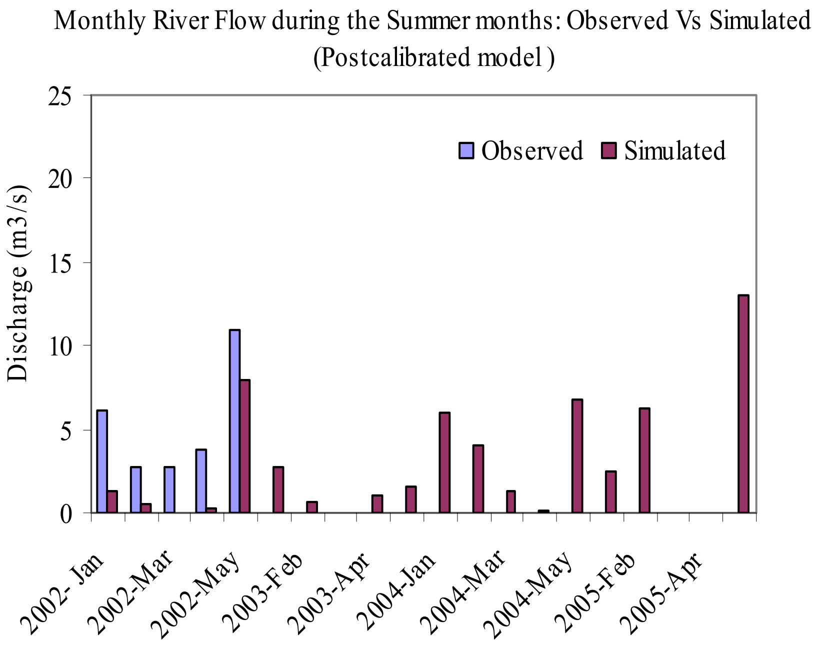
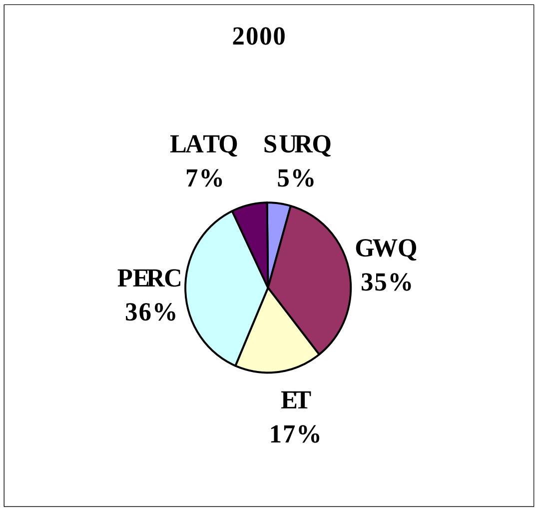
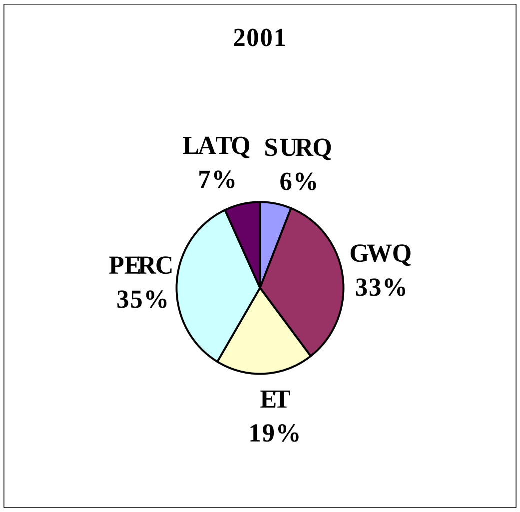


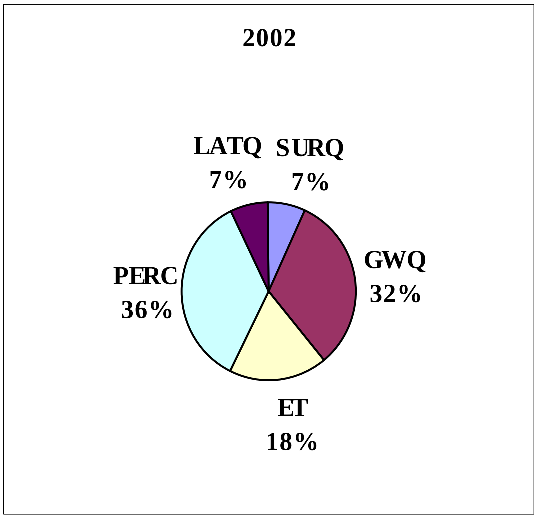
Fig. 4.16. Monthly River Flow during summer months- Postcalibrated model

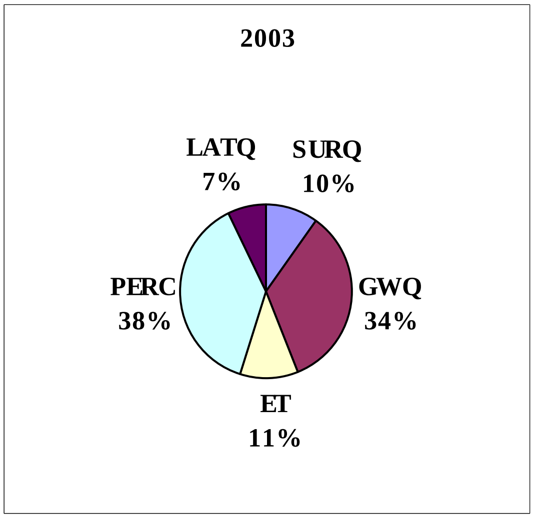
4.3 WATER BALANCING

From the water conservation point of view, one must consider the individual hydrologic component rather than the total river flow. The most important water balance components of a basin are precipitation, surface runoff, lateral flow, deep percolation, evapotranspiration and groundwater flow. All these values other than precipitation can be predicted with reasonable amount of accuracy. This would in turn render great help for the watershed development activities. The predicted values of the water balance components as a percentage of annual rainfall for the years 2000-2006 is shown in Fig. 4.17. It can be seen that major portion of the precipitation received by the basin is lost as deep percolation (32-38%). The percentage of the annual evapotranspiration is found to be 11 to 19%. Since the lateral flow is not too high (7%), the shallow subsurface flow is not very significant. The surface runoff is not very appreciable and it varies from 6 to 13%. So it could be inferred that natural recharge is taking place in the basin in an appreciable level on an annual basis. The basin under study has tremendous scope for additional water conservation and management programme. Both insitu and exsitu measures may be adopted appropriately.









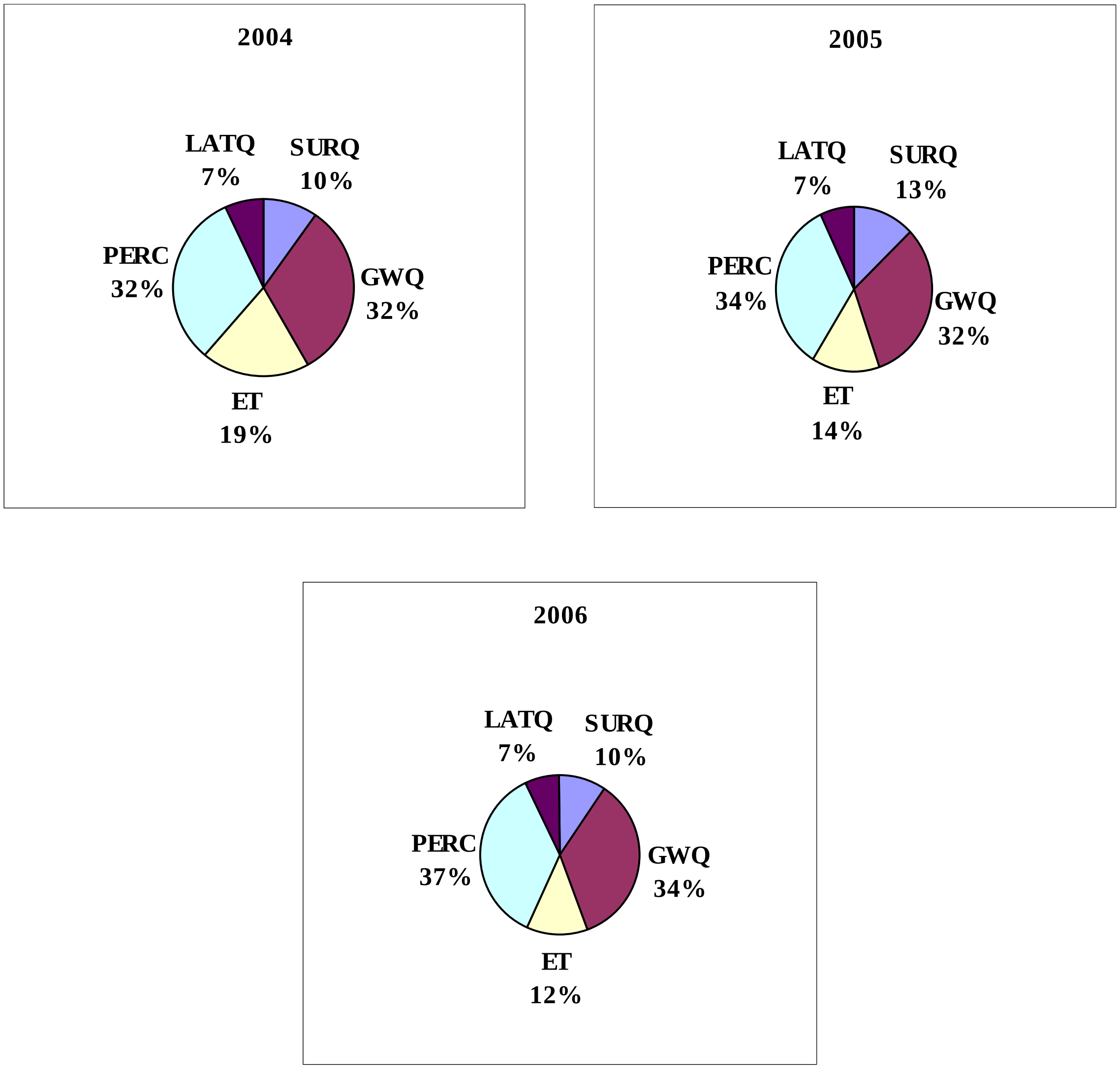


Fig. 4.17. Percentage values of water balance components

SUMMARY & CONCLUSIONS

Chapter V
SUMMARY AND CONCLUSIONS

Watershed simulation studies have been conducted in Kadalundi river basin of Kerala state in India using a GIS integrated physically based distributed model. The geological location of the watershed is from 10°56' to 11°11' North latitude and 75°49' to 76°25' East longitude and the total area is 804 km^2. The main objectives of the study were characterization of the watershed, assessing the hydrological processes taking place in the watershed and to assess the impact of the scenario changes on the watershed processes.

The elevation of the watershed varies from 6m to 1500m as revealed by the Digital Elevation Model (DEM). The soil map of the area shows the major soil series of the area as Vijayapuram (VIJAY) occupying about 44678 ha of the geographic area followed by the Chelikuzhi soil series spread out in 18932 ha. The other soil series of the area are Anayadi, Pallippadi and Pullangod. A landuse map for the study area has been prepared from LISS III imagery of IRS 1C by supervised classification. The classified imagery shows that the main vegetations grown in the watershed are coconut, arecanut rubber and paddy.

SWAT model was build for Kadalundi river basin by inputing all thematic and attribute data. A basin outlet at Karathode corresponding to the gauging station of a Central Water Commission was selected for the simulation studies. The entire watershed was divided into 25 sub basin and 84 hydrologic response units. Model simulations were carried out with the default parameter setting and the simulated outputs were compared with the observed values. Major mismatches between the observed and simulated were observed in summer period. Then the model was calibrated by manually changing the parameters one at a time and evaluating their output performances. Simulations were done on annual, monthly and ten days time interval. Nash Sutcliffe efficiency and Coefficient of Determination were used as the statistics to evaluate the model's predictive capability. The calibrated model gave very high Nash Sutcliffe efficiency and Coefficient of Determination for the annual and monthly model simulations. The study reveals that SWAT model can be used for simulating watershed process for the river basins of Kerala with similar topographic and climatic setting.

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APPENDICES

Appendix 1
Rainfall (mm) data 2006

Date	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
1	0.0	0.0	0.0	0.0	0.0	98.2	12.8	4.2	0.0	0.0	0.0	0.0
2	0.0	0.0	0.0	0.0	0.0	0.0	14.2	4.6	0.0	13.2	15.2	0.0
3	0.0	0.0	0.0	0.0	0.0	13.6	38.2	11.0	0.0	0.0	10.6	0.0
4	0.0	0.0	34.2	0.0	0.0	0.0	32.2	10.4	0.0	3.2	13.4	0.0
5	0.0	0.0	0.0	0.0	5.6	11.8	10.2	31.0	0.0	1.6	14.6	0.0
6	0.0	0.0	1.8	0.0	0.0	0.0	5.8	-	0.0	5.2	17.6	0.0
7	0.0	0.0	2.6	0.0	0.0	0.0	15.6	2.2	0.0	4.6	0.0	0.0
8	0.0	0.0	0.0	0.0	15.8	0.0	40.8	0.0	2.4	23.4	0.0	0.0
9	0.0	0.0	0.0	0.0	0.0	0.0	2.2	0.0	48.6	3.4	0.0	0.0
10	0.0	0.0	20.8	0.0	0.0	0.0	10.6	7.8	56.2	16.4	16.2	0.0
11	0.0	0.0	0.0	0.0	0.0	0.0	18.2	37.2	7.6	5.0	2.6	0.0
12	0.0	0.0	0.0	0.0	0.0	0.0	28.8	25.2	83.6	0.0	0.0	0.0
13	0.0	0.0	0.0	0.0	0.0	0.0	32.4	33.6	78.2	1.4	1.6	0.0
14	0.0	0.0	0.0	0.0	0.0	0.0	23.0	29.0	37.4	27.6	0.0	0.0
15	0.0	0.0	0.0	3.0	0.0	0.0	17.8	28.0	14.8	43.2	0.0	0.0
16	0.0	0.0	0.0	0.0	0.0	0.0	11.0	44.2	65.2	14.2	6.8	0.0
17	0.0	0.0	0.0	0.0	2.6	2.8	5.2	18.4	44.6	3.6	0.0	0.0
18	0.0	0.0	0.0	0.0	0.0	0.0	10.4	9.8	14.4	2.8	2.2	0.0
19	0.0	0.0	0.0	0.0	8.2	0.0	53.2	4.2	13.8	7.0	15.2	0.0
20	0.0	0.0	0.0	0.0	0.0	0.0	6.4	0.0	16.0	13.2	0.0	0.0
21	0.0	0.0	0.0	5.8	0.0	56.0	5.4	0.0	11.6	0.0	0.0	0.0
22	0.0	0.0	0.0	0.0	0.0	3.8	3.2	0.0	24.4	0.0	0.0	0.0
23	0.0	0.0	0.0	0.0	8.2	140.6	3.2	0.0	0.0	0.0	0.0	0.0
24	0.0	0.0	0.0	0.0	2.2	23.2	0.0	0.0	2.2	0.0	0.0	0.0
25	0.0	0.0	0.0	0.0	6.4	48.6	0.0	0.0	39.6	1.0	26.0	0.0
26	0.0	0.0	0.0	0.0	52.4	1.6	8.8	0.0	21.2	0.0	0.0	0.0
27	0.0	0.0	0.0	0.0	29.2	11.4	9.0	0.0	0.0	0.0	0.0	0.0
28	0.0	0.0	0.0	0.0	82.4	64.0	32.0	0.0	0.0	5.2	0.0	0.0
29	0.0		0.0	0.0	66.2	16.4	3.6	2.8	7.2	43.0	0.0	0.0
30	0.0		0.0	0.0	48.5	58.2	13.4	9.2	0.0	1.0	0.0	0.0
31	0.0		9.2		14.4		6.4	0.0		2.8		0.0

Appendix 1I
Temperature (^{0}C) data 2006

Date	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
1	23.0	35.0	37.0	36.5	37.0	27.0	28.5	31.5	32.5	32.0	30.0	33.5
2	33.0	35.5	36.5	36.0	37.5	31.0	30.5	30.5	33.0	31.0	33.5	33.0
3	32.5	35.0	37.5	37.5	36.5	31.0	31.0	32.0	34.5	32.5	33.0	32.5
4	33.0	35.5	37.5	37.5	38.0	30.0	30.0	30.0	34.5	33.0	33.0	32.5
5	34.0	36.0	36.5	36.5	37.5	31.0	30.5	29.5	33.5	32.0	32.5	33.5
6	34.5	36.5	30.5	36.5	36.0	30.0	31.5	30.5	34.0	33.0	33.0	33.5
7	33.5	35.5	36.0	35.5	36.0	31.5	32.0	31.5	34.0	31.0	33.5	32.0
8	34.0	35.5	36.0	37.0	36.5	32.5	31.0	32.5	34.0	30.0	29.0	33.0
9	34.0	33.5	36.0	36.5	36.5	33.0	31.5	33.0	34.0	31.0	29.5	33.5
10	33.5	35.0	36.0	36.0	36.5	34.0	32.0	31.5	31.5	30.5	32.0	33.0
11	34.5	35.5	35.0	37.0	37.5	34.0	31.5	29.0	30.0	29.5	33.0	34.5
12	33.0	35.5	36.0	37.0	33.5	33.0	27.0	27.5	28.0	31.0	33.0	35.0
13	36.0	35.0	36.5	37.0	37.0	35.0	27.0	27.5	27.0	33.5	33.5	33.5
14	35.5	35.0	36.0	37.0	37.0	35.0	25.5	30.5	29.0	32.5	33.5	35.0
15	34.5	36.0	36.5	37.0	38.0	35.0	28.5	30.5	29.5	32.5	33.0	34.0
16	35.0	37.5	36.5	36.0	36.5	34.5	30.0	30.5	27.0	33.0	33.0	34.0
17	35.0	35.5	36.0	35.0	36.0	30.5	30.5	31.0	27.0	33.5	33.0	32.0
18	35.5	35.5	36.5	34.5	34.0	32.0	30.5	30.0	28.0	33.0	31.5	32.5
19	35.5	36.5	36.5	38.0	34.0	34.5	30.5	31.0	28.5	34.0	29.0	33.5
20	34.5	36.5	37.5	37.5	37.0	34.0	29.0	31.5	31.0	32.0	32.5	33.5
21	35.5	37.5	36.5	36.5	36.0	33.0	30.0	31.0	29.0	33.5	32.0	33.0
22	35.5	36.5	36.5	36.0	36.5	30.0	29.5	32.5	28.0	33.0	32.0	33.0
23	36.0	36.5	37.5	36.0	36.0	29.5	30.5	33.0	28.0	34.0	32.0	33.5
24	35.5	37.5	37.0	36.5	35.0	26.0	31.5	33.0	30.5	33.5	33.5	33.5
25	33.5	36.5	35.5	36.5	35.0	29.5	32.5	32.5	30.0	33.0	34.0	34.0
26	34.0	37.0	36.0	37.5	29.0	26.5	32.0	33.0	27.5	33.0	32.5	34.0
27	34.0	36.5	36.5	37.5	32.5	30.5	30.0	33.0	30.0	31.0	33.5	30.0
28	35.0	37.0	37.5	37.0	27.5	29.0	30.0	33.0	32.5	32.0	33.0	33.0
29	34.5		37.5	36.5	26.5	29.0	30.0	33.0	31.5	31.0	33.5	34.0
30	36.0		37.5	36.5	29.0	27.0	31.0	31.0	31.5	31.0	33.5	34.5
31	34.5		37.0		29.0		31.0	31.0		31.5		33.0

WATERSHED SIMULATION USING GIS INTEGRATED PHYSICALLY BASED MODEL

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ABSTRACT OF THE PROJECT REPORT

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In
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ABSTRACT

A study has been taken up for the Kadalundi river basin of Kerala state to study the hydrologic behaviour of the basin. Widely recommended SWAT model has been used for the study. It focused on watershed processes simulation and calibration. The geographical area of the watershed is 804 km^2. The elevation ranges from 6m to 1500m. Vegetation comprises of coconut, arecanut, rubber, paddy and forest. GIS techniques are made use of to incorporate spatial variability more thoroughly and efficiently.

This study revealed that the model predict the low flow of the river with very good accuracy. The watershed was divided into 25 sub basin and 84 HRUs. Average river flow during monsoon months are in the range of 70-130m^3/s and the same goes to an abysmally marginal level of 0-1m^3/s during summer months. Contribution of different sub watersheds towards the total stream flow has been quantified. Hence, recommendations to alleviate the water scarcity and develop micro watersheds can be given more specifically and effectively.