Evaluation of Management Practices on Crop Yield in a semi-arid tropical watershed using a process based Hydrologic Model

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A Thesis Submitted to

Indian Institute of Technology Hyderabad

In Partial Fulfillment of the Requirements for

The Degree of Master of Technology

Department of Civil Engineering

July 2015

Abstract

Effective management of irrigation water requires a prior knowledge of crop water requirement. This study aims at understanding water-plant-yield relations at sub-catchment scale, by analyzing crop water productivity (CWP) considering various management scenarios. A hydrologic model of the Singur-Manjeera Basin in Telangana, India was developed in the present study. Process based hydrologic model, SWAT was used to simulate crop yield on monthly time step for the irrigation years 2013-15. Major crops grown in the region include Cotton, Maize, Paddy and Sugarcane. Data on meteorological, soil, land-use, crop, irrigation, and management practices was provided using ArcSWAT. A total of 348 hydrological response units (HRUs), 20 sub basins, and 20 reaches were delineated. Model calibration (for crop yield and actual evapotranspiration) was performed at HRU level specific to Cotton (Kharif) and Paddy (Khartif) crops using SUFI-2 algorithm in SWATCUP. The calibrated model was further applied to evaluate the impact of various conservation practices by considering changes in Available soil Water Content (AWC), Irrigation, fertilizer. Statistical analysis was performed to rank the management practices (that are specific to the region) considering higher CWP

Contents

Chapter 1

Introduction

India is not new to water scarcity problems. As a Semi-Arid region, India is facing shortage of water.Industrial and domestic water users in India consume 9 percent and 7 percent respectively, while the agricultural sector consumes 84 percent of total water supply. (CWC, 2012). This rapid growth, combined with limited water supply and the continuing importance of agriculture, illustrates the critical need for improved Water Usage Efficiency (WUE) in India. Agriculture is the largest source of employment (more than 50 %) in India. Nearly 70 per cent of the population is dependent on agriculture for livelihood (Amarasinghe et al., 2007). Also agriculture, being the biggest water consuming sector is under severe scrutiny for the account of the water it uses (FAO, 2007). Agriculture and its allied sectors contribute to more than 20 percent of Nations GDP (Arjun, 2013). As there is no significant increase in the area under agriculture, improvement of management practices plays a major role not only to meet the increasing demand for food with the available limited resources but also to become less dependent on the imports thereby improving the nations GDP. Water scarcity has increased the need for land management and improving WUE in agriculture. Effective management of irrigation water requires a prior knowledge of crop water requirement. Approaches to farming that seek to minimize the use of agricultural chemicals and fertilizers without sacrificing economic viability are known as Sustainable Agriculture and Integrated Farm Management. Reliable Agricultural Practices are to be adapted for long term improvement and sustainability of crop yield. There are practical ways to ensure that risks to the environment are minimized without sacrificing the agricultural productivity. These methods are known as Best Management Practices (BMPs). The Implementation of BMPs specific to the region not only improves the yield but also has environmental dimensions i.e., they promote optimum utilization of pesticides and fertilizers thereby reducing the nutrient loads on the sub-surface water systems. BMPs include integrated pre harvesting practices like soil and water management, nutrient management and pest management, harvesting and post-harvest handling and other logistics. Individual producers must decide which combination of BMPs is best suited to their farm enterprise, taking into account the specific soils, climate, and management factors. BMPs range from measures that involve a change in farming operations, like conservation tillage and crop rotation, to simple actions such as not applying manure before forecasted rainfall. Characterized by semi-arid environment, water is becoming a scarce commodity in India vowing to the increasing population, urbanization, industrialization and agricultural development of water intensive crops (Amarasinghe, et al. 2007). Improving the productivity of major crops in the study region is of prime importance in order to achieve self-sufficiency. The water efficiency in India for most of the irrigation systems is low and is estimated to be in the range of 35-40% (Molden et al. 2010a). Groundwater used for irrigation has increased from about 40 percent of the net irrigated area in the 1960s to about 57 percent in the late 1990s. (International Best Practices and Policy Lessons for India, 2012). Much of this expansion has occurred in water-scarce river basins resulting in increasing the groundwater overdraft in many aquifers. As a result, the expansion of groundwater irrigation, and its sustainable management, are critical issues for future water management. Groundwater uses about 44 percent of the total volume of water used for irrigation but contributes 57 percent of Indias irrigated area (International Best Practices and Policy Lessons for India, 2012). Telangana State in India is largely dependent on agriculture and forms a part of Deccan Plateau having semi-arid climatic conditions. A number of farmer suicides have been reported in the recent years resulting from improper management activities, failure of bore well, less crop yield, and low crop value. Scientific understanding of crop-water-weather relations of the region can help in developing efficient management strategies (including irrigation scheduling, crop rotation) for improved crop water productivity. Singur-Manjeera (SM) Basin is one of the agriculturally intense regions of the State, where in the irrigation is completely met from the groundwater resources.

1.0.1 Description of the Study Area

The study area encompasses six mandals between the Singur and Manjeera Reservoirs, out of which three mandals namely Kohir, Munpalle and Sadasivapet are located in Medak district and the other three mandals namely Chakrampalle, Mominpet and Marpalle are located in Rangareddy district, Telangana State. The area of the watershed under study is 910 sq.km. and exists between the East Longitudes 77.032 to 78.078 and North Latitudes 17.415 and 17.792. Major villages in the study region include Nizampur, Sadasivapet, Mominpet, Kamkole, Patlur and Chakrampalle. The index map of the study area delineating su-basins and stream network is represented in Figure 1. The study area is referred as Singur-Manjeera (S-M) basin throughout the report.

The climate of the region is primarily semi-arid with a mean annual precipitation of 910 mm(CGWB ,2013).The Major crops grown in the region include Cotton (40-50%), Maize(25-30%), Paddy(10-15% and Sugarcane(5-10%). The entire study area is covered by hard rock except for the 0.2% of the alluvium area.Groundwater occurs under unconfined to confined conditions in hard rock (Archean and Deccan traps ages) and recent alluvial formations.The groundwater resources available in the district is 1,05,038 ha.m. The common groundwater abstraction structures are dug wells, dug-cum bore wells and bore-wells,

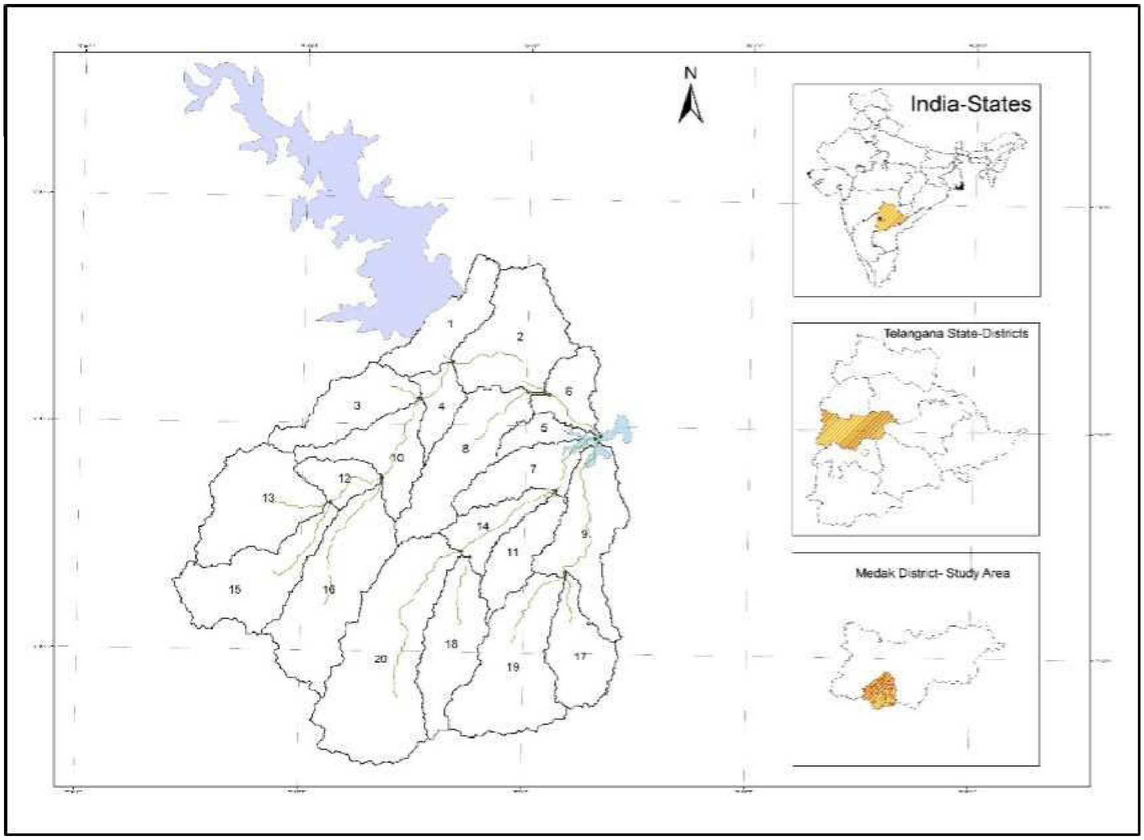


Figure 1.1: Index map of the study area delineating stream networks and sub-basins

their yields mainly depending on the recharge conditions of the area. Due to indiscriminate drilling of the bore wells yields have fallen drastically.Lack of recharge to fracture confined aquifer and existing borewells becoming to defunct and even leading to failure. The wells are capable of sustaining 2 to 5 hrs of pumping with an average discharge of 14400 lph. The depth to water level varies from a minimum of 3.85 m.bgl to a maximum of 21.00 bgl (Pre-monsoon) and 0.98 m.bgl to maximum of 22.65 m bgl(Post-moonsoon) The water level fluctuation between pre-moonoon and post-moonsoon varies between 0.00 to 7.88 m. The groundwater in the district is in general suitable for both domestic and irrigation purposes. The electrical conductivity ranges from 733 to 5266 micro Siemens/cm at 25°C. Nitrate values ranges from 20-270 mg/l, however 60% of area is reported as 45mg/l of nitrate.

1.0.2 Objectives of The Research

The major objective of the study is to understand the water plant yield relations at sub-catchment scale for the S-M watershed using SWAT model. The sub-objectives of the research include:

1. Preparation of Land-use, Soil and slope maps of the S-M watershed in GIS environment at sub-basin scale resolution

2. Determination of various parameters governing the hydrological process through Laboratory/ Insitu techniques confirming to the IS standards.

3. Representation of crop management schedules for Kharif and Rabi seasons for all the major crops in the study region through frequent interaction with farmers and Village Revenue Officers(VROs)

4. Development of a comprehensive hydrological model of the S-M watershed using ArcSWAT

5. Simulation of actual evapotranspiration (AET) and crop yield on monthly time step for the existing agricultural conditions using SWAT

6. Predict the model parameters sensitive to hydrologic and crop yield processes

7. Investigate teh co-relation between AET and crop yield across the stud area and quantify the yield of crops using Crop ater Producivity (CWP)

8. Evaluation of the existing management practices and identifying the Best Management Practices (BMPs) which form an optimized value for CWP for the major crops in the study region

1.0.3 Organization of Thesis

The thesis is organized as Six chapters. The brief description of the contents is given below:

Chapter one deals with the motivation for the research, the current agricultural scenario in India and a brief description of the study area. The main and sub-ojectives of the reasearch are discussed in brief at the end

Chapter Two includes a comprehensive literature review on some of the existing models in SWAT with main emphasis on Crop yield and Management Practices, Calibration and Uncertainity analysis with SWATCUP

Chapter three deals with the laboratory/field techniques adapted for the collection of data, processing of data for the hydrological and crop yield simulation and calibration.

Chapter four provides comprehensive overview about various factors effecting the AET and plant growth.

Results of the simulations(for AET and Crop Yield) and calibration (for PET and Crop Yields) were discussed in this chapter. Evaluation of the existing management parameters and potential impact of the Best Management Practices were discussed in Chapter five.

Summary and conclusions followed by limitations and future scope of the work was presented in Chapter Six

Chapter 2

Literature Review

2.1 Introduction

SWAT was developed to predict the impact of land management practices on water, sediment and agricultural chemical yields in large complex watersheds with varying landuse and management conditions over long periods of time (from reference [9]). Simulations of physical processes are done on a continuous, daily time step basis by partitioning the watershed into sub-basins and sub watersheds for modeling purposes. The model input components include the parameters governing the hydrological processes, plant growth and land management practices. The model is computationally efficient and is capable of simulations for very large basins with a variety of management practices. Based on the input information provided for each sub-basin, they are further divided into lumped land areas comprising of unique land cover, soil and management combinations called Hydrological Response Units(HRUs) . HRUs represent the uniqueness of the sub-basin area specific to landuse, management and soil characteristics and are not spatially referenced in the watershed. The hydrological cycle in the watershed is simulated based on the water balance equations. Standard methods applicable to estimate various components of the water budget equations are used and all the parameters are simulated at HRU level. Surface runoff is estimated by the SCS curve number method or the GreenAmpt method. Redistribution of water between the surface and sub-surface layers is done through Storage routing techniques. Sediment yield is estimated by the Modified Universal Soil Loss Equation (MUSCLE). SWAT uses a heat unit theory to simulate plant growth. Harvest Index is used to calculate yield and plant growth can be inhibited by temperature, water, nitrogen or phosphorous stress. SWAT allows very detailed management information to be incorporated in a simulation.(from reference [9]) . Management operations can be scheduled by Julian day and calender without considering cropping rotations and without using heat unit scheduling.

2.2 Hydrological Modeling with SWAT

A large range of publications in the literature touch upon various aspects related to a particular component of hydrological processes like water balance, stream flow, groundwater recharge, runoff, evapotranspiration. Fu *et.al.,2007* [4] examines the impacts of climate variability upon the regional hydrological regimes of the Yellow River in China. A relationship among the stream-flow, precipitation, and temperature, indicated that stream-flow is sensitive to both precipitation and temperature.

Jyrkama and skyes *et.al.,2007* [6] developed a physically based methodology that can be used to characterize both the temporal and spatial effect of climate change on groundwater recharge. The method,is used to estimate potential groundwater recharge at the regional scale with high spatial and temporal resolution. The results of the study indicated that the rate of groundwater recharge is expected to improve as a results of temperature change.

Nunes *et.al.,2009*[10] studied the impacts of climate change on storm runoff and erosion in a Mediterranean watershed.The sensitivity of runoff and erosion to incremental degrees of change to storm rainfall, pre-storm soil moisture, and vegetation cover, in two Mediterranean watersheds are analyzed using the MEFIDIS model.The results indicated that decreasing soil moisture levels caused by climate change could be sufficient to offset the impact of greater storm intensity in Mediterranean watersheds.

Joh,Hyung-Kyung*et.al.,2010*[5] employed a multi variable objective function to calibrate SWAT model due to the paucity of actual hydrological measurement data in Korea. Streamflow, evapotranspiration, and soil moisture are used as calibration variables to asses the performance and reduce the uncertainities of SWAT model output.The model performance was assessed by comparing its results with the observed data. It was concluded that multi variable measurements showed better agreements with the measurements compared to those using a single variable measurement.

2.3 Crop Yield Simulation with SWAT

Srinivasan *et.al.* (2010)[15] proposed a framework for developing input data for SWAT for the Upper Mississippi River basin. The study involved the application of the physically based, spatially distributed SWAT model for hydrological budget and crop yield predictions from an unguaged perspective. Performance evaluation for SWAT hydrological budget and crop yields simulations was done without calibration. The uncalibrated SWAT model is used for prediction of annual stream flows at 11 USGS guages and crop yield at four digit Hydrological Unit Code(HUC)scale. The performance of the model is found to be reasonably good for base flow contribution and marginally poor for monthly stream flow as against the annual flow which can be attributed to the incomplete information available about reservoirs and dams within the area under study. Crop yield predictions for Corn and Soyabean yields developed similar evaluation statistics to those calculated using calibrated SWAT models. The hydrological budget and crop yield simulations showed that SWAT model can effectively asses the consequences of various management practices and predict the effect of climate and landuse changes.

Aaron R.Mittelstet *et.al.*[8] analyzed the crop yields and salinity levels in the North fork River, Oklahoama, USA using the SWAT model.

A baseline SWAT model was set up, calibrated and validated to simulate stream flow and wheat and Cotton yields. The SWAT model and an empirical regression equation were used to analyze variable weather impacts on crop yields and salinity levels. The simulated annual wheat and dryland cotton yields are within the acceptable limits. Therefore it has been realized that SWAT can be utilized to predict the change in salinity based on ionic strength and the proposed empirical streamflow regression equation. The effect of weather variability on crop yields was significant from year to year but it was observed that the meteorological parameters are insignificant when it comes to long term predictions of yields over a period of 50 years

Jose R. Avila-Carrasco et.al.[3] used the SWAT 2009 model to calibrate long term annual average Actual Evapotranspiration (AET), deep aquifer recharge rates, plant biomass values acquired based on expert knowledge of researchers and managers for the Calera watershed, Mexico. The model performance was assessed based on various statistical parameters and it was identified that the model reproduced the calibrated target values of the three water budget variables within an acceptable range. The calibrated SWAT model was proposed to bes used to evaluate alternative water management scenarios for the Calera watershed and other ungauged or data scarce watersheds.

Monireh Faramarzi *et.al.*[**?**] (2010) studied the crop yieldwater relations in wheat across Iran for a sustainable production.Irrigated and rainfed wheat yield (Y) and consumptive water use (ET) was modeled at sub-basin level with uncertainty analysis at a subbasin level using a pre-calibrated model. Simulated Y and ET were used to calculate crop water productivity (CWP) to analyze the impact of several stated policies to improve the agricultural system in Iran. Selected management scenarios were assessed by improving the soil available water capacity (AWC) at provincial level and it was inferred that a better water management in rainfed wheat will lead to a larger marginal return in the consumed water. The results have indicated that majority of additional wheat production would need to be produced in the water scarce provinces.

2.4 Evaluation of BMP scenarios

Srinivasan *et.al.2006*[12] evaluated the long term impacts of WQMPs on nonpoint source pollution at the farm level and watershed level using SWAT model.A pre-BMP scenario and a post-BMP scenario representing the conditions of the watershed after implementation of WQMPs were simulated to estimate the reductions in nonpoint source pollution due to WQMP implementation.It was concluded that that a modeling approach can be used to estimate the impacts of water quality management programs in large watersheds.

Yuzhou Luo *et.al.2009*[7] evaluated the pesticide fate and transport processes in agricultural fields and instream network. Management-oriented sensitivity analysis was conducted by applied SWAT simulations for pesticide distribution. Results of sensitivity analysis showed the governing processes in pesticide outputs as surface runoff, soil erosion, and sedimentation.It was recommended that conservation practices designed to reduce field yield and in-stream transport capacity of sediment, such as filter strip, grassed waterway, crop residue management, and tailwater pond are to be implemented in the watershed.

Mazdak Arabi *et.al.2006*[1] evaluated BMPs using SWAT model by calibrating and validating the model for streamflow, sediment and nutrient yields. The effectiveness of BMPs like grassed waterways, grade stabilization structures, field borders and parallel terraces were tested after the model was calibrated. Results of the study indicated that the impacts of these BMPs on sediment and nutrient yields was very sensitive at sub-basin level in SWAT. In addition to this optimal watershed subdivision level for representation of the BMPs was identified through numerical simulations.

2.5 Uncertainty and Calibration using SWATCUP

Abbaspour *et.al.2007*[14] presented a methodology by linking three programs to SWAT namely SWATCUP, GLUE, ParaSol to calibrate large scale distributed models where it is difficult to calibrate and interpret the calibration because of large model uncertainty, input uncertainty, and parameter nonuniqueness. The paper summarizes the application of SWATCUP on these three procedures providing an application example using SUFI-2.

Srinivasan *et.al.2012*[2] presented a calibration technique, SWAT-

CUP a decision-making framework that incorporates a semi-automated approach (SUFI2) using both manual and automated calibration and incorporating sensitivity and uncertainty analysis. The importance of parameter sensitivity analysis, better understanding of the overall hydrologic processes like baseflow ratios, ET, sediment sources and sinks, crop yields, and nutrient balance parameter sensitivity, manual component of the SWAT-CUP calibration to provide statistics for goodness-of-fit were elaborated in detail. Advantages of SWAT CUP over other calibration procedures such as improvement of model run time efficiency; inclusion of the impact of uncertainty in the conceptual model were discussed.

M Talebizadeh *et.al.2010*[16] evaluated the capability of two different types of models, SWAT as a process-based model and ANNs as a data-driven model in simulating sediment load. The issue of uncertainty in the simulated outputs of the two models which stems from different sources was also investigated. Calibration and uncertainty analysis of SWAT were performed using monthly observed discharge and sediment load values and through the application of SUFI-2 procedure. The issue of uncertainty in the ANN model was also accounted for by training a network several times with different initial weights and bias values as well as randomly-selected training and validation sets, each time a network trained.The results concluded that SWAT model has a superior performance in estimating high values of sediment load, whereas ANN model estimated low and medium values more accurately even when the prediction interval for the results of ANN was narrower than that of SWAT which suggests that ANN outputs are with less uncertainty.

Rokhsare Rostamian *et.al.2010*[11] used SWAT to model the runoff and sediment in the Beheshtabad and Vanak 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, p-factor, the percentage of data bracketed by the 95 prediction uncertainty (95PPU) and r-factor, the ratio of average thickness of the 95PPU band. The predicted runoff values were quite similar to those for discharge indicating that these measures indicate a fair model calibration and accounting of uncertainties.

Jrgen Schuol *et.al.2010*[13] provides a procedure to provide a procedure to improve the estimations of freshwater availability at subbasin level and monthly intervals by applying the SWAT model. The procedure includes model calibration and validation based on measured river discharges, and quantification of the uncertainty in model outputs using Sequential Uncertainty Fitting Algorithm (SUFI-2). The aggregated results for several countries are compared with two other studies. It was seen that for most countries, the estimates from the other two studies fall within the calculated prediction uncertainty ranges. It as concluded that this study the modeling procedure in this study proved quite successful.

Chapter 3

Model Development

3.1 Introduction

In spite of the fact that the hydrological cycle is a framework that is genuinely simple to handle and comprehend, it is a long way from simple to evaluate the procedures in the framework.In order to do this various types of hydrological models are used.Variations in climate,topography, land types and land-use as well as various man-made interferences with the system make it complex to construct general models that treat the whole hydrological cycle applicable any given catchment. Most hydrologic systems are extremely complex, and are region specific.Therefore, abstraction is necessary if we are to understand or control some aspects of the processes. The catchment hydrologic models have been developed for many different reasons and therefore have many different forms. However, they are in general designed to meet one of the two primary objectives. One objective of catchment modelling is to gain a better understanding of the hydrologic phenomena operating in a catchment and to know how changes in the catchment may affect these phenomena. Another objective of catchment modeling is the generation of synthetic sequences of hydrologic data for facility design or for use in forecasting. These models also provide valuable for studying the potential impacts of changes in landuse or climate. There has been variety of uses of these models and as a result, the rapid increase both in scientific understanding and in technical support, from data collection systems and computer technology, have produced an enormous range in levels of sophistication.Hydrologic models can be variously classified. One of the classification methods used by Singh (1988) is used here that classifies hydrologic models as:

(1) Theoretical models

(2) Empirical models

(3) Conceptual models

Theoretical models

Theoretical models (sometimes called white-box models or physically-based models) are the consequences of the most important laws governing the phenomena. A theoretical model has a logical structure similar to the real-world system and may be helpful under changed circumstances. Examples of theoretical models may include watershed runoff models based on St. Venant equations, infiltration models based on two phase flow theory of porous media (Morel-Seytoux, 1978), evaporation models based on theories of turbulence and diffusion (Brutsaert and Mawdsley, 1976), and groundwater models based on fundamental transport equations (Freeze, 1971). An example of physically-based models is the SHE model (Abbott et al., 1986).

Empirical models

Empirical models (sometimes called black-box models or input output models) do not aid in physical understanding. They contain parameters that may have little direct physical significance and can be estimated only by using concurrent measurements of input and output. Examples are stochastic time series models. In many situations, empirical models can yield accurate answers and can, therefore, serve a useful tool in decision-making. The ARMA (autoregressive moving average model) and other time series models are examples of this class.

Conceptual models

Conceptual models (sometimes called grey-box models) are intermediate between theoretical and empirical models. Generally, conceptual models consider physical laws but in highly simplified form. There are many models belong to this class; an example which is familiar for us is the HBV model.

All three types of mathematical models are useful but in somewhat different circumstances. Each of these three types of mathematical models has its own effectiveness, depending upon the objective of study, the degree of complexity of the problem, and the degree of accuracy desired. There is no conflict between these models; they represent different levels of approximation of reality.

3.2 SWAT

3.2.1 Overview of SWAT

Soil and Water Assessment Tool (SWAT) is a river basin or watershed scaled, semi-distributed model developed to predict the impact of land management practices on water, sediment and agricultural chemical yields. SWAT is generally applied to large complex watersheds with varying soil, land use and management conditions over a long period of time.SWAT is a public domain model jointly developed by USDA Agricultural Research Service (USDA-ARS) and Texas A and M AgriLife Research.SWAT is a continuous time(long-term yield) model and operates on a daily time step. In addition to simulating the fate and transport of sediment, nutrients, pesticides, and bacteria, the model has the capability to simulate crop growth, tile drainage, wetlands, reservoirs, and carbon dynamics, broadening the models utility and appeal.SWAT is physically based model wherein, the physical processes associated with water movement, sediment movement, crop growth, nutrient cycling etc. are directly incorporated in SWAT. The benefits of this approach is that, watersheds with no monitoring data (eg. stream gauges) can be modeled and the relative impact of alternative input data (eg. changes in management practices, climate, vegetation etc.) on water resources can be quantified. SWAT is also computationally efficient as simulation of very large basins can be performed without excessive investment of time or money. SWAT enables the users to study long term impacts of climate change and management practices on the water resources of the watershed under consideration.

3.2.2 Limitations of SWAT model

The main weakness of the model is the non-spatial representation of HRU inside each sub catchment. This kept the model simple, semi-distributed and supported application of the model to almost every catchment. Land use, soil and slope heterogeneity of the model is accounted through sub-catchments. This approach ignores flow and pollutants routing between HRUs. Wide range of different input datasets needs to be obtained to run the model and numerous parameters needed to be modified during the calibration. This discourages modelers to use SWAT, by compromising on the model performance to predictions. More extensive use of the model would be expected with adding more groundwater routines and algorithms or with permanent coupling of the model with groundwater flow and transport models. SWAT ignores the movement of nitrate concentration as it moves through the vadose zone.

3.3 Data Processing in ArcSWAT

SWAT requires comprehensive datasets of weather, soil, topography, vegetation, and land management activities of the watershed at hru level provided on daily time steps

3.3.1 Data Collection

Weather data

SWAT requires daily meteorological data that can either be read from a measured data set or been generated by a weather generator model.The meteorological variables used for this study for driving the hydrological balance include precipitation, minimum and maximum air temperature, wind speed,relative humidity and solar radiation. The data was recorded on daily scale for the period May 2013 to May 2015 (to account for two complete irrigation years). These data were obtained from two automatic weather stations (AWS) located at Nizampur (17:6850, 78.0) and Kamkole (17.50,78.050). AWS captures the data at 30 minute intervals, which was accumulated / averaged for the given day.]

Soil Data

SWAT requires soil textural and physiochemical properties such as available water content, hydraulic conductivity, bulk density, infiltration capacity of each soil type. The undisturbed soil samples were

Parameter	Standard Method Adapted
Soil Bulk Density	IS 2720-Part 29
Saturated Hydraulic Conductivity of soil IS	IS17312-2005
Available Water Content	FAO table for AWC based on soil texture
Infiltration Capacity	ASTM D 3385-09

Table 3.1: Standard procedures adapted for Soil data analysis

collected from six locations distributed over the study area and was used to determine various soil parameters in the laboratory. Standard IS code methods were adapted to determine various soil parameters whose details are provided in the figure 3.1

Topographical data

Terrain characteristics and slope parameters are derived from the digital elevation model(DEM) of the study area. A 90 m DEM was downloaded from Shuttle Radar Topography Mission (SRTM) website and re-sampled to 30 m using cubic interpolation method.ArcSWAT tool was used to delineate the watersheds and drainage patterns of the region. Sub-basin parameters such as slope, sinks, and stream network characteristics were also derived from the DEM.

Landuse data

Landuse image was prepared by taking into reference the 30 m multispectral Landsat Google Earth image.

Management Practices

The various details on land management practices such as tillage, planting, irrigation, fertilizer application, harvesting operations, were gathered from the local Village Revenue Officers(VROs) from various Mandal offices across Ranga Reddy and Medak districts

3.3.2 Data Analysis

Weather Data

Meteorological parameters obtained at 30 minutes interval were changed to daily scale by aggregating the corresponding values of rainfall, computing the averages of solar radiation, wind speed, relative humidity, and considering the minimum and maximum values of temperatures of the day.

Soil Data

The undisturbed soil samples were used to determine the soil texture whose procedure is discussed below:

- **Soil Texture** Textural classification of the soil was performed as per the US specification. Soil texture defines the composition of the soil particles expressed as the percentage of sand, silt, and clay of total volume. The soil is first spread on a newspaper to dry. Then all stones, trash, and roots, were removed. Lumps and clods are then crushed, and the soil is pulverized. A tall, slender jar is filled with a one-quarter full of soil. Water is added until the jar is three-quarters full A teaspoon of sodium hexa-meta phosphate is then added and shaked hard for 10 to 15 minutes.This shaking breaks apart the soil aggregates and separates the soil into individual mineral particles. The jar is then un-disturbed for 2 to 3 days and the soil particles are allowed to settle down according to size. After 1 minute, the depth of the sand is marked on the jar. After 2 hours, the depth of the silt is marked. The clay level is labeled when the water clears off,which took about 1 to 3 days. The total thickness of the sand, silt and clay layers is measured followed by the calculation of the percentage of each layer. Finally the soil texture class is found out from the soil texture triangle (as specified by the Food and Agricultural Organization of the United Nations).

- **Soil Bulk density**: Soil Bulk density was determined through laboratory experiment in accordance with IS code 2720 Part 29. Undisturbed soil samples were collected from six locations in the study region to be considered as representative of the entire watershed.

- **Soil Hydraulic Conductivity**: Soil Hydraulic Conductivity was determined through laboratory experiment in accordance with IS code 17312 2005. Constant Head permeability test was performed to determine the saturated hydraulic conductivity of the soil.

Soil name	Geographic Location	Soil Bulk Density(g/cc)	Saturated Hydraulic Conductivit(mm/hr)	AWC%	Organic Content %	Infiltration rate(cm/hr)
Soil A	N 78°;17.68°	1.523	9.150	0.14	1.038	1.46
Soil B	N 77.90°;17.52°	1.562	8.650	0.14	1.038	1.52
Soil C	N 77.95°;17.58°	1.528	9.150	0.14	1.038	1.59
Soil D	N 77.98°;17.48°	1.613	28.500	0.14	1.038	1.64
Soil E	N 77.85°;17.64°	1.57	7.680	0.14	1.038	1.03
Soil F	N 77.84°;17.64°	1.54	38.500	0.14	1.038	1.46

Table 3.2: Standard procedures adapted for Soil data analysis

- **Soil Infiltration Capacity**: Soil Infiltration Capacity was determined through field experiments conducted at six locations of the study region considered to be representative of the entire watershed.US specification (ASTM D 3385-09) was adapted to determine the infilration capacity using a double ring infiltrometer.

- **Organic Content**: Organic content data used in the analysis was obtained from the data used for a research project in the same study region.

The available water content of the soil is based on the estimates published by Saxton and Rawls (2006). The field capacity and permanent wilting point required for this analysis are obtained from the texture of the soil determined from the procedure discussed previously.

Landuse Data

Landuse image was prepared by taking into reference the 30 m multispectral Landsat Google Earth image.A grid of multispectral images is formed, geo-referenced and landuse map is developed subsequently by taking the grid as a reference. Various land use patterns in the study region are identified by visual inspection and the land use map is prepared.

Management Practices

An extensive survey was conducted at six different villages of the study region considering the heterogeneity of the watershed. A standard questionnaire form was prepared in accordance with the data requirement for SWAT model with main emphasis on various land management practices like tillage, planting, irrigation, fertilizer application, harvesting operations was given. In addition to the land management practices data, crop yields specific to two crops, Cotton(Kharif) and Paddy(Rabi) were collected at two locations for the agricultural years 2013-14 and 2014-15. The management practices of all the major crops in the watershed are summarized and are classified into nine groups based upon the crop rotation followed for the crop. Since the data related to the spatial representation of the crops following similar rotation class was not available,it is assumed that the classes are distributed uniformly among the sub-basins in the watershed. Table 3.1 shows the detailed classification of existing management classes in the study region

3.4 Hydrologic Modeling

SWAT is a comprehensive, semi-distributed river basin model that requires a large number of input parameters. SWAT operates on a daily time step and is designed to predict the impact of land use and manage-

Crop Rotation Class	Area(Ha)	Kharif 2013(June-Sept)	Rabi 2013(Oct-Feb)	Summer 2014(March-May)	Kharif 2014(June-Sept)	Rabi 2014(Oct-Feb)	Summer 2015(March-May)
Class-I	5942.7	Cotton	Onion	Fallow	Cotton	Onion	fallow
Class-II	126.3	Cotton	Fallow		Cotton	Fallow	
Class-III	126.3	Maize	Fallow		Maize	Fallow	
Class-IV	74.3	Maize	Bengal-gram	Fallow	Maize	Bengal-gram	fallow
Class-V	22.3	Maize	Sunflower	Fallow	Maize	Sunflower	fallow
Class-VI	22.3	Paddy	Sunflower	Fallow	Paddy	Sunflower	fallow
Class-VII	200.6	Paddy	Fallow		Paddy	Fallow	
Class-VIII	37.1	Sugarcane		Fallow	Sugarcane		Fallow
Class-IX	74.3	Fallow					

Table 3.3: Crop Management Scenarios Practiced in the Singur-Manjeera Watershed

ment on water, sediment, and agricultural chemical yields in ungauged watersheds. The model is process based, computationally efficient and capable of continuous simulation over long time periods. Major model components include weather, hydrology, soil properties, plant growth, nutrients, pesticides, bacteria and pathogens, and land management. In SWAT, a watershed is divided into multiple sub-watersheds, which are then further subdivided into hydrologic response units (HRUs) that consist of homogeneous land use, management,topographical, and soil characteristics.

The HRUs are represented as a percentage of the sub-watershed area and may not be contiguous or spatially identified within the SWAT simulation. A HRU is the least spatial entity having uniform soil, slope, and land use characteristics.Water balance is the driving force behind all processes in SWAT because it impacts plant growth and the movement of sediments, nutrients, pesticides, and pathogens. Simulation of watershed hydrology is separated into i) the land phase,which controls the amount of water, sediment, nutrient, and pesticide loadings to the main channel in each subbasin, and ii) the in-stream or routing phase, that simulates the movement of water, sediments, etc., through the channel network of the watershed to the outlet.

Hydrologic processes simulated by SWAT include canopy storage,surface-runoff,infiltration, evapotranspiration, lateral flow, tile drainage,redistribution of water within the soil profile, consumptive use through pumping (if any), return flow, and recharge by seepage from surface water bodies, ponds, and tributary channels. SWAT uses a single plant growth model to simulate all types of land cover and differentiates between annual and perennial plants. Datasets used for simulation include:

1. Weather data: Rainfall, relative humidity, minimum and maximum temperatures, solar radiation, wind speed at daily scale.

2. Soil data: Various soil properties were derived by performing various field/laboratory techniques by taking a representative of six soil samples throughout the study region.

3. Land-use map: Prepared by taking into reference 30 m multispectral Landsat Google Earth image in ArcGIS environment.

4. Management practices: This was obtained after the discussions with local farmers and VROs.

   Datasets used for calibration include:

5. Actual Evapotranspiration values simulated by the model on daily time-step. The actual evapotranspiration values are simulated by

the model based on a method developed by Ritchie (1972) which computes evaporation from soils and plants separately.

ArcSWAT is the geographic information system (GIS) interface to SWAT, and was used as the pre-processor to input the spatial and temporal data sets. SWAT was run on monthly step for the irrigation years 2013-14 and 2014-15 ((1 June 2013 to 31 May 2015) by providing a warm up of two years (1 January 2011 to 1 January 2013)

The first step involved in the modeling is to delineate the watershed. Arc SWAT watershed delineator tool was used to process the DEM of the study area, and analyze for flow direction and accumulation.A threshold area of 250 hectares was specified for stream network and catchment delineation. This watershed was further divided into 20 sub-basins.

The second step is HRU analysis that involves landuse, soils and slope map representation using GIS. Theissen polygon technique was used to generate a soil map consisting of various soil parameters. The soil map consists of six types of soils characterized by Theissen weights which depend on the parameters unique to each soil.A total of 4 slope classes (0 to 2; 2 to 4;4 to 6;6 and more) were derived by processing the DEM for use with HRU analysis. The threshold values considered for each parameter in the HRU analysis are given below.

1. Landuse % over sub-basin area= 5

2. Soil class % over landuse area= 20

3. Slope class % over soil area = 20

This has resulted in the generation of 348 HRUs across the study area. Meteorological data from the two AWS stations, and the management data from the field visits was accordingly inputted to the model on monthly steps. The SWAT model was then run for a period of two year by providing two years of the data as warm up period and the corresponding output datasets (actual evapotranspiration, cumulative crop yield) were generated at HRU level. Figure 3.4 and Table 3.3 provide the spatial distribution of modeling units and their details respectively.

Data type	**Format**	**Scale/res**	**Source**	**Remarks**
Topgraphy Landuse	Image	-	Google Earth	-

Table 3.4: Description of datasets considered in SWAT simulation and calibration

3.5 Crop Yield Modeling

The plant growth component in SWAT is a modified version of the EPIC plant growth model.Plant development in SWAT is based on daily accumulated heat units,potential biomass is based on a method developed by Penman-Monteith.The growth cycle in plant is controlled by plant attributes present in the plant growth database.Harvest index is the parameter used to calculate yield.The plant growth model is used to assess the removal of water and nutrients from the root zone, transpiration, and biomass/yield production.Plant growth can be inhibited by water, temperature, nitrogen or phosphorus stress.In addition, SWAT models the movement and transformation of several forms of nitrogen and phosphorus, pesticides,and sediment in the watershed. SWAT allows the user to define management practices taking place in every HRU..Yield is calculated by multiplying the above ground bio-mass by a harvest index. The Harvest Index is the fraction of above ground plant dry biomass that is removed from the cultivated land as the yield which the biomass also depends on nutrient availability and temperature stress while the harvest index only depends on water stress. In addition, SWAT also incorporates provision for detailed root growth, micro nutrient cycling and toxicity responses and simultaneous growth of multiple plant species (through crop rotations)in the same HRU.

The main objective of crop yield simulation was to model the variation of yields for crops,Cotton(Kharif) and Paddy(Kharif) representing their spatial and temporal variation with uncertainty analysis at HRU level.The hydrologic model developed was extended to include crop yield using the crop growth module present in SWAT. The timings of operations of all the agricultural practices are listed in the management file.Irrigation and fertilization are specified manually based on the data collected.

Potential Evapotranspiration was simulated by Penmann-Montheith method. Actual Evapotranspiration is simulated by SWAT using the method proposed by Ritchie(1972). Crop growth paramters such as Leaf Area Index and root development were simulated on monthly time step. The partition between daily soil evaporation and transpiration was made based on monthly average value of LAI.

3.6 Calibration and Uncertainity

SWAT input parameters are process based and must be held within a realistic uncertainty range.The first step in the calibration and validation process is the determination of the most sensitive parameters for a given watershed. Sensitivity analysis is the process of determining the rate of change in model output with respect to changes in model inputs. It is necessary to identify the key parameters and the parameter precision required for calibration. This helps in determining the predominant processes for the component of interest. Global sensitivity analysis was performed,and the parameters sensitive to Crop yield and Actual Evapotranspiration were analyzed.Calibration and uncertainity analysis were performed in this study using observed values for bothb actual evapotranspiation and crop yield specific to Cotton and Paddy crops for the irrigation year 2014-15.Parameters sensitive to both crop yield and evapotranspiration were considered. The model was initially calibrated for Evapotranspiration and subsequently for crop yield.The SUFI-2 program in the SWAT-CUP package (Abbaspour, 2007) was used for parameter optimization. In the SUFI-2 stochastic optimization,parameter nonuniqueness(or parameter uncertainty) is also addressed simultaneously along with the calibration process. Using SUFI-2, all sources of uncertainty are mapped to a set of parameter ranges. Initial ranges are based on physically meaningful limits, within which a number of Latin hypercube parameter set samples (McKay et al., 1979) are obtained and simulated for each calibration iteration. Hence, parameters as well as simulation results are always expressed as distributions. For this reason, statistics such as R2 or Nasch-Sutcliffe (NS), which compare two signals, are not adequate for calculation of goodness of fit. For this purpose, SUFI-2 uses two different indices to quantify the goodness of calibration/uncertainty performance (Abbaspour et al., 2004, 2007). First,the P-factor, which is the percentage of data bracketed by the 95 % prediction uncertainty (95PPU) band (maximum value 100%) calculated at the 2.5% and 97.5% levels of the cumulative distribution of a variable obtained through Latin hypercube sampling.Second, the R-factor, which in this study is referred as Rm-factor, is calculated as the average width of the uncertainty band divided by the mean of the corresponding measured variable. Normally, standard deviation is used in the calculation of R-factor (Abbaspour, 2007).Ideally, we would like to bracket most of the measured data (plus their uncertainties) within the 95 PPU band (P-factor) while having the narrowest band (R-factor).Calibration is an effort to better parameterize a model to a given set of local conditions, thereby reducing the prediction uncertainty. Model calibration is performed by carefully selecting values for model input parameters (within their respective uncertainty ranges) and then by comparing model predictions for a given set of assumed conditions with observed data for the same conditions. The final step is validation for the component of interest(Evapotranspiration and Cumulative crop Yield).Model validation is the process of demonstrating that a given site-specific model is capable of making sufficiently accurate simulations.

Chapter 4

Simulation Results

4.1 Sensitivity Analysis

Parameter sensitivities are determined by calculating the statistical relation between the Latin hypercube generated parameters against the objective function values. The sensitivity of each parameter is estimated from the relative change of each parameter with respect o the objective function. One at a time sensitivity was conducted for all the sensitive parameters with a minimum of three simulation runs for each parameter and the potentially sensitive parameters are selected. A total of four parameters are found to e sensitive to actual evapotranspiration and a total of fie parameters are found to be sensitive to Crop yield parameters whose detailed description along with their respective thresholds are discussed in detail subsequently.

4.2 Calibration of Actual Evapotranspiration

Reference Evapotranspiration was estimated using the ASCE Standardized Reference equation and was multiplied with FAO Single Crop coefficient to obtain the observed value for Actual Evapotranspiration. Simulated Evapotranspiration was estimated by the model on a method developed by Ritchie(1972) as discussed previously.A total of four parameters were identified which are potentially sensitive to Evapotranspiration.

1. *Available Water Capacity of soil layer* the plant Available Water capacity is calculated by subtracting the fraction of water present at permanent wilting point from that present at field capacity.

2. *Maximum rooting depth of soil profile* It is defined as the maximum depth upto which the roots can develop in a given soil layer. This can change from layer to layer

3. *Specific yield of shallow acquifer* Specific yield is defined as the ratio of volume of water that drains by gravity to total volume of the rock.

4. *Groundwater Revap Coefficient* The abstractions caused due to diffusion and evaporation of water during its movement from shallow aquifer to vadose zone and the effect of direct uptake of water from shallow aquifer by the deep rooted plants are accounted for in Groundwater revap coefficient.

The model sensitive parameters specific to Evapotranspiration along with their best fitted values, initial and final ranges used in simulation are given in Table 4.1.A total of 100 simulation runs have been performed by providing the absolute minimum and maximum values as the lower and upper bounds for the sensitive parameters. The objective function used for calibration of actual evapotranspiration is the Coefficient of determination R^2. Figures 4.5,4.6,4.7,4.8 shows the 95 PPU plots for calibrated ET values for Cotton and paddy crops foe the sub-basins 3 and 8 respectively.The ET values for Cotton varied between 250-310 mm. The ET values of Paddy rangd between 150-340 mm. It has been observed that Cotton has more ET values than paddy due to the prolonged cropping period.Also the model is slightly overestimating the Paddy ET values for HRUs 45 (Sub-basin 3) and HRU 117 (Sub-basin 8) and slightly underestimating the Cotton ET values for the same. Figures show the parameter value Vs objective function value graphs known as "Dotty Plots"

Parameter Representation in SWAT	A SOL_AWC.sol	R SOL_ZMX.sol	V GW_SPYLD.gw	V GW_REVAP.gw
Description of the parameter	Available water capacity of the soil layer	Maximum rooting depth of soil profile (mm)	Specific yield of the shallow aquifer (m3/m3)	Groundwater "revap" coefficient
Initial value	0.15	2499	0.15	0.02
Final Fitted Value	0.15075	2566.473	0.1115	0.1515

Table 4.1: Description of model sensitive parameters specific to AET considered for calibration

4.3 Calibration of Crop Yield

Crop yield at the end of harvest for the irrigation year 2014-15 is calibrated at the subbasins 1,3,8,15,17,18. The parameters sensitive to crop yields

1. Biomass/energy ratio: It is the amount o dry biomass produced per unit intercepted solar radiation. It is assumed to be independent of plant's growth stage. It represents the potential or unstressed growth rate (including roots) per unit of intercepted photosynthetically active radiation

2. Harvest Index: The Harvest Index is the fraction of the above-ground biomass that is removed in he harvest operation.

3. Maximum Leaf Area Index: It is defined as the potential Leaf Area Index which occurs when the plant does not undergo any water or nutrient stress

4. Initial Leaf Area Index : It is defined as the Leaf Area Index of the landcover growing at the beginning of the growing season.

5. Maximum root depth for the crop: It is defined as the deepest increment of soil core in which the live root plants are found.

Table provides the threshold ranges of the above discussed parameters.The method of calibration adapted to update their values and the and source files of the same.A total of ten simulation runs are found to be optimal for the calibration of Crop yield specific to Cotton and

Parameter Representation in SWAT	V BIO_E{..}.crop.dat (Cotton)	V BIO_E{..}.crop.dat (Paddy)	V HVSTI{..}.crop.dat (Cotton)	V HVSTI {..}.crop.dat (Paddy)	V BLAI{..}.crop.dat (Cotton)	V BLAI{..}.crop.dat (Paddy)	V LAI_INIT {..}.mgt	V RDMX{..}.crop.dat (Cotton)	V RDMX{..}.crop.dat (Paddy)
Description of the parameter	Biomass/ Energy Ratio	Biomass/ Energy Ratio	Harvest index	Harvest index	Max leaf area index	Max leaf area index	Initial leaf area index	Max root depth	Max root depth
Initial value	15	20	0.4	0.3	1.25	5.8	65	2.3	0.9

Figure 4.1: Description of model sensitive parameters specific to crop yield considered for calibration

Paddy for the agricultural year 2014-15. Figure shows the 95 PPU plot for both the crops for the irrigation year 2014-15. The Crop Yield values for Cotton and Paddy varied between 800-2400 kg/Ha and 500-1900kg/Ha respectively for the agricultural year 2014-15. It has been observed that Cotton has more Crop yield values than paddy due to the prolonged cropping period.The width of 95 PPU band is low for sub-basins: 3,8,17,and 18.Observed and best simulated crop yields (for both crops and almost all sub-basins) are well in agreement.Sub-basin 1 has highest 95 PPU band specific to Cotton(high uncertainty), and highest prediction error (The difference between observed and simulated values) specific to paddy.As yield and ET are closely related, calibration of yield increases our confidence in ET as well

4.4 Correlation between Actual Evapotranspiration and Crop yield

Model simulated Actual Evapotranspiration and crop yield are in close agreement with the observed values, specific to HRUs 46, 114 (Cotton) and 45, 117 (Rice).The relationship between Cotton and Paddy crops for the irrigation year 2014-15.Data points of all the subbasins for both Cotton and Rice crop were used in the illustration.A strong positive correlation between ET and crop yield was observed for both crops(R^2=0.8). This clearly states that, increase in crop yield is mainly attributed to increase in AET. Figures 4.1 and 4.2 shows the crop yield-ET correlation for Cotton and rice crops for Sub-basins 3 and 8 respectively.

4.5 Crop Water Productivity

The Crop Water Productivity links water consumption to yield and thus provides as an indicator for the value of unit of water. It is given by the relation

$$CWP = \frac{Y}{ET}$$

which is the consumptive use of the crop.

Evapotranspiration was calculated on monthly basis. After the model was calibrated for both Evapotranspiration and yield at HRU level for the certain selective HRUs, the SWAT simulation was run using the calibrated model. Then the CWP values for the two major crops under study (Cotton and Paddy) for the irrigation year(2014-15) was calculated for the entire subbasin. Yield-ET-CWP assessment maps were prepared for the entire watershed for Cotton and Paddy for the irrigation year 2014-15 at HRU level. Since spatial distribution of HRUs cannot be identified in SWAT,each subbasin of the watershed was classfied into three classes which inlude Cotton,Paddy and rest of the crops. Based on the percentage of land cultivated for Cotton and Paddy,each subbasin was arbitrarily divided into these three predefined classes and the assesment maps were prepared. From the assesment maps shown in the figure it can be inferred a strong correlation exists between yield and ET(during 2014-14 kharif season) except subbasin 20. It was also identified that subbasins in the direction of flow of the Manjeera river(ex:5,6,7) have recorded the highest yield and hence the highest CWP.Paddy ,being an irrigated crop was observed to have higher values of CWP compared to Cotton which is a rainfed crop

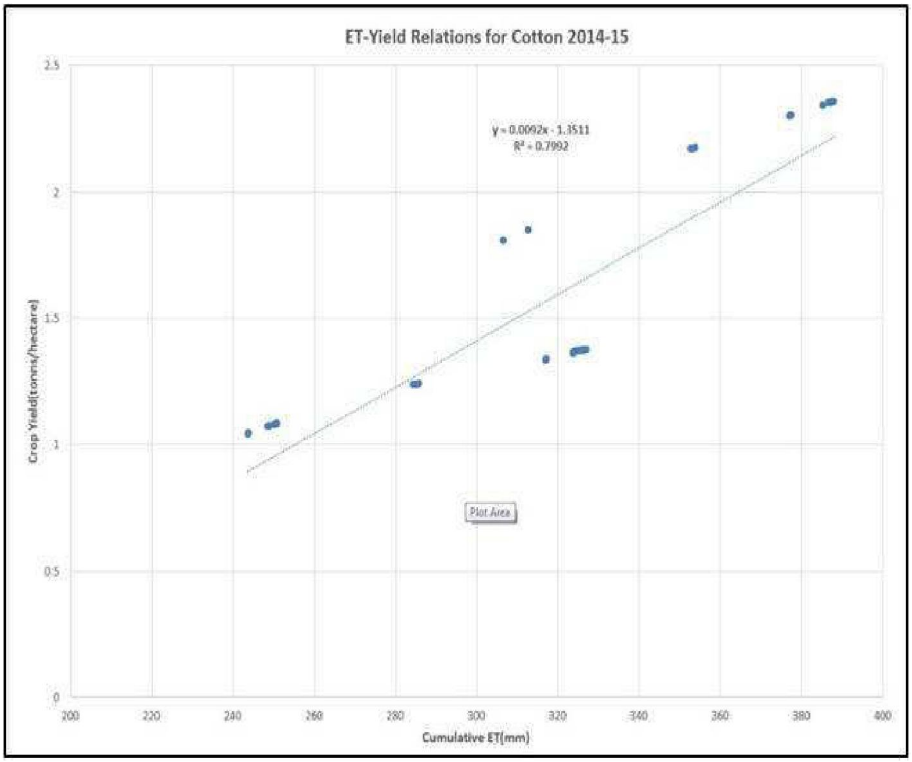


Figure 4.2: ET-Yield correlation for Cotton in 2014-15

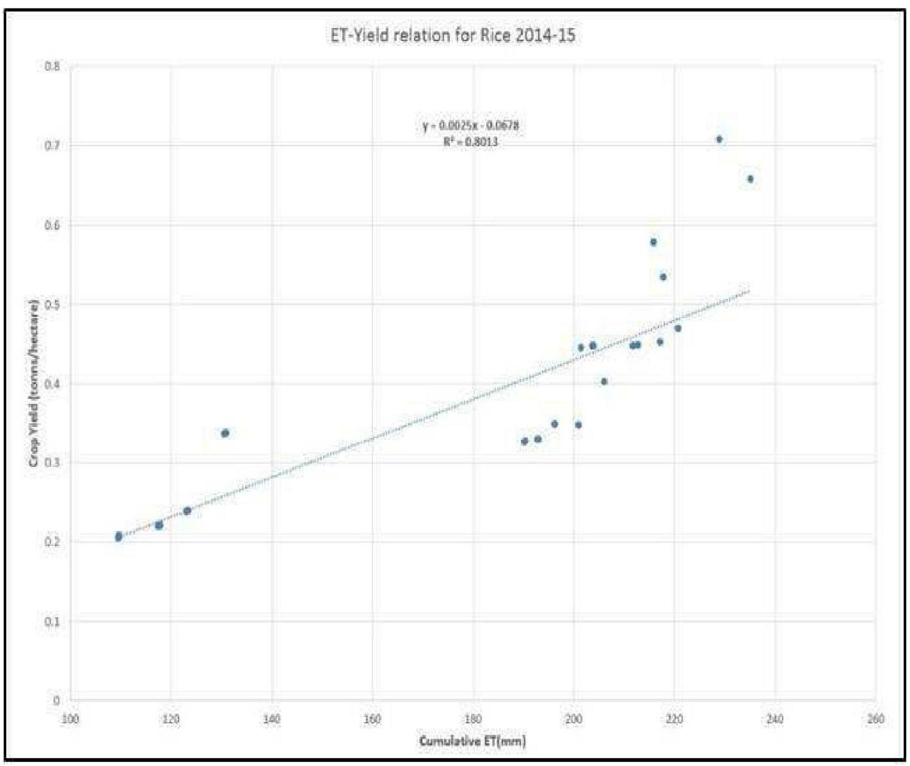


Figure 4.3: ET-Yield correlation for Rice in 2014-15

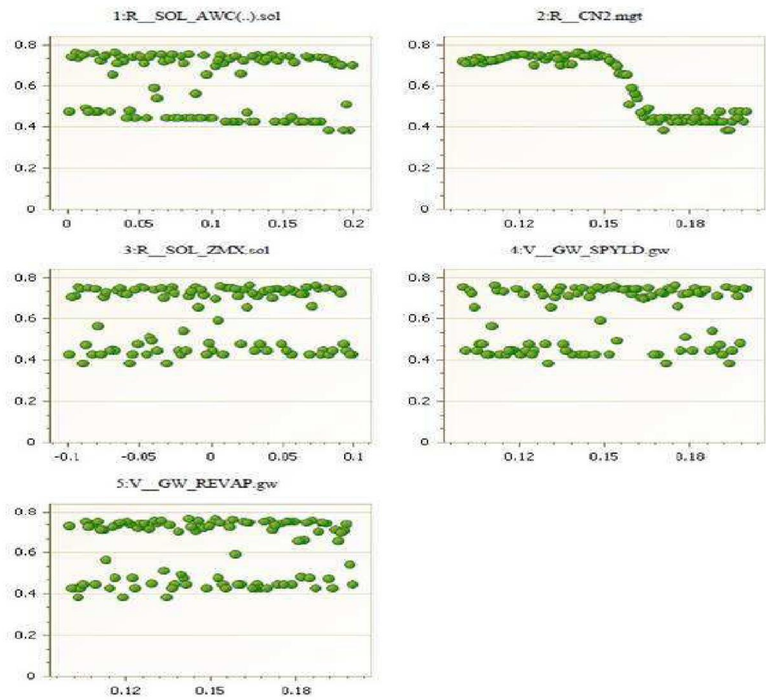


Figure 4.4: Dotty Plots ET calibration

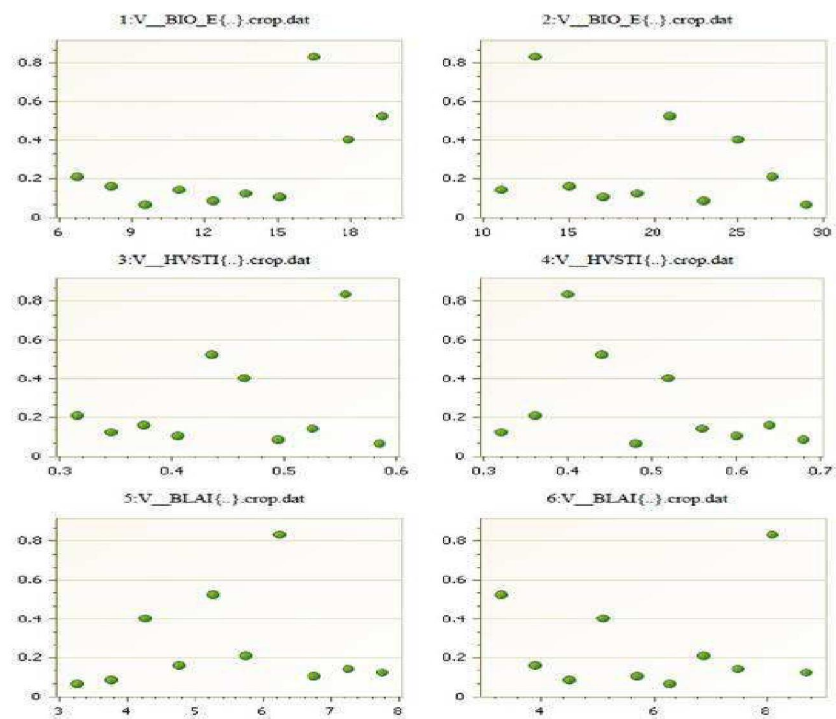


Figure 4.5: Dotty Plots Crop Yield calibration

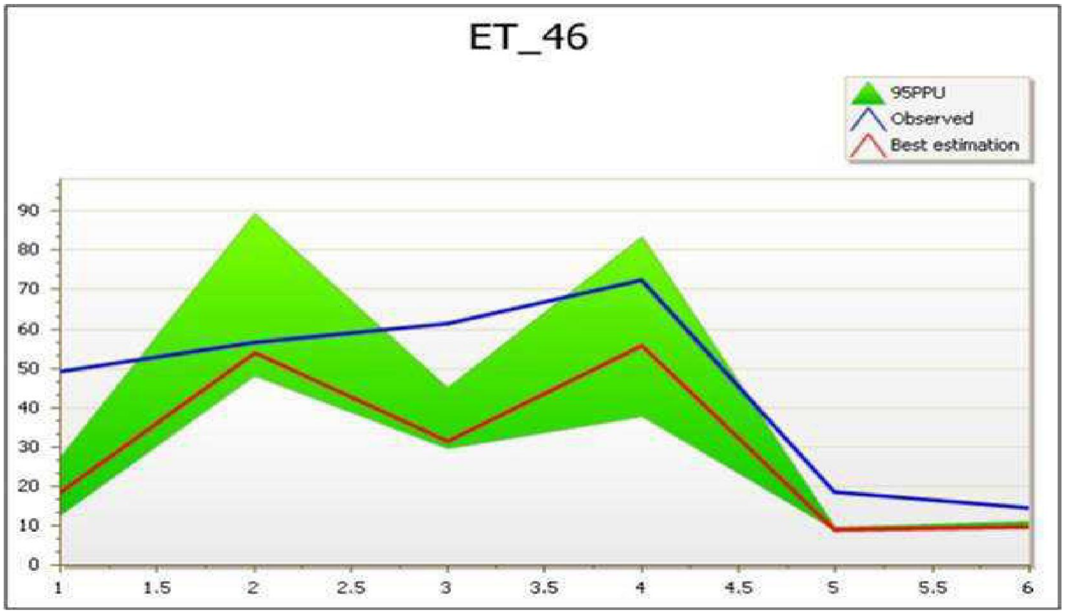


Figure 4.6: Comparison of simulated and observed ET values specific to Cotton crop for 2014-15 for sub-basin 8

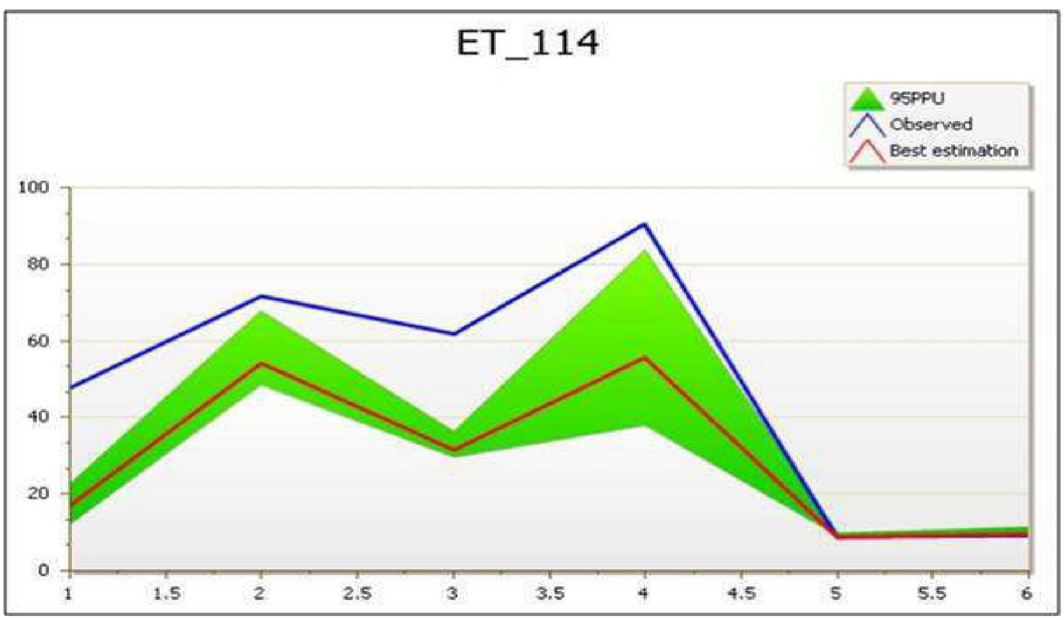


Figure 4.7: Comparison of simulated and observed ET values specific to Cotton crop for 2014-15 for sub-basin 3

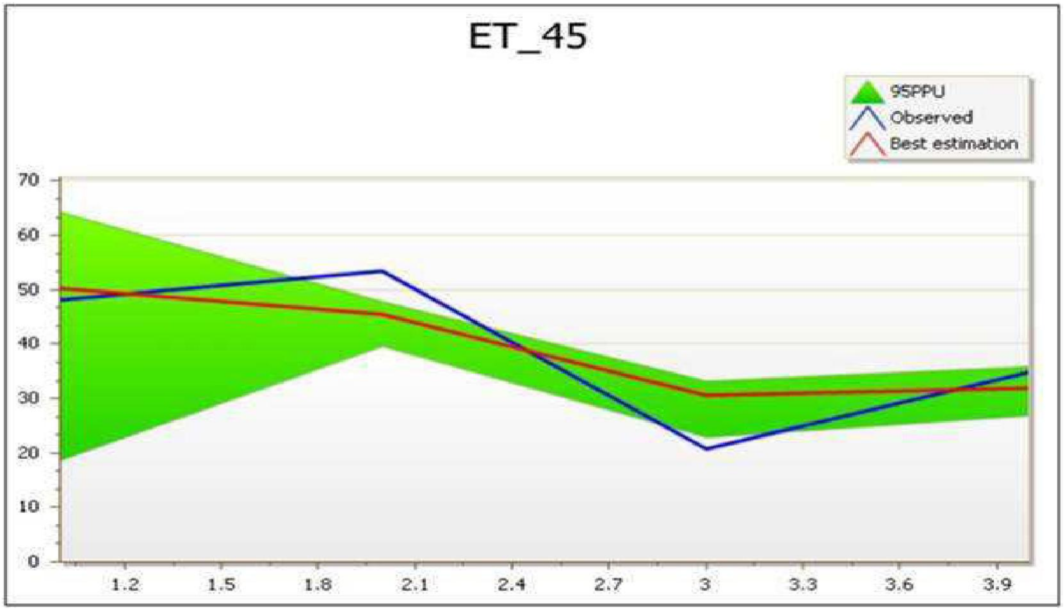


Figure 4.8: Comparison of simulated and observed ET values specific to Paddy crop for 2014-15 for sub-basin 8

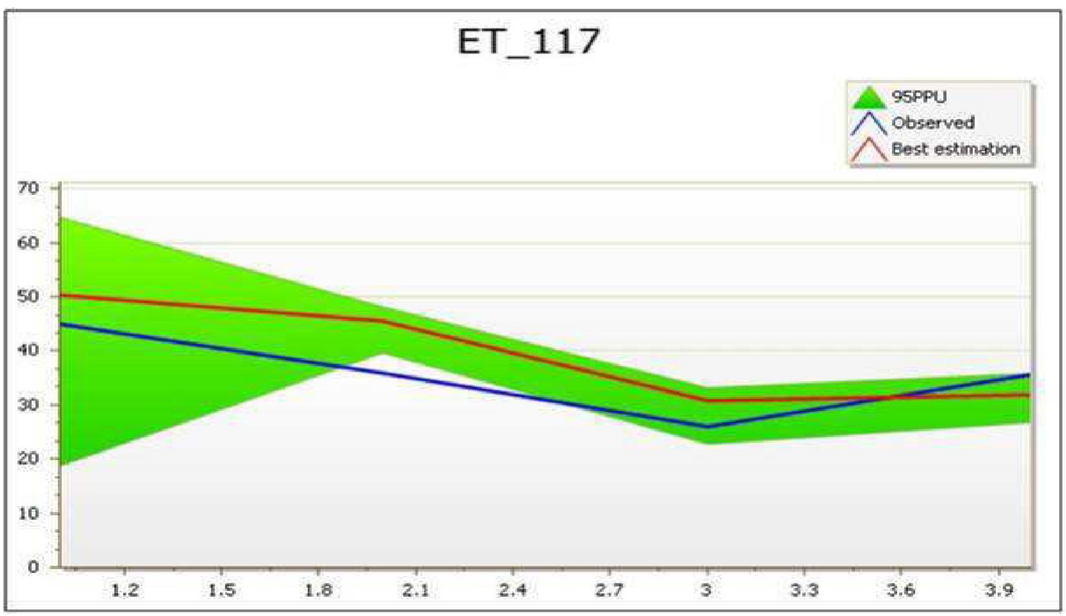


Figure 4.9: Comparison of simulated and observed ET values specific to Paddy crop for 2014-15 for sub-basin 3

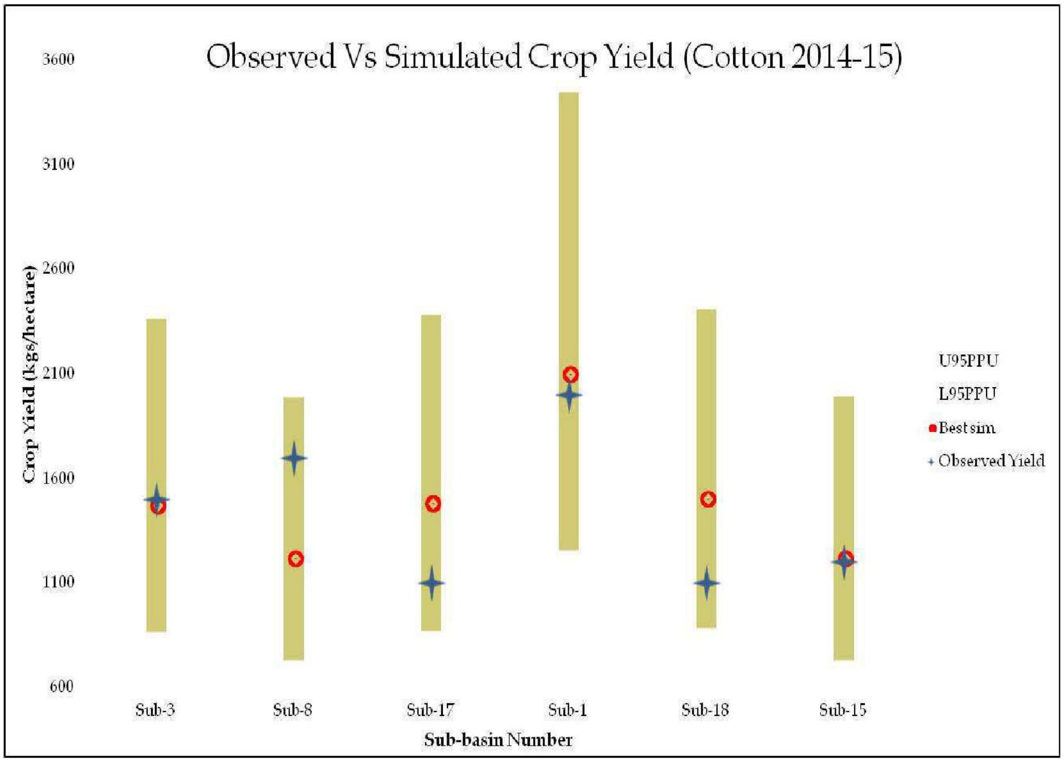


Table 4.2: Comparison of simulated and observed yield specific to Cotton for subbasin 3 2014-15

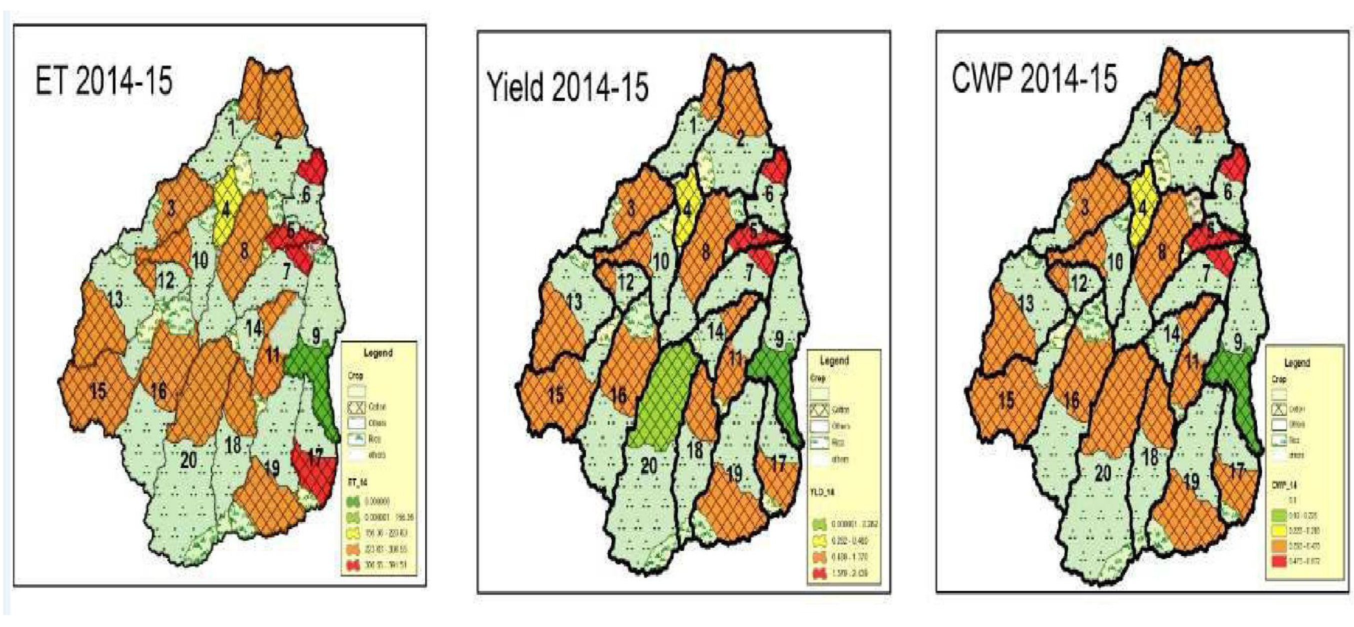


Figure 4.10: Yield-ET-CWP assessment maps for Cotton and Paddy 2014-15

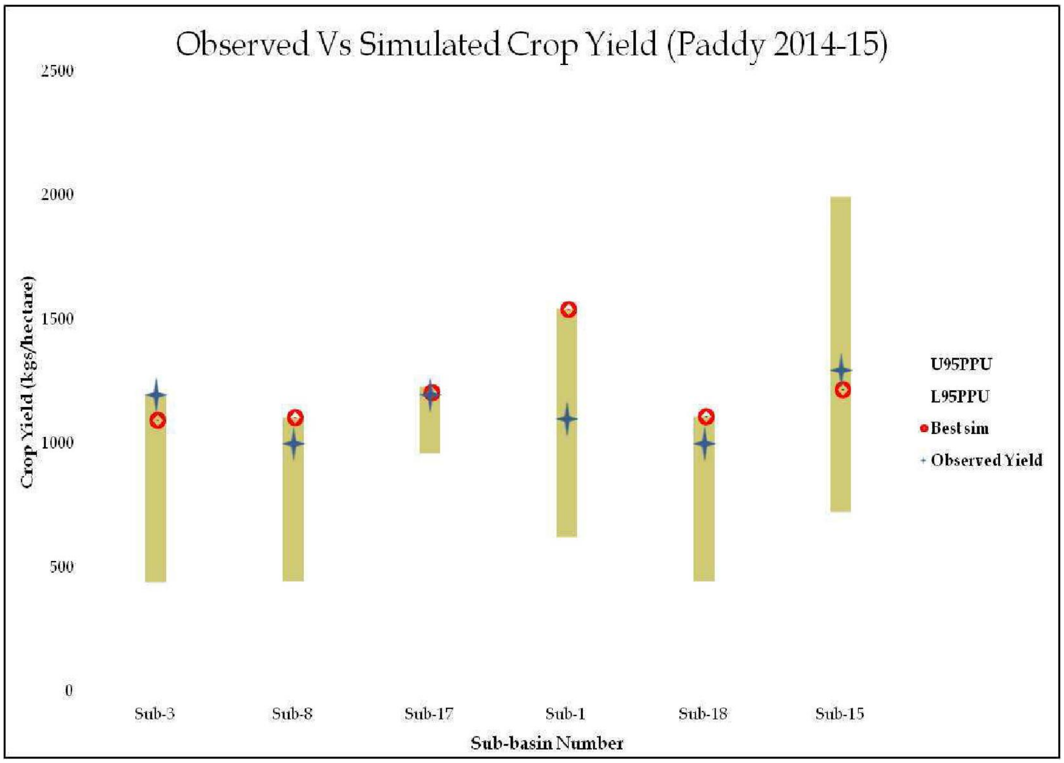


Table 4.3: Comparison of simulated and observed yield specific to Cotton for subbasin 8 2014-15

Chapter 5

Evaluation of Management Scenarios

5.1 Introduction

Implementing Best Management Practices (BMPs) can minimize the potential for agricultural nonpoint source water pollution and other adverse environmental and social problems. BMPs are practices based on the best available research and scientific data. They permit efficient farming operations while achieving the least possible adverse impact upon the environment or human, animal and plant health. Selection, design and implementation of appropriate BMPs require evaluation of resources involved, and the potential impacts on them.BMPs also require evaluation of the needs for sustainable agriculture, farm operations and markets and existing practices.Approaches to farming that seek to minimize use of agricultural chemicals and fertilizers without sacrificing economic viability are strongly recommended. These approaches are known as Sustainable Agriculture, and Integrated Farm Management. The goals of the various systems are to minimize chemical input and maintain environmental quality and agricultural productivity.

It is usually possible to select, combine design and implement BMPs to protect surface and ground water and accommodate other environmental, social and economic concerns. The effects of practices on both ground and surface water quality must be considered when solving agricultural nonpoint source problems.

5.2 Management scenarios considered for evaluation

The calibrated SWAT model was applied for simulation for the entire watershed to arrive at the baseline scenario. The baseline scenario depicts the existing management scenarios followed in the watershed for the calibrated model.It was used as a reference to analyze four other scenarios of potential best management practice options in order to optimize CWP values specific to Cotton and Paddy for the irrigation years 2014-15.They include an improvement of soil Available Water Capcity(AWC) by 5%(AWC_1)and 10%(AWC_2), Auto irrigation(Auto_IRR)where in the irrigation requirements of the crop are allowed to be met by the model based on the amount of water needed by the plant, Auto Fertilization operation(Auto_fert), wherein,the fertilizer to the crop was applied whenever, the nitrogen stress of the crop falls below a predefined threshold. An assessment of these BMPs were applied to all applicable lands or channels across the whole watershed.The detailed description of each of these four management scenarios is as follows:

1. AWC_1:Soil management through improving soil fertility or available water capacity(AWC) has been considered as one of the priorities and future challenges on the enhancement of agricultural productivity.Proper soil management practices are usually urged by policy makers for sustainable agriculture.However, their impact on water use is usually not known.In this scenario, the soil Available Water Capcity(AWC) was increased by 5% and the CWP values obtained for the entire watershed for the crops Cotton and Paddy are compared with baseline scenario. It was observed that the average CWP value for Cotton was found to increase by 6.19 % due to a 5% increase in the AWC.The CWP of Paddy crop has improved by 9% as compared to the baseline scenario.So it can be inferred an improvement in the soil Available Water Capcity(AWC) by 5% leads to a slight improvement n the CWP of Cotton crop and a significant improvement of CWP values were observed for Paddy crop specific to the irrigation year 2014-15.

2. AWC_2: In this scenario, the soil Available Water Capcity(AWC) was increased by 10% and the CWP values obtained for the entire watershed for the crops Cotton and Paddy are compared with

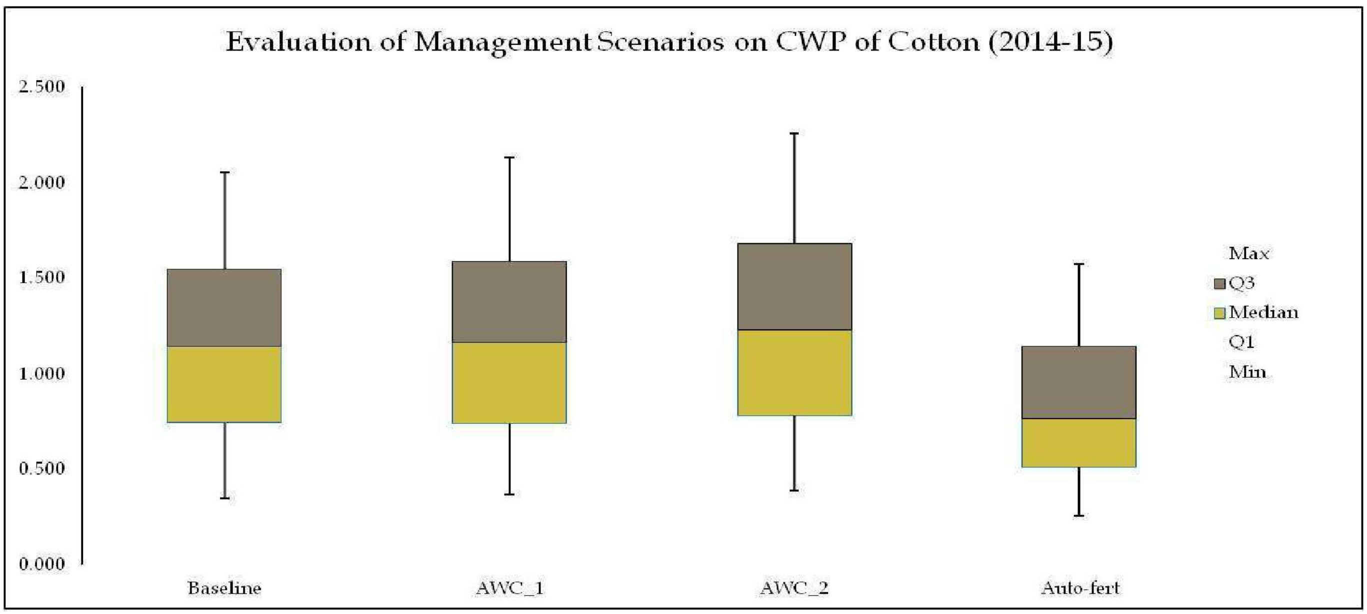
baseline scenario. It was observed that the average CWP value for Cotton was found to increase by 12% due to a 10% increase in the AWC.The CWP of Paddy crop has improved by 18% as compared to the baseline scenario.So it can be inferred an improvement in the soil Available Water Capcity(AWC) by 10% leads to a significant improvement of CWP values for both the crops specific to the irrigation year 2014-15

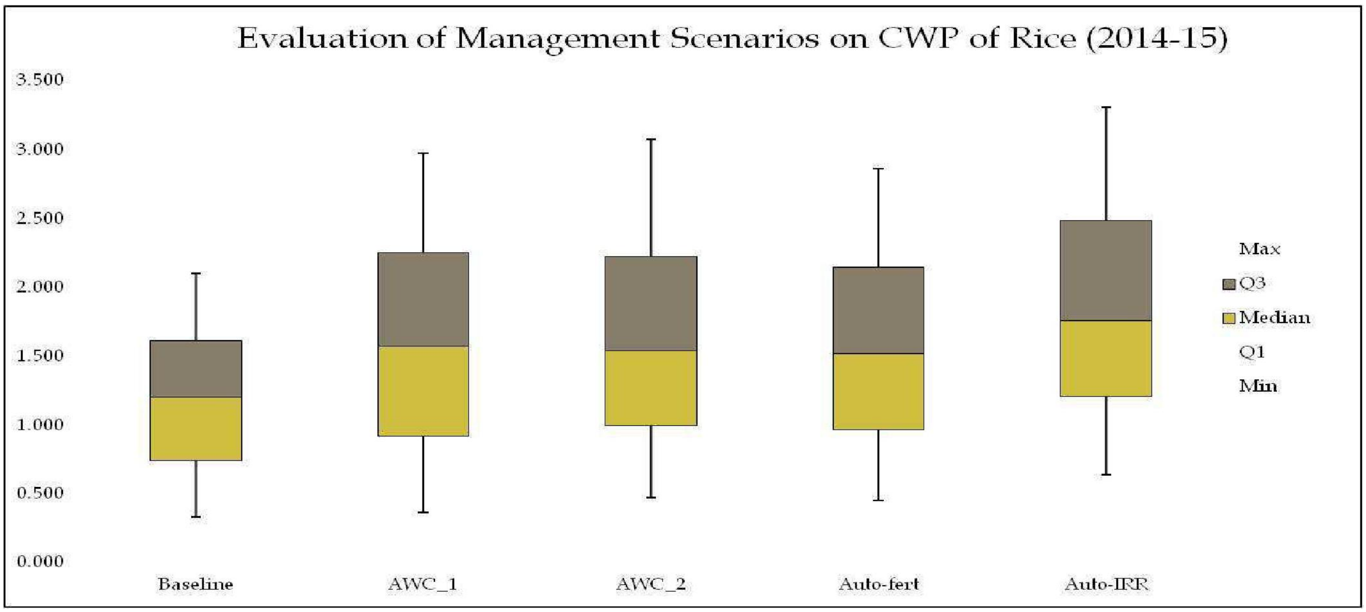
3. Auto_IRR: This scenario was considered only for paddy as Cotton is a purely rain-fed crop in the study region. The management scenarios were updated by discarding the dates of irrigation considered for the crop and Auto-irrigation was applied where-in the crop is provided with adequate amount of water whenever the water availability for the crop drops down below a pre-defined threshold. It was observed that Auto IRR is potentially the best management practice specific to paddy as there has been an increase in CWP value of over 20% when compared to the baseline scenario. So it can be inferred that irrigation scenario has the highest significant effect on CWP of Paddy.

4. Auto_fert: Fertilizer application has been one of the major ways to increase crop yield. To assess yield changes with increasing fertilization an option in the SWAT program that applies unrestricted fertilizer as required known as Auto-fert was used.It has been observed that as fertilizer constraint is relaxed for rainfed Cotton, there has been a significant drop in the CWP values. For Paddy,

the removal of fertilizer constraint has significantly improved the CWP values. So it can be inferred that the Fertilizer application of the existing management scenario has been in agreement with the nutrient requirement of the crop.For Paddy,Auto fertilization has resulted in increased CWP. So, it can be inferred that an increase in CWP of Paddy can be achieved through improving fertilizer application.

The figures show the evaluation of management scenarios specific to Cotton and Paddy with Crop Water Productivity (CWP) as the criteria for the irrigation year 2014-15.




Evaluation of Management Scenarios on CWP of Rice (2014-15)
3.500
3.000
2.500
2.000
1.500
1.000
0.500
0.000
Baseline
AWC_1
AWC_2
Auto-fert
Auto-IRR
Max
Q3
Median
Q1
Min

Chapter 6

Conclusions

6.1 Summary of the work

Effective management of irrigation water requires a prior knowledge of crop water requirement.An understanding water-plant-yield relations at sub-catchment scale, by analyzing crop water productivity (CWP) considering various management scenarios was performed. A hydrologic model of the Singur-Manjeera Basin in Telangana, India was developed in the present study. Process based hydologic model, SWAT was used to simulate crop yield on monthly time step for the irrigation years 2013-15. Major crops grown in the region include Cotton, Maize, Paddy and Sugarcane. Data on meteorological, soil, land-use, crop, irrigation, and management practices was provided using ArcSWAT. A total of 348 hydrological response units (HRUs), 20 sub basins, and 20 reaches were delineated. Model calibration (for crop yield and actual evapotranspiration) was performed at HRU level specific to Cotton (Kharif) and Paddy (Khartif) crops using SUFI-2 algorithm in SWATCUP. The calibrated model was further applied to evaluate the impact of various conservation practices by considering changes in Available soil Water Content (AWC), Irrigation, fertilizer. Statistical analysis was performed to rank the management practices (that are specific to the region) considering higher CWP

6.2 Conclusions

1. A comprehensive hydrologic and crop yield model of the Singur-Manjeera catchment is developed using SWAT
2. A total of 20 sub-basins and 348 HRUs were delineated
3. The model was simulated on monthly step for 2013-15, and calibrated for ET and crop yield at HRU level
4. SUFI-2 algorithm in SWATCUP was used for model calibration, and parameter uncertainty analysis
5. Model sensitive parameters to hydrology include Soil water content, Sp. Yield, REVAP Coefficient.
6. Model sensitive parameters to crop yield include Harvest Index,Leaf Area Index,Bio Mass Efficiency,Maximum root depth of the crop.
7. Goodness of calibration / uncertainty analysis was evaluated using p-Factor, R-factor, R2, and MSE.
8. A strong co-relation between ET and crop yield was observed for both Cotton and Rice crops.

9. Both Cotton and Rice have recorded same CWP
10. AWC prior to tillage has a profound effect on productivity of Rice compared to rain fed Cotton
11. Spatially, the sub-basins along the main stream of the watershed has recorded highest CWP
12. Fertilizer application practiced within the study area has resulted in higher CWP for Cotton, and lower CWP for Rice
13. Improving irrigation amount (efficiency) will greately improve CWP

6.3 Limitations of the research

Following are the limitations of the present research.

1. Same meteorological data was used for warm-up and during actual simulation as data for the previous contiguous years were not available for the study region
2. As the data specific to the spatial representation of the crop classes following similar rotations were not available,the classes were uniformly distributed among all the sub-basins which does not replicate the actual field conditions
3. Although,groundwater levels is considered to be a significant factor which effects ET-Yield relations,the model was not calibrated for ground water levels as the modeling of groundwater level in SWAT at HRU level on a monthly timestep is complex.

4. BMP evaluation was performed considering the optimization of the CWP as the sole objective. But the effect of nutrient loading and Ground water depletion levels are to be considered as significant factors to propose an ideal BMP in addition to imprvement in crop yield

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Declaration

I declare that this written submission represents my ideas in my own words and where others' ideas or words have been included, I have adequately cited and referenced the original sources. I also declare that I have adhered to all principles of academic honesty and integrity and have not misrepresented or fabricated or falsified any idea/data/fact/source in my submission. I understand that any violation of the above will be a cause for disciplinary action by the Institute and can also evoke penal action from the sources that have thus not been properly cited, or from whom proper permission has not been taken when needed.

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This thesis entitled by "Evaluation of Management Practices on Crop Yield Simulations in a semi-arid watershed using process based Hydrologic Model" by P V N Gautham is approved for the degree of Master of Technology from IIT Hyderabad.

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