Integration of satellite data in the SWAT watershed water quality model: A case study of Roxo reservoir watershed, Portugal.

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By

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This work is dedicated to:

Nosa
(For his endless love)

&

Iyobosa
(For giving me the opportunity to experience motherhood)

Abstract

Various research on Roxo watershed have shown cases of the eutrophic nature of the Roxo reservoir. The processes that influence nutrients sources, transport, and delivery from watershed to lakes and reservoirs are most efficiently evaluated using computer models such as the Soil Water Assessment Tool (SWAT). This research evaluates the capability of the *"SWAT"* hydrology (H)/water quality model (WQ) in simulating stream flow and nutrient (nitrogen and phosphorous) transport from watershed to surface water (Roxo reservoir). Effort was made to calibrate and validates the SWAT model in Roxo reservoir watershed for hydrologic component because nutrient (N & P) fluxes are believed to be influenced by water fluxes. This research examines the impact of different rainfall forcing methods on the Soil Water assessment Tool (SWAT) hydrology/water quality model. ArcSWAT2005 interfaced with ArcGIS 9.2 was used to extract and process the input parameters which include a digital elevation model (DEM), land cover and soil map GIS data layers. Three types of rainfall forcing, which include the SWAT weather generator, point gauge and satellite observation rainfall data were used for simulation. A comparison was made between the simulation outputs and the result shows that the point gauge rainfall input to be better than the weather generator and satellite rainfall forcing. After analyzing cold simulation results, the gauge simulation was chosen for hydrologic model calibration. The model was calibrated and validated for stream flow in one location at the outlet of the catchment using monthly time steps. A sensitivity analysis was carried out to help determine the parameters to adjust during the calibration. Of these parameters, the most sensitive were the Curve number (CN), threshold depth of water in the shallow aquifer required for return flow to occur (Gwqmn), base flow alpha-factor (Alpha_Bf), threshold depth of water in the shallow aquifer for 'revap' to occur (Revapmn), soil evaporation compensation factor (Esco) and available water capacity of the soil layer (Sol_Awc). Statistical indicators like the Natsh-Sutcliffe (NSE) and Percentage bias (PBIAS) as well as graphical techniques and plots of 1:1 line were used to evaluate the SWAT model performance. In general simulations matched observed stream flow as the NSE estimates gave good range of values (about 0.77) for calibration period (2001-2004) and validation (about 0.64) for the period 2005-2007. A strong correlation was found between observed and simulated stream flow as the regression R^2 of the 1:1 plots gave 0.77 and 0.75 for calibration and validation respectively. The calibrated model was further used to assess nutrient (N & P) export and loadings into the Roxo reservoir. The results reveal that there is a strong relationship between nutrient concentration and stream flow. Furthermore the model results from model output was used to identify critical and source areas in the watershed, the information extracted from this can be used to evaluate management scenarios to reduce runoff, sediment and nutrient losses from watershed. Though hydrologic calibrations results reveal SWAT as a great tool for understanding the hydrologic component of the Roxo reservoir, water quality calibration will be needed to ascertain reliable nutrient loads to help in effective soil and water management , planning and decision making processes in the catchment.

Keywords: SWAT, rainfall forcing, sensitivity analysis, auto-calibration, nutrient export.

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Acronyms

COTR:	Centro Operativo e de Technologia de Regadio
SNIRH:	Sistema Nacional De Informacao De Recursos Hidricos
SCS-N:	Soil Conservation Service- Curve Number
NRCS:	Natural Resource Conservation Service
CORINE:	Coordination of information on the environment
EEA:	European Environment Agency
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
MSG	Meteosat Second Generation
MPE	Multi-Sensor Precipitation Estimate
NEXRAD Stage III	Next Generation Weather Radar
TRMM	Tropical Rainfall Measuring Mission

1. Introduction

Background

The importance of water quality is enormous because of its linkage to various uses which includes its impact on agriculture, public health, drinking water and other intrinsic values. Conversely, pollution of any water sources by nutrients is detrimental to daily water consumption and human food chain. Quality of life is often judge on the availability of pristine waters. In same discourse, Maidment (1992) states that water contamination deprives present and future generations of a birthright. Freshwater of adequate quality is therefore a necessity for sustainable development.

High nutrient loads from upstream watershed activities such as urban runoff, hydrological modifications and agriculture have been identified as the leading cause of impairment in some lakes and reservoirs (Migliaccio et al., 2007; USEPA, 2000) . These nutrients load into lakes and reservoirs are a concern because of their potential to accelerate eutrophication rates which results in water quality problems. As reservoirs become eutrophic, they are often characterized by hypolimnetic dissolved oxygen depletion, increases in suspended solids, progression from a diatom population to a blue-green or green algae population, changes in food web structure and fish species composition, and decreasing light penetration (Henderson-Sellers and Markland, 1987; OECD, 1982).

Various research on Roxo watershed (Chisha, 2005; Shakak, 2004) have shown cases of the eutrophic nature of the Roxo reservoir. According to Migliaccio *et al.* (2007), the processes that influences nutrients sources, transport, and delivery from watershed to lakes and reservoirs are most efficiently evaluated using computer models such as the Soil Water Assessment Tool (SWAT).

This research therefore evaluates the capability of the *"SWAT"* hydrology water quality model (WQ) in simulating stream flow and nutrient (nitrogen and phosphorous) transport from watershed to surface water (Roxo reservoir). Effort is being made to calibrates and validates the SWAT model in Roxo Reservoir Watershed for hydrologic component because nutrient (N & P) fluxes are believed to be influenced by water fluxes (Pohlert et al., 2005).

1.1. Problem statement

Roxo reservoir is located in Beja district of Alentejo province in southern Portugal with catchment area of about 353 km^2. Major source of water to the reservoir is the river Roxo. Average area covered by the reservoir is 1,378 ha. The reservoir dam was constructed in the year 1968 primarily for irrigation and domestic water supply. It also provides water to some local industries (Pawan and Gieske, 2006). Ensuring good water quality of this reservoir is therefore very important because of its linkage to various uses. However, eutrophication has remained a major cause of water quality impairment in the reservoir and this negative impacts call for further investigation.

1.2. Justification

Nonpoint source or diffuse pollution is a leading cause of water quality problems in Roxo reservoir and worldwide, but due to its distributed nature, it cannot be monitored directly in the same manner as point sources. In this context, computer models such as SWAT have the potential to be used as tools for supporting watershed management policy, because they can provide estimates of sediment, nutrient and pesticide loadings for agricultural watersheds (FitzHugh and Mackay, 2000). A review of various non point source pollution models and their applications by Borah and Bera (2003) gave an indication that SWAT is suitable for long term continuous predictions in agricultural watersheds such as the Roxo reservoir watershed.

In addition, the SWAT model has shown the following merits that thus warrant its use in this research: Ability to represents landscape processes and the impacts of agricultural management and land uses on water quality which is one major focus of the research; It has an easy to use interface for model set-up which has been integrated into ArcGIS as extensions; it is one of the nine contemporary methodologies currently used for quantifying diffuse losses of N and P by European research institutes to inform policy makers at national and international levels (Euroharp, 2005). All versions of the model and documentations are available online (http://www.brc.tamus.edu/swat) free of charge; the model is supported by the knowledge of its developer and users by means of online user forum; thus it is a hydrological model that respects the principles of good modelling practice.

The accuracy of WQ models in predicting the hydrologic and erosion behaviour depends, to a large extent, on the quality of the knowledge in respect of the spatial rainfall. This is so because rainfall is a key input for all H/WQ models as it stimulates flow and mass transport process in hydrologic systems. But predictions using rainfall records from the national service stations produced inaccurate estimations (Chaplot et al., 2005), it is thus expected that by using these rainfall records in conjunction with satellite rainfall estimate, the predictive capability of the WQ/H models will be improved.

Chaubey et al. (1999) also carried out a study of uncertainty in model parameters due to spatial variability of rainfall. The authors concluded that a large uncertainty in estimated parameters resulted from the spatial variability of rainfall. Their results shows that uncertainty in the estimated parameters using the rainfall observed by a single gauge exceeded the rainfall measurement error and large uncertainty in estimated model parameters can be expected if detailed variations in the input rainfall are not taken into account.

Therefore this research compares different measurement systems of rainfall: a point based gauge, SWAT weather generator and satellite measurement from MSGMPE products. The best output from the comparison of the measurement systems was further used to provide correct input to drive the SWAT model to quantitatively assess diffuse pollution within the Roxo watershed and to simulate nutrient transport from the Roxo watershed to surface water (Roxo reservoir).

1.3. Purpose of study

To compare the application of different weather/climatic observation systems (i.e. satellite and ground based data) as inputs to drive the hydrologic/water quality model (SWAT), to quantitatively assess diffuse pollution of water resources in the Roxo watershed.

1.4. Research objectives

1. Comparing the capabilities of the climate observation systems by running SWAT model with:
    - Climate average gauge datasets using the SWAT weather generator;
    - Observed daily time series data of ground based point meteorological observations (COTR & SNIRH networks);
    - Meteosat (MSG) satellite time series data available through eumetcast system;
2. Determine the effects of the three climate datasets on the SWAT model behaviour and outputs
3. Calibrate and validate the SWAT model output with Roxo reservoir daily water balance
4. Make a quantitative assessment of diffuse pollution load into Roxo reservoir from predictions of nutrient (N & P) loadings in runoff.

1.5. Research questions

- Can meteorological satellite data be used in representing weather and climatic conditions in the SWAT model?
- Can the SWAT model output provide information on the sources of pollutants, quantities, mode of transport and the transient nature of pollution events in the Roxo catchment conditions?
- Can SWAT accurately predict nutrient (N) loads in the Roxo watershed?

1.6. Research hypothesis

- Parameterization of the SWAT water quality model give better estimate with satellite data as opposed to ground based point data
- Estimation of rainfall forcing in water quality model through remote sensing technique give better prediction as opposed to weather station point data.

1.7. Research methodology

This research was carried out in three key stages and includes: pre-fieldwork, fieldwork and a post fieldwork.

Pre-fieldwork entails the early stage of the study and focused on problem definition, literature review, formulation of research objectives and questions, as well as downloading of satellite images from databases.

During field work stage, all spatial and non spatial data to be used in the study were collected; water quality samples and verification of land cover were also carried out.

Post field work was the final stage of the project and it involves preparation of all input data to be used in modelling, model set up and parameterization; model runs, sensitivity analysis and finally the calibration and validation of the SWAT model. See Figure 1 for a diagrammatic representation of the methodology adopted.

1.8. Organization of thesis

This thesis is structured into eight chapters. Chapter 1 discusses background of study, problem statement, justification, purpose, research objectives, research questions and hypothesis. Chapter 2 covers literature review on hydrologic/water quality modelling as well as calibration techniques used in the SWAT hydrologic model. In chapter 3, a brief description of the study area is given, followed by the SWAT model description as well as data preparation and model setup. Chapter 4 deals with simulation results and presentation techniques. In chapter 5, a presentation of sensitivity analysis, calibration and validation result of the SWAT model are shown. Chapter 6 presents calibrated model output and result analysis while chapter 7 summarizes the results derived and chapter 8 contains conclusions and recommendations of the study.

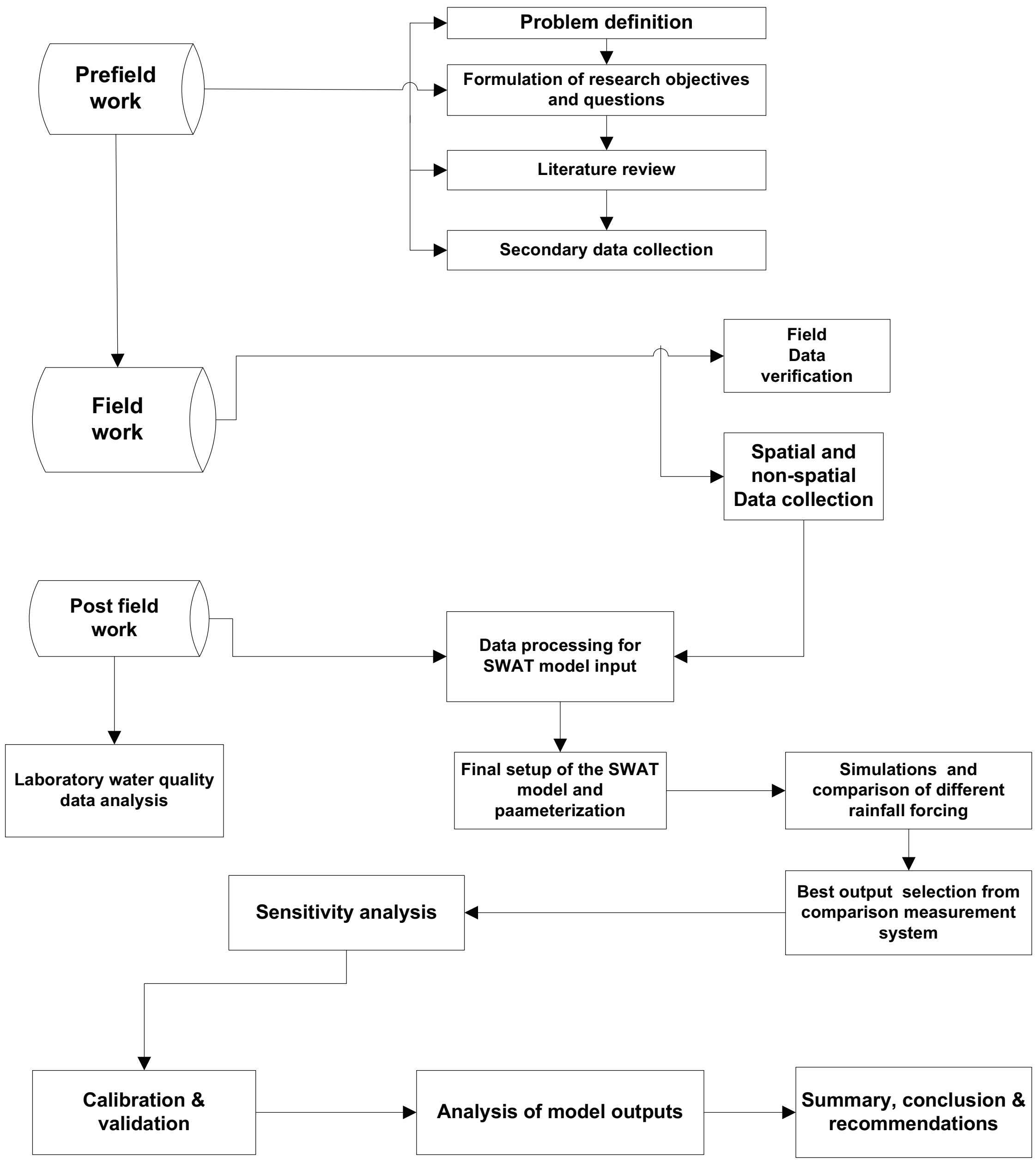

Figure 1-1: Schematic representation of the research methodology

2. Literature review

2.1. Introduction

The complexity that characterizes a watershed arises from the myriad of hydrologic processes occurring in the watershed. Such processes are precipitation, interception, surface runoff, infiltration, groundwater percolation and evapotranspiration; all these processes are best represented by the runoff hydrograph that best describes the watershed response. The ability of a watershed to respond depends on terrain feature (size, shape, direction and slope), land cover/use, soil classes, rainfall events and human activities. It is a well established fact that bad agricultural practice can lead to water quality problems in watershed by increasing erosion rate from fields and supplying nutrients and pesticides to streams and reservoirs.

Managing nutrient (N & P) loads into reservoirs requires understanding of nutrient transport and delivery from the watershed–stream system (Migliaccio et al. 2007). Nutrients are generally transported from the landscape into streams during runoff events; however, they may also enter stream flow from other sources such as groundwater recharge and point source effluent discharges. As water transports nutrients downstream, they cycle through the stream ecosystem in biotic and abiotic forms and get deposited into downstream water bodies such as lakes and reservoirs (Migliaccio et al., 2007).

So many approaches can be used to gain such an understanding. Researches in the past several decades made effort to tackle problems of surface water pollution by ascertaining link between land management practices, environment and water quality degradation (Tong and Chen, 2002).In recent times computer modeling has gained extensive recognition as a cost effective tool for developing agricultural and other landuse practices that protect water quality (Chaplot et al., 2005; Collins and McGonigle, 2008; Drolc and Zagorc Koncan, 2008; Easton et al., 2008; FitzHugh and Mackay, 2000; Galbiati et al., 2006; Grizzetti et al., 2005; Kannan et al., 2007; Tripathi et al., 2003)

2.2. Hydrologic, watershed and water quality models

Computer models are mostly applied for simulation purposes or for forecasting purposes. Simulation purpose focuses on understanding specific aspects of area of interest. They are used to understand how certain system properties and characteristics affect flow processes and flow patterns. They are used to assess the system sensitivity to certain natural or imposed impacts such as climate and land use. Computer simulations help to understand cause-effect relationship as well as their implications. In case of forecasting, its objective generally is to predict or forecast a certain hydrological phenomenon such as discharge in a river (Reintjes, 2007).

Singh (1995) classified such computer models as processes (lumped or distributed; deterministic, stochastic or mixed); scale (temporal or spatial; distributed, event based, continuous and large time scale) and by method of solution (numerical, analog or analytical).

Event based models are use to analyze single events storms and assess watershed management practices especially structural practices. Agricultural Non-Point Source Pollution model (AGNPS), Areal Non-Point Source Watershed Environment Response Simulation (ANSWERS), Dynamic Watershed Simulation model (DWSM), and Kinematic runoff and Erosion model (KINEROS) are examples of single rainfall event models. Continuous simulation models are design to analyze long term effects of hydrologic changes and watershed management especially agricultural practices. Annualized Agricultural Non-Point Source model (AnnAGNPS), ANSWERS-continuous, Hydrological simulation Program-Fortran(HSPF), all described in Singh (1995) and Soil Water Assessment Tool (SWAT) (Neitsch et al., 2005) are examples of continuous model. Several of these physically based distributed models have been developed to predict runoff, erosion, sediment and nutrient transport from agricultural watershed under various management regimes (Tripathi et al., 2003). **S**WAT has been successfully applied to model water quality issues including sediments, nutrients and pesticides in watersheds. SWAT has been applied to model phosphorus in TMDL analysis of the Bosque River watershed in Texas. In the Hydrologic Modeling of the United States Project (HUMUS), SWAT was used to analyze water management scenarios. SWAT is included in EPA's BASINS modeling framework (Texas Water Resources Institute, 2008), it is also included in the Euroharp project. It was also used in this thesis to simulate streamflow and nutrient transport from watershed to surface water (Roxo reservoir) and their corresponding source apportionment.

2.3. Previous water quality modelling research in the Roxo reservoir watershed

Some previous studies on WQ issues in the study area include that of Gokmen (2006) who evaluated SWAT model setup process using Roxo catchment as case study. Shakak (2004) used the AGNPS model to assess pollution risks of the upper part of Roxo catchment and concluded that nutrient pollution risk in the catchment is a key concern during low situation and that increasing fertilizer to agricultural fields increases nutrient contaminant in catchment. Chisha (2005) assessed the levels of nitrogen and phosphorous loads contributed by the Outerio (a sub-catchment of Roxo catchment) to the Roxo lake with GWLF water quality model by simulating loadings from point and non point for a time step of ten years, his result shows that agricultural runoff was the main source of nutrient pollution. Gurung (2007) used a system dynamic based approach (STELLA) to model eutrophication in Roxo Reservoir. He focused on determining extent of eutrophication in the reservoir using chlorophyll as a proxy; STELLA however is not suitable for spatial study. This study takes a step further by calibrating and validating the SWAT hydrologic and water quality model for the Roxo reservoir watershed.

2.4. Weather generator

Basic requirement for any watershed hydrology model is the capability to assess surface runoff adequately because it influences the transport of sediments and agro-chemicals. An accurate simulation of runoff processes is thus useful in assessing the watershed’s impact on the environment. Knowledge of sediment yield from a watershed is quite essential, as it is often required to determine the quantity of sediment delivered to downstream reservoir (Tripathi et al., 2004). Many process-based hydrological models, including SWAT, have the capability to generate rainfall and, thereafter, surface runoff, sediment yield and nutrient losses on daily, monthly and annual bases.

Tripathi et al., (2004) used the SWAT weather generator to simulate rainfall, runoff and sediment yield for a period of 8 years and compared the results with observation data, the monthly average rainfall predicted by the model was in close agreement with the observed monthly average values. The simulated monthly average values of surface runoff and sediment yield also compared well with observed values. Tripathi study revealed that the SWAT model can generate monthly average rainfall satisfactorily and thereby can produce monthly average values of surface runoff and sediment yield close to the observed values from weather generator.

2.5. Point and satellite based rainfall estimations

The importance of precipitation as well as its spatial and temporal variations in the hydrological and environmental sciences cannot be overemphasized. Rainfall itself drives the hydrologic cycle. The simulation of rainfall runoff is thus important because it is the main cause of diffuse pollution which mainly comes from agricultural practices and other poor land use management. Hydrologic and water quality model depend on accurate weather and climatic prediction to enhance their capabilities and potentials. In the field of hydrology, a major concern is precipitation over an area, like a drainage basin rather than at a point (Dingman, 2002).

The Mediterranean climate is known for its variety and variability because of surrounding orography, and relative high temperature of the sea to different origin and physical characteristics of air masses. The area is characterized by a scarcity of dense rain gauge networks or precipitation radar networks from which reliable real-time assessments of precipitation can be obtained, due to the presence of the Mediterranean Sea and to the complex topography. In addition, rain gauge observations are not generally available in real time in many regions, and missing reports and grossly erroneous reports occur in cases of extremely heavy rainfall and in regions of steep terrain. Thus remotely sensed information from satellites, having a high spatial coverage and high temporal sampling, can play a key role in monitoring precipitation in flood-prone regions, sea precipitation, and other extreme weather events (Kamarianakis et al., 2006). The study of Kamarianakis et al., (2006), show satellite observations to overestimate precipitation in hydrologic model.

Rainfall can be estimated from gauge data that are readily available on land only and remote sensing technique, either from ground-based weather radars or from satellite. Radars are active devices, emitting radiation at wavelengths ranging between 1 and 10 cm, and receiving the echo from targets such as raindrops. The maximum range of radars is only about 300 km, so offshore coverage is limited. Also, radars are prohibitively expensive in the Third World. Satellite-based measurements offer global coverage or a good part of it (Geerts, 98). Satellite based rainfall estimates offer complete spatial coverage and provide often the only real-time precipitation estimates in many pockets of a watershed. Satellite-based rainfall monitoring provides a method of producing rainfall estimates for an entire region, without the need for extensive real time surface observations. Satellite rainfall estimates (Blackmore et al., 2006) have the potential to be fed into crop yield and hydrological models.

Different types of satellite rainfall estimation algorithms exist and include: algorithms that primarily use infra-red (IR) data; algorithms that primarily use passive microwave (PM) data; algorithms that use a combination of IR and PM data (Blackmore et al., 2006). The algorithms are either used alone or in a combination with another in the estimation of precipitation. Due to large overestimation of rainfall in some regions with these algorithms, it is expected that the SEVIRI instrument on board MSG

(Meteosat Second Generation) records data from several visible, near IR and thermal IR channels, and a combination of these channels should provide more information on rainfall than the single channel used by TAMSAT and other precipitation estimator.

Tobin et al., (2008) used the Cimarron River Basin (3110 sq km) in Oklahoma as a test bed to compare the SWAT hydrological model performance while using different methods of precipitation quantification and obtained robust simulations with TRMM and NEXRAD data precipitation estimate in simulating stream flow for a period of 2 years, they obtained acceptable monthly results with very little adjustment of model parameters using TRMM 3B42 precipitation data (mass balance error = 3 percent; Monthly Nash-Sutcliffe efficiency coefficients (NS) = 0.77). Both Oklahoma Mesonet rain gauge and NEXRAD Stage III data (mass balance error = -5 percent; Monthly NS = 0.95; Daily NS = 0.69) produces superior simulations even at a sub-monthly time scale. In their study, it was noted that all types of precipitation data perform better than a synthetic precipitation dataset generated using a weather simulator (mass balance error = 12 percent; Monthly NS = 0.40.

In the same discourse Tobin et al., (2008) compared the performance of National Weather Service (NWS) rain gauge, NEXRAD Stage III, and TRMM 3B42 (Version 6) data as input for driving the SWAT hydrological modeling of two watersheds, the Middle Nueces River Basin in South Texas and the Middle Rio Grande Basin in South Texas and northern Mexico. Their study demonstrated that NWS rain gauge data did not generate acceptable simulations while the remotely sensed precipitation and satellite estimated precipitation data yields robust result and thus supports hydrologic modeling with the SWAT hydrologic model.

Kalin and Hantush (2006) carried out a comparison study with rain gauge station and NEXRAD using the SWAT model to estimate stream flow, base low and surface runoff. The results show that NEXRAD precipitation and rain gauge gave robust simulation of R2 of about 0.90. However the NEXRAD simulation did not show any improvement in model results compared to rain gauge stations.

2.6. SWAT application in calibration and validation techniques

Model calibration is often important in hydrologic modeling studies, since uncertainty in model predictions can be increased if models are not properly calibrated. Factors contributing to difficulties in model calibration include calibration data with limited metadata, data with measurement errors, and spatial variability of rainfall or watershed properties poorly represented by point measurements (Storm and White, 2005).

The SWAT model is highly parameterized with twenty six parameters for flow components, six for sediment, and nine for water quality. Model results can be in an acceptable range for one set of parameter values, but can become totally unacceptable for another set of parameter values for the same given input. Therefore determining acceptable set of parameters is critical in creating a successful watershed model. However, it is not feasible to determine these parameters from experiments because of several reasons such as cost involved in experimental setup, physical variability present in the watershed, interaction among different parameters and scale issues. Consequently, parameter values are determined by calibration process within the modelling framework (Eckhardt and Arnold, 2001)

SWAT uses the manual and automatic calibration techniques. Manual calibration for SWAT model is explained in detail by Santhi et al. (2001), but this process is time consuming and subjective depending on modeler preference and expertise. Therefore, manual calibration is not a preferable option when large numbers of parameters are involved (Eckhardt and Arnold, 2001). Thus Duan et al. (1992) suggested Shuffled Complex Evolution- University of Arizona (SCE-UA) algorithm for automatic model calibration which has been extensively used in hydrologic model calibration (Santhi et al., 2001; Sorooshian et al., 1993; van Griensven, 2005; Van Griensven et al., 2006).SCE-UA is a global search algorithm belonging to the family of genetic algorithms. It samples population (parameter set) from entire feasible space (upper and lower bound specified by user) and based on evolutionary steps, entire population converges towards the neighborhood of global optimum. Eckhardt and Arnold (2001) used SCE-UA algorithm for calibrating 18 parameters of SWAT-G model, and concluded that automatic calibration can be successfully used for calibration of complex distributed hydrologic models.

Van Griensven et al. (2002) used auto calibration preceded by sensitivity analysis with multi objective and multi site criterion for river water quality modeling in Belgium using ESWAT (Extended SWAT). Total seventeen objective functions (OFs) were defined at three sites (representing flow, Dissolve Oxygen, Biological Oxygen Demand, Ammonia, Nitrate, and Phosphate at three sites) in Dender River watershed, and they were normalized to form Global Optimization Criterion (GOC). SCE-UA algorithm was used to minimize GOC for 32 parameters selected during sensitivity analysis. Because stream flow and water quality are related, using multi-objective calibration (instead of doing step by step calibration i.e. first flow then water quality) put more constraints on many parameters. Results showed that GOC also correspond to optimum for individual OFs with few exceptions, and simulated results were in good agreement with measured observations for stream flow and water quality. Because of its wide range of applicability, SCE-UA algorithm was incorporated in SWAT-2005 as auto calibration tool along with sensitivity analysis tool (van Griensven, 2005).

Regardless of calibration procedures used in estimating model parameters, it is not possible to find parameter values that represent the true parameter set. Because of inherent assumptions and simplifications in model structure, and errors associated with input and observed datasets, there can be several parameter sets that can produce similar model response for a given input. This concept of non-unique parameter sets is called '*equifinality'* (Beven, 1993). Identification of uncertainty associated with different stages in modeling process such as input data uncertainty, parameter uncertainty and model output uncertainty, is a major area of research in hydrologic modeling.

2.7. Summary

This chapter reviews watershed and hydrologic model and also looked at the application of SWAT model in the Roxo watershed and elsewhere. The use of weather generator, point and satellite rainfall estimations and their applications in the SWAT model was also addressed. Although other types of precipitation estimation in SWAT model output resulted in robust simulations, the use of MSGMPE rainfall estimation in SWAT model simulation is relatively new and this form one of the focal point of this research, as attempt was made to drive the SWAT model with the estimates from the MSG precipitation. Related work on calibration of semi distributed hydrologic model was also examined.

3. Materials and Methods

3.1. Description of study area

Roxo reservoir watershed is located in Portugal. Portugal (Coutsoukis, 2003) is located in south western Europe and is circumscribed in the north Atlantic ocean in the west of Spain. Its Geographic coordinates are 39 30 N, 8 00 W. It has a total land area of 91,951 km^2 including the Azores and Madeira Islands and makes up about 15 percent of the Iberian Peninsula. The river Tagus splits the country into two parts. The mountainous areas of Portugal lie to the north of the river. South of the Tagus are dominant rolling plains. This part of the country, administratively known as Alentejo Province is very fertile. The area is renowned for its wheat fields, and cork and olive plantations. Other major crops are maize, rice, potatoes, vine and tomatoes. Portugal is a main exporter of olive oil, and is an important producer of wine and tomato paste. Current environmental issues in Portugal include soil erosion; air pollution caused by industrial and vehicle emissions; water pollution, especially in coastal areas.

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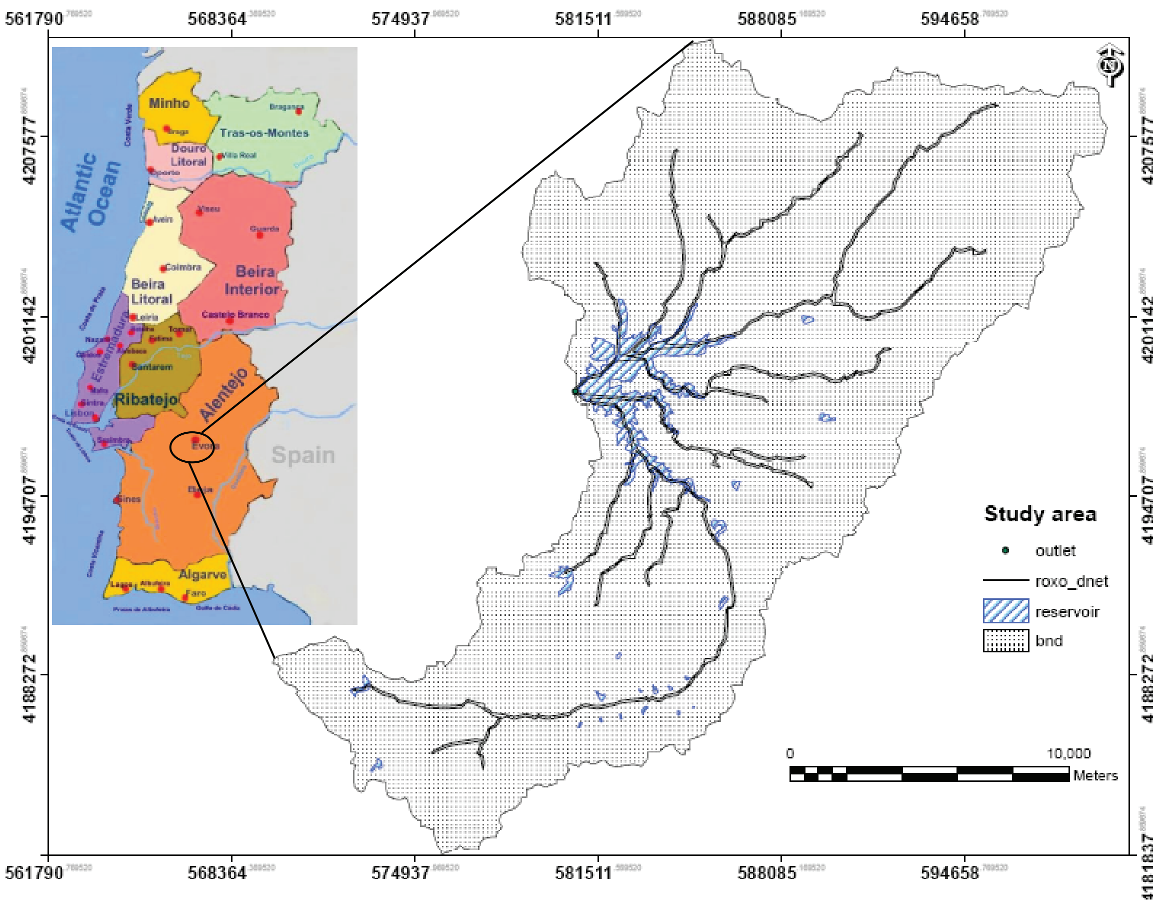


Figure 3-1: Location of Roxo reservoir watershed in Portugal

The 350km^2 Roxo reservoir watershed, lies between latitudes of 37^{0}50'45'' and 38^{0}1'10''N and between longitudes of 7^{0}51'51'' and 8^{0}12'34''W in Beja district of Alentejo Province in the south of Portugal and is about 150km south east of Lisbon and this is shown in Figure 3-1 above. Major source of water to the reservoir is river Ribera do Roxo. The Roxo reservoir with an average area size of 13.8km^2 forms the outlet of the watershed and it is of high economic importance as the major source of water for irrigation and domestic use to Aljustrel and Beja towns.

The study area is characterized by flat to rolling terrain with elevation ranging from 114 to 293m. The peak is in Beja district in the north eastern part of the watershed where the land ascends to an elevation of about 293 m above mean sea level. The landscape gently drops in the west and south-western directions with the lowest point at about 100 m above sea level at close proximity to the reservoir. The Roxo watershed has a Mediterranean climate with large temperature variation between summer and winter and characterized by cyclical droughts. The mean monthly maximum (in July/august) and minimum (December) temperature are 40^{0}C and 5^{0}C respectively. The average annual rainfall in the study area is estimated to be about 550 mm. The estimation is based on the long-term rainfall data recorded at four rain-gauge stations located at Aljustrel, Barragem do Roxo, Santa Victoria and Beja. Driest period are in May to September while the wettest months are October to April.

Based on Corine land cover project (EEA, 2000) land use Land cover data, the landuse classification in Roxo reservoir watershed is made up of Discontinuous urban fabric; Eucalyptus forest; Mixed Agricultural areas; Mixed Forest; Natural grasslands; Non-Irrigated Arable land; Olive groves; Permanently irrigated land; Water bodies. More than 65% of the watershed classified Non Irrigated Arable Land. The high intensity of agricultural practices has been the main cause of diffuse pollution of ground and surface water. Thus the Roxo reservoir watershed has undergone heavy eutophication because of excessive inputs of nutrients (N & P) from fertilizers and manure applications. The study area is characterized mainly by clay loam soils texture, while the soil hydrologic group range from A to D. The geology consists of rocks of gabbro, amphibolites and serpentinites which are very weathered and fractured in nature (Almeida and Silva, 1987).

3.2. Model description

ArcGIS-SWAT2005 edition was used in this study. ArcGIS-SWAT (developed for ArcGIS platform) is a geodatamodel and geographic information system (GIS) interface for the Soil and Water Assessment Tool (SWAT) (Neitsch et al., 2000; Neitsch et al., 2002a).The ArcGIS-SWAT data model is a system of geodatabases (geodatabases are special types of databases) that stores SWAT geographic, numeric and text input data thus resulting in a structured style (Olivera et al., 2006). The geodatabase is made up of object classes, feature classes, and feature datasets from which all input data needed by SWAT are being retrieve and all output created by SWAT are stored. The use of geodatabase in SWAT modelling plays an important role in storing the geographic data to describe sub-basins, reaches, outlets, inlets and the benefits of state of the art database technology. The capabilities inherent in database technology are quite large and we mention few examples here: they were design to work with bulky amount of information which was not possible to handle with text files. In SWAT, volume of information is important because the geodatabase stores geographic information, hydrologic parameters, and time series of each hydrologic feature of the system. Database technology are also capable of cross referencing of records in different tables by means of related attributes; speeding up query of records; and performing complex aggregate calculations.

The ArcGIS-SWAT data model is made up of dynamic and static geodatabase. .The dynamic geodatabase stores information of study site and the static geodatabase stores non-project specific information like look up tables and databases of default parameter values (Olivera et al., 2006). "*ArcGIS-SWAT interface includes modules for watershed delineation, HRU definition, synthetic weather generator, exporting data from the geodatabase to prepare SWAT input files, importing SWAT results from output files to the dynamic geodatabase, analysis of propagation of uncertainty, data visualization and statistical analysis and model integration. The first three modules include spatial analysis using topographic, land use, soil type and weather data*" *(Olivera et al., 2006)* and these will be discussed in this section of the thesis as they form the framework for the SWAT model setup.

The physically-based SWAT model (Neitsch et al., 2005) was developed to predict the impact of management on water, sediments and agricultural chemical yields. The model operates on a daily time step. The model simulates the water cycle and the nutrient fate based on spatial information on climate, topography, soil properties, land use and management practices. The basin spatial variability is represented by a semi-distributed approach. The study site is subdivided into a number of sub-basins, which are characterised by one or more hydrological response units (HRUs). Each HRU corresponds to a particular combination of soil and land use within the sub-basin. In each sub-basin, only soil types and land use classes exceeding the user defined threshold area are considered to set the overlay combination.

SWAT also has the ability to predict changes in sediment, nutrients - such as organic and inorganic nitrogen and organic and soluble phosphorus, pesticides, dissolved oxygen, bacteria and algae loadings from different management conditions in a watershed. SWAT operates on a daily time step and can be used for long-term simulations. SWAT coding and subroutines are modular, allowing for addition of new subroutines when necessary. SWAT has been successfully applied to model water quality issues including sediments, nutrients and pesticides in watersheds.

The major components simulated by SWAT include hydrology, weather, erosion, crop growth, agricultural management, and nutrients and pesticide fate. A complete description of each component is given in (Neitsch et al., 2005). This research only gives an overview of the component that is very relevant to it.

3.2.1. **Hydrology**

SWAT simulates water balance because it is the driving force behind everything that happens in the watershed (Neitsch et al., 2005).The hydrology model is based on the water balance equation, and the processes of surface and subsurface runoff, percolation, groundwater return flow, evapotranspiration and channel transmission losses are simulated (Grizzetti et al., 2005). Simulation of the hydrology of a watershed can be separated into two major divisions. The first division is the land phase of the hydrologic cycle, depicted in Figure 3-2. The land phase of the hydrologic cycle controls the amount of water, sediment, nutrient and pesticide loadings to the main channel in each sub-basin. The second division is the water or routing phase of the hydrologic cycle which can be defined as the movement of water, sediments, etc. through the channel network of the watershed to the outlet (Neitsch et al., 2005).

The hydrologic cycle of the land phase simulation in SWAT is based on the water balance equation:

$$SW_t = SW_0 + \sum_{i=1}^{t}(R_{day} - Q_{surf} - E_a - w_{seep} - Q_{gw}) \quad (3\text{-}1)$$

where SW_t is the final soil water content (mm H2O), SW_0 is the initial soil water content on day i (mm H2O), t is the time (days), R_{day} is the amount of precipitation on day i (mm H2O), Q_{surf} is the amount of surface runoff on day i (mm H2O), E_a is the amount of evapo-transpiration on day i (mm H2O), w_{seep} is the amount of water entering the vadose zone from the soil profile on day i (mm H2O),and Qgw is the amount of return flow on day i (mm H2O).

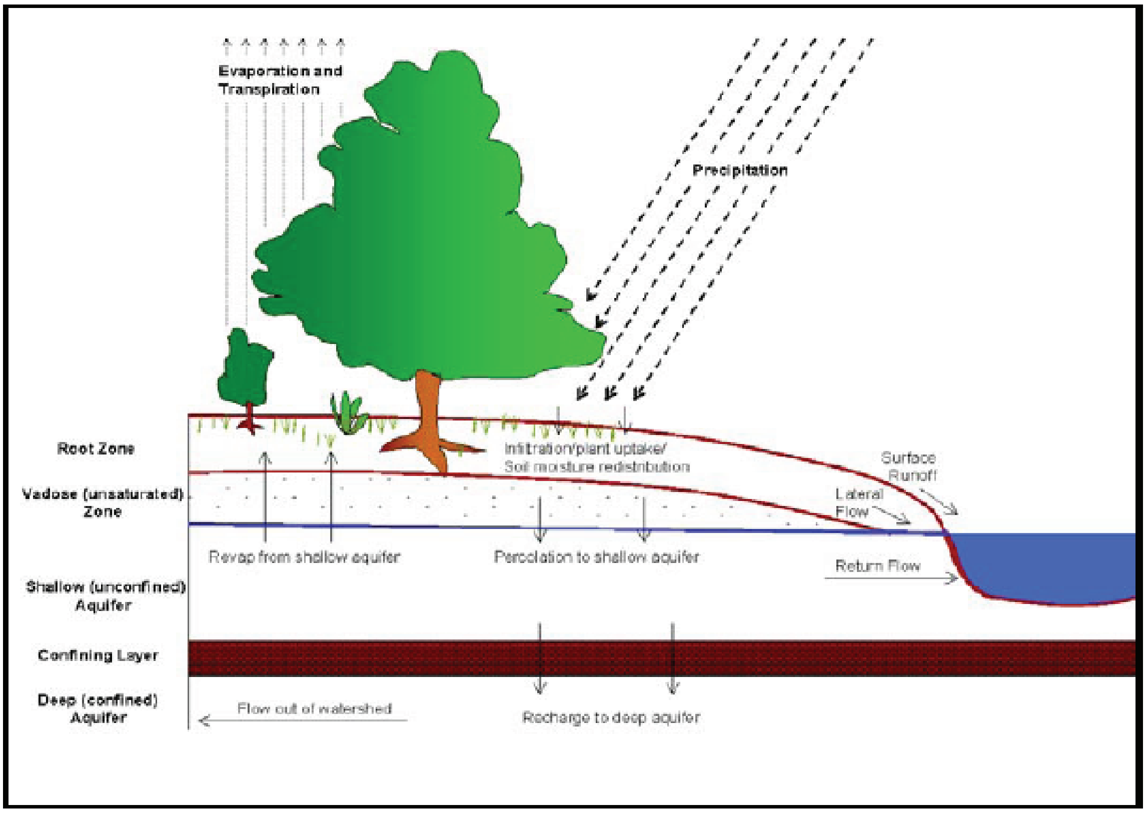


Figure 3-2: Schematic representation of the hydrologic cycle
After Neitsch et al.(2005)

3.2.2. Surface runoff

Surface runoff occurs whenever the rate of water application to the ground surface exceeds the rate of infiltration (Neitsch et al., 2005). The two methods for estimating surface runoff in SWAT are: the modified SCS curve number method and the Green and Ampt infiltration. The SCS-CN method is the most widely used method for computing surface runoff for rainfall event, with very few studies carried out by Green and Ampt infiltration (Neitsch et al., 2005). The SCS runoff equation is an empirical model developed to provide a consistent basis for estimating the amounts of runoff under varying land use and soil types and is given as:

$$Q_{surf} = \frac{(R_{day} - I_a)^2}{(R_{day} - I_a + S)} \quad (3\text{-}2)$$

Where Q_{surf} is the accumulated runoff or rainfall excess (mm H2O), R_{day} is the rainfall depth for the day (mm H2O), I_a is the initial abstractions which includes surface storage, interception and infiltration prior to runoff (mm H2O), and S is the retention parameter (mm H2O). The retention parameter varies spatially due to changes in soils, land use, management and slope and temporally due to changes in soil water content. The retention parameter ***S*** is defined as (Neitsch et al., 2005):

$$S = \left(\frac{1000}{CN}\right) - 10 \qquad (3\text{-}3)$$

Where *CN* is the curve number for the day. The equation above indicates that precipitation, P, must exceed 0.2S before any runoff is generated. Furthermore, this equation yields a depth of runoff. To calculate runoff volume, the computed depth must be multiplied by area. The curve number indicates the runoff potential of an area for the combination of land use characteristics and soil type. Higher curve numbers translate into greater runoff. The initial abstractions, *Ia*, is commonly approximated as $0.2S$ and equation (1) becomes:

$$Q_{surf} = \frac{\left(R_{day} - 0.2S\right)^2}{\left(R_{day} + 0.8S\right)} \qquad (3\text{-}4)$$

The SCS curve number is a function of the soil's permeability, land use and antecedent soil water conditions. The NRCS has classified more than 4000 soils into four hydrologic soil groups according to their minimum infiltration rate for bare soil after prolonged wetting. The characteristics associated with each hydrologic soil group are given in Appendix A-1. The amount of moisture present in the soil is known to affect the volume and the rate of runoff. Consequently, the NRCS developed three antecedent soil moisture conditions: Dryer antecedent conditions (Condition I) reflect soils that are dry but not to the wilting point; Wetter conditions (Condition III) characterize soils that have experienced heavy rainfall, light rainfall and low temperatures within the last five days (saturated soils); and Condition II is the average condition. Curve numbers for dryer antecedent conditions (Condition I) and for wetter antecedent conditions (Condition III) are given in Appendix A-2 from Tetra Tech Inc (2004).

3.2.3. **Climate**

The weather variables forcing the hydrological balance are daily precipitation, maximum and minimum daily temperature, solar radiation, wind speed and relative humidity. Comprehensive information on this input can be found on the SWAT2005 Theoretical Documentation.

3.2.4. **Erosion/sediment**

Sediment yield is estimated for each HRU with the Modified Universal Soil Loss Equation (MUSLE) as described in Williams (1975) . Using MUSLE single-storm sediment yield can be estimated. The hydrology model supplies estimates of runoff volume and peak runoff rate, which are used to calculate the runoff erosive energy variable. Other factors of the erosion equation have been evaluated by Wischmeier and Smith (Geza and McCray, 2008; 1978). MUSLE is given in Neitsch (2005) as:

$$Y = 11.8 * \left(Q_{surf} * q_{peak} * Area_{hru}\right)^{0.56} K_{USLE} * C_{USLE} * P_{USLE} * LS_{USLE} * R \qquad (3\text{-}5)$$

Where Y is the sediment yield on a given day (metric tons), $\boldsymbol{Q_{surf}}$ is volume of surface runoff (mm H2O)/ha), $\boldsymbol{q_{peak}}$ is the peak runoff rate (m^3s^{-1}), $\boldsymbol{Area_{hru}}$ is the area of HRU (ha), $\boldsymbol{K_{USLE}}$ is the USLE soil erodibility factor, $\boldsymbol{C_{USLE}}$ is the crop management factor, $\boldsymbol{P_{USLE}}$ is the erosion control practice factor, $\boldsymbol{LS_{USLE}}$is the topographic factor, and R is the is the coarse fragment factor.

3.2.5. Nutrient

The transport of nutrients from land areas into streams and water bodies is a normal result of soil weathering and erosion processes. However, excessive loading of nutrients into streams and water bodies will accelerate eutrophication and render the water unfit for use (Neitsch et al., 2005). Movement of mineral and organic forms of nitrogen and phosphorus from land areas to the stream network will be briefly described here.

3.2.6. Nitrogen

SWAT tracks the movement and transformation of several forms of nitrogen (N). Nutrients may be introduced to the main channel and transported downstream through surface runoff and lateral flow. The three major forms of nitrogen in mineral soils are organic nitrogen associated with humus, mineral forms of nitrogen held by soil colloids, and mineral forms of nitrogen in solution. Plant use of nitrogen is estimated using the supply and-demand approach. In addition to plant use, nitrate and organic N may be removed from the soil via mass flow of water. Amounts of NO_3 contained in runoff, lateral flow and percolation are estimated as products of the volume of water and the average concentration of nitrate in the layer. Organic N transport with sediment is calculated with a load function for individual runoff events. The load function estimates the daily organic N runoff loss based on the concentration of organic N in the topsoil layer, the sediment yield and the enrichment ratio. Organic nitrogen levels are assigned based on C: N ratio for humic material. The enrichment ratio is the concentration of organic N in the sediment divided by that in the soil as described in Neitsch et al (2002a) (Geza and McCray, 2008). In SWAT, the concentration of nitrate in the mobile water fraction is computes as:

$$Conc_{NO_{3,mobile}}= \frac{NO_{3ly}*exp\frac{-w_{mobile}}{(1-\theta_e)*SAT_{ly}}}{w_{mobile}} \quad (3\text{-}6)$$

Where $conc_{NO3,\ mobile}$ is the concentration of nitrate in the mobile water for a given layer (kg N/mm H2O), NO_{3ly} is the amount of nitrate in the layer (kg N/ha), w_{mobile} is the amount of mobile water in the layer (mm H2O), $\theta_e$is the fraction of porosity from which anions are excluded, and SAT_{ly} is the saturated water content of the soil layer (mm H2O). Anions are excluded due to repulsion from particle surfaces or negative adsorption and replaced by cations (Neitsch et al., 2005).
The amount of mobile water in the layer is the amount lost by surface runoff, lateral flow or percolation, given by:

$$w_{mobile} = Q_{surf} + Q_{lat,ly} + w_{perc,ly}, \quad \text{for top 10mm} \quad (3\text{-}7)$$

$$w_{mobile} = Q_{lat,ly} + w_{perc,ly}, \quad \text{for lower soil layers} \quad (3\text{-}8)$$

Where w_{mobile} is the amount of mobile water in the layer (mm H2O), Q_{surf} is the surface runoff generated on a given day (mm H2O), $Q_{lat,\ ly}$ is the water discharged from the layer by lateral flow (mm

H2O), and $w_{perc, ly}$ is the amount of water percolating to the underlying soil layer on a given day (mm H2O). In SWAT the top 10mm soil layer is allowed to interact with the surface runoff and transport nutrients from this layer, which is calculated as:

$$NO_{3\,surf} = \beta_{NO_3} * conc_{NO_3} * Q_{surf} \quad (3\text{-}9)$$

Where NO_{3surf} is the nitrate removed by surface runoff (kg N/ha), $\boldsymbol{\beta_{NO_3}}$ is the nitrate percolation coefficient, $conc_{NO3}$, mobile is the concentration of nitrate in the mobile water for the top 10 mm of soil (mm H2O), and Q_{surf} is the surface runoff generated on a given day (mm H2O).
The loading function of organic form of nitrogen s given by:

$$orgN_{surf} = 0.001 * conc_{orgN} * \frac{sed}{area_{hru}} * \epsilon_{N:sed} \quad (3\text{-}10)$$

Where $orgN_{surf}$ is the amount of organic nitrogen transported to the main channel in surface runoff (kg N/ha), $conc_{orgN}$ is the concentration of organic nitrogen in the top 10mm (g N/metric ton soil), sed is the sediment yield on a given day (metric tons), $area_{hru}$ is the HRU area(ha), and $\epsilon_{N:sed}$ is the nitrogen enrichment ratio.

A larger proportion of clay sized particles in a sediment load to the main channel leads to the occurrence of a greater proportion or concentration of organic N, resulting in the enrichment of organic N. The enrichment ratio is defined as the ratio of concentration of organic nitrogen transported with the sediment to the concentration in the soil surface layer (Neitsch et al., 2005)

The concentration of organic nitrogen in the soil surface layer and the nitrogen enrichment ratio are, respectively, calculated in SWAT as:

$$conc_{orgN} = 100.\frac{(orgN_{frsh,surf} + orgN_{sta,surf} + orgN_{act,surf})}{\rho_{b.}depth_{surf}} \quad (3\text{-}11)$$

$$\epsilon_{Nsed} = 0.78 * (conc_{sed,surq})^{-0.2468} \quad (3\text{-}12)$$

Where $orgN_{frsh,surf}$ is nitrogen in the fresh organic pool in the top10mm (kg N/ha), $orgN_{sta,surf}$ is nitrogen in the stable organic pool (kgN/ha), $orgN_{act,surf}$ is nitrogen in the active organic pool in the top 10mm (kg N/ha), $\rho_{b.}$ is the bulk density of the first soil layer (Mg/m^3), $depth_{surf}$ is the depth of the soil surface layer (10 mm), and $conc_{sed,surq}$ is the concentration of the sediment in surface runoff (Mg sed/m3H2O). The concentration of sediment in surface runoff is calculated as:

$$Conc_{sed,surq} = \frac{sed}{10 * area_{hru} * Q_{surf}} \quad (3\text{-}13)$$

Where sed is the sediment yield on a given day (metric ton) $area_{hru}$is the HRU area (ha), and Q_{surf} is the amount of surface runoff on a given day (mm H2O).

3.2.7. Phosphorus

SWAT simulates the movement and transformation of several forms of phosphorous (P). The three major forms of phosphorus in mineral soils are organic phosphorus associated with humus, insoluble forms of mineral phosphorus and phosphorus in soil solution. The concentration of solution phosphorus in all layers is initially set to 5 mg/kg soil, representative of unmanaged land under native vegetation and 25 mg/kg soil for a cropland. The amount of soluble P removed in runoff is predicted using labile P concentration in the top 10 mm of soil, the runoff volume and a partitioning factor. Phosphorus in soil is mostly associated with the sediment phase. Organic and mineral P attached to soil particles are transported by surface runoff to the main channel (Geza and McCray, 2008).

The amount of solution P transported in surface runoff as calculated by SWAT is:

$$P_{surf} = \frac{P_{solutionsurf} * Q_{surf}}{\rho_b * depth_{surf} * k_{d,surf}} \quad (3\text{-}14)$$

Where P_{surf} is the amount of soluble phosphorus lost in surface runoff (kg P/ha), $P_{solutionsurf}$ is the amount of phosphorus in solution in the top 10mm (kg P/ha), Q_{surf} is the amount of surface runoff on a given day (mm H2O), ρ_b is the bulk density of the top 10mm (Mg/m^3), $depth_{surf}$f is the depth of the surface layer (10 mm), and $k_{d,surf}$ is the phosphorus soil partitioning coefficient (m^3/Mg).

The amount of organic and mineral P that is transported attached to the sediment particles is calculated by SWAT using the loading function developed by McElroy et al (1976) and modified by Williams and Hann (1978), cited in Neitsch et al. (2005):

$$sedP_{surf} = 0.001 * conc_{sedP} * \frac{sed}{area_{hru}} * \epsilon_{p:sed} \quad (3\text{-}15)$$

Where sedP_{surf} is the amount of phosphorus transported with sediment to the main channel in surface runoff (kg P/ha), $conc_{sedP}$ is the concentration of phosphorus attached to sediment in the top 10mm (g P/metric ton soil) calculated using equation (13), sed is the sediment yield on a given day (metric tons), $area_{hru}$ is the HRU area (ha), and $\epsilon_{p:sed}$ is the phosphorus enrichment ratio calculated using the same equation (12) for N above.

The concentration of phosphorus attached to sediment in the soil surface layer, $conc_{sedP}$, is computed as:

$$conc_{sedP} = 100 * \frac{(minP_{act,surf} + minP_{sta,surf} + orgP_{hum,surf} + orgP_{frsh,surf})}{\rho_b * depth_{surf}} \quad (3\text{-}16)$$

Where $minP_{act,surf}$ is the amount of phosphorus in the active mineral pool in the top 10 mm (kg P/ha), $minP_{sta,surf}$ is the amount of phosphorus in the stable mineral pool in the top 10 mm (kg P/ha), $orgP_{hum,surf}$ is the amount of phosphorus in the humic organic pool in the top 10 mm (kg P/ha), $orgP_{frsh,surf}$ is the amount of phosphorus in the fresh organic pool in the top 10 mm (kg P/ha), b ρ is the bulk density of the first soil layer (Mg/m3), and depth surf is the depth of the soil surface layer (10 mm).

3.3. Model input

The ArcSWAT interface requires weather data input and three spatial dataset; a digital elevation model (DEM), land use and soil layers. Data on flow was used for calibration purpose. Thus the model setup involved the implementation of: (1).Watershed Configuration; (2).HRU Analysis; (3). Weather Data Definition and (4). Selection of management practices.

3.3.1. Watershed configuration and sub-watershed discretization

Watershed configurations define the spatial relationship of objects within the watershed. Three techniques are basically used: sub watershed discretization, hill slope discretizaion and grid cell discretizaion. All GIS interfaces developed for SWAT use the sub watershed discretization to divide a watershed (Neitsch et al., 2005).

The sub watershed discretization partitions the watershed into sub-basins based on topographic characteristics of the watershed. This technique preserves the natural flow paths, boundaries, and channels required for realistic routing of water, sediment and chemicals. The ArcSWAT interface is made up of 5 menus. The Watershed Delineation tool is the first interface to use in SWAT model setup. In this study, the watershed delineation tool was used to discretize the sub-watersheds. The watershed delineation carries out advanced GIS functions to aid in segmenting watersheds into hydrologically connected sub-watersheds for use in watershed modelling with SWAT (Winchell et al., 2008). The watershed delineation interface comprise of (1). DEM setup; (2).Stream definition; (3).Outlet and inlet definition; (4).Watershed outlets(s) Selection and definition; (5).Calculation of sub-basin parameters. The key procedures are: DEM importation; optional definition of area of interest (Mask); optional importation of stream network; DEM pre-processing; specification of critical source area; review and edition of the stream network points; Running the calculation of sub-basin parameters; and optional location of reservoir.

3.3.1.1. DEM setup:

A 90 X 90 m resolution DEM was downloaded from SRTM (Shuttle Radar Topography Mission) website on august 1st 2008 (Zomer et al., 2008) as shown in Figure 3 - 3 .The image with a geographic coordinate system - WGS84 datum was acquired in the Geotiff format and later converted to ESRI grid format as required by the delineation tool. After acquisition, it was necessary to reproject the image from its geographic coordinate system into an appropriate and choice coordinate system. The UTM – Zone 29 N – WGS 1984 projection was chosen in this research; details are shown in Table 3 - 1. According to a study carried out by Cotter et al (2003), minimum DEM data resolution for flow, sediment, NO3-N, and TP predictions, should range from 30 to 300 m. Based on this findings, a 90m X 90m DEM resolution was therefore suitable for this study. However an effort was made to resample the 90m DEM resolution into a 30 m with a finer resolution which was finally adopted in the DEM setup. After loading the appropriate DEM, the interface allows for a quick check on the projection setup, were the user can check on all DEM properties which include units (X-Y,Z,), cell size ,cell area and projection reference. Due to correct loading, only Z-unit (meters) was readjusted as other properties appeared satisfactory. The mask option that uses source map was used while the optional *burn in* option was not applied.

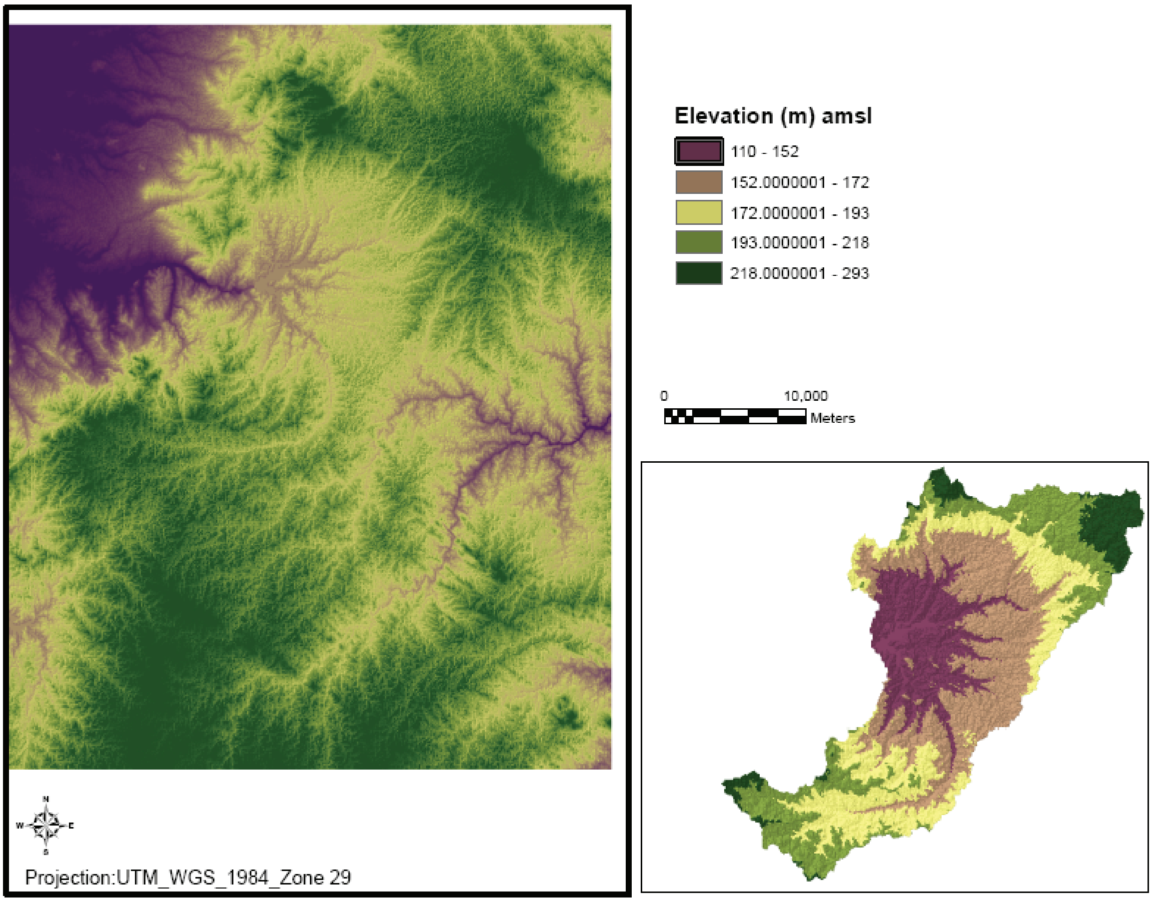


Figure 3-3: Digital elevation model for Roxo reservoir watershed

Table 3-1: Spatial Reference

Projection	*Universal Transverse Mercator*
Datum	WGS 1984
Zone	29
Central Meridian	-9
Reference latitude	0
False Northing	0
False Easting	500000
Scale factor	0.9996

3.3.1.2. Stream definition:

In this section, stream definition was carried out by using a DEM- based or predefined streams and watersheds. The DEM-based option was used, which allows to define flow direction and accumulation *The watershed delineation module identifies streams and drainage divides from DEMS using the eight direction pour point algorithm "(Jensen and Domingue,1988),* cited in Olivera et al. (2006). It follows the procedure presented by Olivera (2001) for DEM–based and watershed delineation but with adaptation to the SWAT data structure. Reaches are defined wherever drainage areas are greater than a user defined threshold value; sub-basin outlets are automatically defined on each of the reaches upstream of confluences and at user defined points; sub-basins are define as the incremental drainage area of each outlet. Thus no sub-basin has more than one reach and no reach lies in more than one sub-basin.

The ArcSWAT watershed delineation interface as used here allows a definition of threshold area of 369 - 73866Ha in the stream definition sections. SWAT suggested minimum value was 1477.7Ha and this gave rise to 24 numbers of sub-basins and outlets. Although recommended in the SWAT user manual (Neitsch et al., 2005) to define greater number of sub-basin to incorporate more complexity into dataset rather than many HRU within few sub-basins, the initial threshold value was increased to 1500Ha to generate a 13 sub-basins with the assumption that the 13 sub-basin is able to depicts enough variability in the study area. The steam network created 87 outlets during the first instance and finally 13 outlets were created.

3.3.1.3. Definition of additional elements

These elements are Outlet and Inlet Definition; Watershed Outlets(s) Selection and Definition; Addition of Reservoir. Delineation tool interface was being used to interactively define inlets points to the system allowing the exclusion of upstream drainage areas and the isolation of areas to be modelled in the watershed. Thus some outlets were deleted to reduce the number of sub basins to be. A selection of the whole watershed outlets button delineated the Roxo catchment. After calculation of Sub basin Parameters, a reservoir was added towards the outlet of the basin (sub basin 5), this was important in this study as nutrient and stream flow data were available from Roxo reservoir. Calibration was thus carried out in this sub basin.

The basin area delineated by ARCSWAT was 351.47km^2, this compares very well with literature and previous research (Mekonnen, 2005; Pawan, 2004) carried out in the study area were the basin area range from 349 - 353km^2. After completion of the delineation, a topographic report and several GIS layers were created: Basin, Watershed, Reach, LongestPath, Outlet, monitory point and reservoirs. Figure 3-4 shows the hydrologic elements of the Roxo reservoir watershed. *Basin* stores the polygon that represents the whole study area; *Watershed* stores the sub-basin polygons; *Reach* stores the segments of the channel network; *LongestPath* stores the longest flow path within each sub-basin; *Outlet* stores the sub-basin outlet points; *Monitory point* stores inlet points to the basin. *The topographic report describes the elevation distribution within the watershed (or "hydrologically" not connected watersheds) and within each sub watershed unit (sub-basin). The layers added to the map contain the parameters of the watershed(s) characterization* (Winchell et al., 2008). Refer to Figure 3-5 for attributes of and relationship among feature class as well as Appendix A-3 and A-4 for result of the topographic report and a snapshot of the watershed delineation tools respectively.

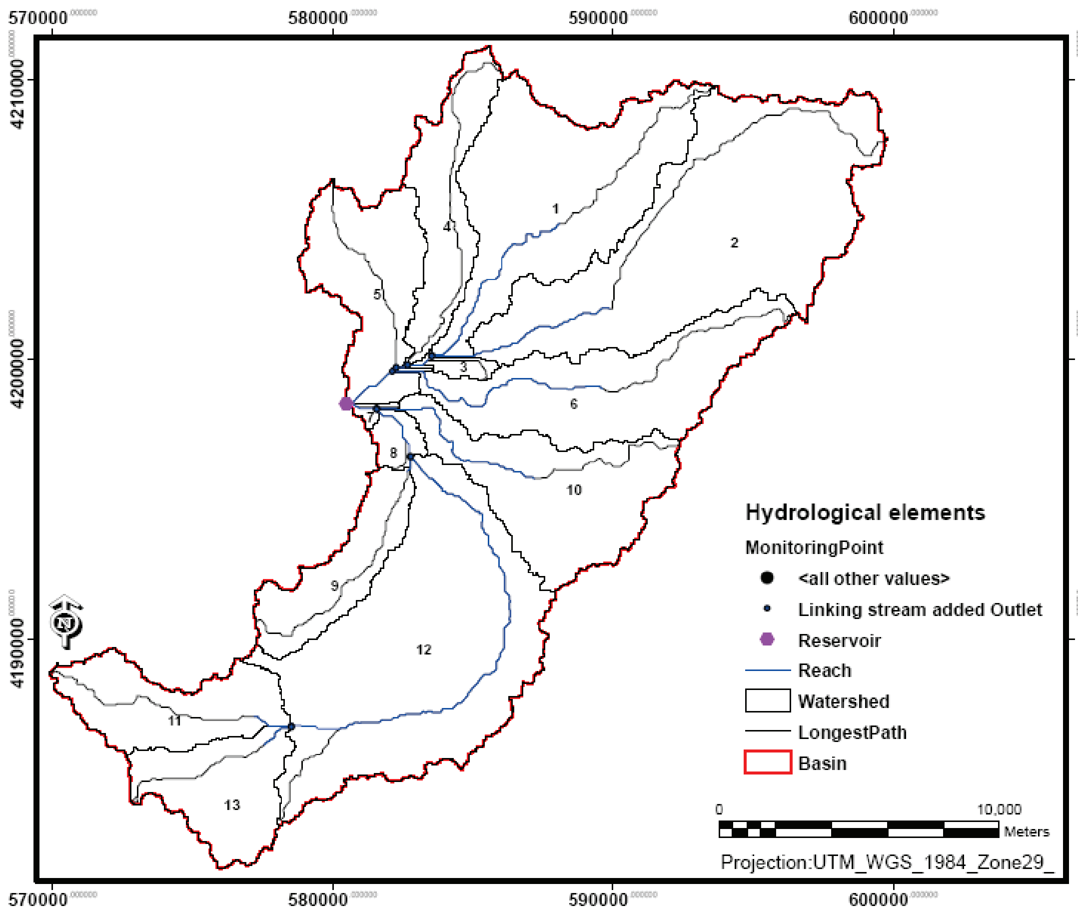


Figure 3-4: Feature classes generated by the watershed delineator

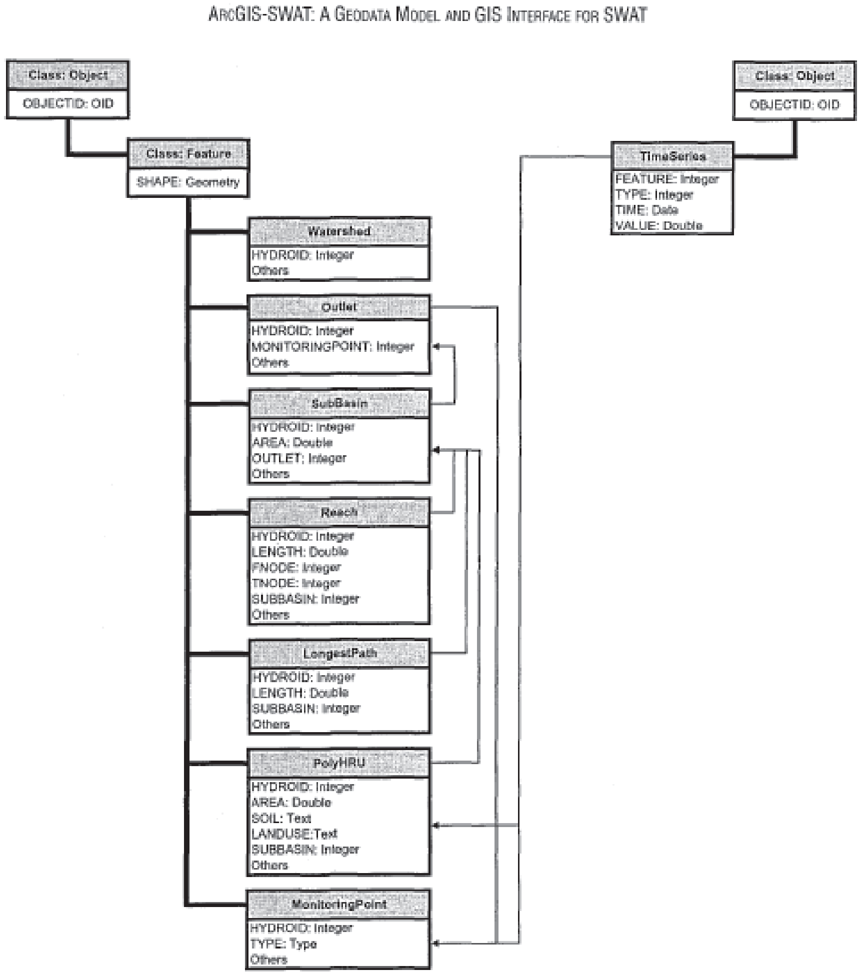


Figure 3-5: Attributes of and relationship among the feature classes and time series object class
(Boxes in rectangular shape depicts feature and object classes.Text on gray color depicts the class name while text on white color shows class attributes).
(Olivera et al., 2006).

3.3.1.4. Hydrologic response unit (HRU) analysis

Hydrologic response units are distinctive soil and land use management combinations within the sub-basin which are modelled without regard to spatial positioning (Neitsch et al., 2004). HRU analysis menu in ArcSWAT2005 was used to characterize, land use, soil, and slope of the Roxo reservoir watershed. The tool was used to import land use and soil layers into the modelling project. The tool was also used to evaluate slope characteristics and determine the land use/soil/slope class combinations for the delineated watershed(s) and the corresponding sub watersheds. All datasets used were in ESRI grid and projected in UTM – Zone 29 N – WGS 1984 datum.

3.3.1.5. Land use/soil/slope definition

The SWAT hydrologic model requires land use and soil data to determine the area and the hydrologic parameters of each land-soil category simulated within each sub-watershed. The slope is defined at the interface.

3.3.1.6. Land use data definition

Land use is one of the most significant factors that affect surface erosion, runoff, and evapotranspiration in a watershed. The land use map of the study area was derived from the European Topic Centre on Terrestrial Environment (CORINE land cover database) which is owned by European Environment Agency (EEA, 2000). "*CORINE is a European Commission programme established with the aim of compiling and coordinating information on the state of the environment and ensuring that the information are consistent and data are compatible within the Member States of the Community as well as at international level. The land cover project is part of the CORINE programme intended to provide consistent geographical information on the land cover of the Member States of the European Community, which is believed to be essential for the management of the environment and natural resources" (Kummsa, 2006).*The choice of selection of this landuse/cover type was based on its free availability from the internet as well as compatibility with GIS software. The dataset also provide user with options to use specified spatial resolution. Another choice for use is high overall accuracy indices at all levels of the CLC nomenclature and high reliability.

The landuse/cover classes in CORINE land cover map were derived from an interpretation of orthocorrected Landsat-7 and Spot images satellite imagery while topographic maps from all countries involved in the project were used as base map. The semantic information is stored in a hierarchic division of land cover classes in a CORINE land cover nomenclature based on three levels of classes as shown in Table 3-2. Level 1 has high cartographic generalised information indicating the major categories of land cover. Level 2 has 15 land use classes and has been compiled for use on scales of 1:500000 and 1:1000000. Level 3 has 44 land use classes and is used for projects on a scale of 1:100000 were more details are needed. The methodology used to derived land cover data as described in the CORINE database home, involves rasterization of vector CLC00 database as provided by National Teams within ICLC2000 project. All features in their original vector database are classified and digitized based on satellite images with 100 m positional accuracy (according to CLC specifications) and 25 ha minimum mapping unit into the standardized CLC nomenclature (44 CLC classes). The resolution of the raster data is 100 x 100 metres, compatible with standard EEA reference grids. ESRI spatial analyst was used to rasterize all vector polygon and each on the resulting output raster dataset from the conversion process was assigned based on the value of the polygon found at the center of each cell. A CORINE Land Cover 2000 Project (CLC2000) in Portugal was carried out in the context of the IMAGE and CORINE Land Cover 2000 (I&CLC2000) initiative from the European Commission. The CLC2000 for Portugal has an overall thematic accuracy of 82.8, with a confidence interval of 80.5-85.2, and majority of the CLC classes are mapped with high accuracy (Caetano et al., 2006).

Table 3-2: CORINE land cover nomenclature

Level 1	Level 2	Level 3
1.Artificial surfaces	1.1.Urban fabric	1.1.1. Continuous urban fabric
	1.2.Industrial, commercial and transport units	1.2.1. Discontinuous urban fabric
		1.2.2. Road and rail networks and associated land
		1.2.3. Port areas
		1.2.3. Airports
	1.3.Mine, dump and construction sites	1.3.1. Mineral extraction sites
		1.3.1.Dump sites
		1.3.1.Construction sites
	1.4.Artificial, non-agricultural vegetated areas	1.4.1.Green urban areas
		1.4.2.Sport and leisure facilities
2. Agricultural areas	2.1.Arable land	2.1.1. Non-irrigated arable land
		2.1.2. Permanently irrigated land
		2.1.3. Rice fields
		2.2.1. Vineyards
	2.2.Permanent crops	2.2.2. Fruit trees and berry plantations
		2.2.3. Olive groves
		2.3.1. .Pastures
		2.4.1. .Annual crops associated with permanent crops
	2.3.Pastures	2.4.2. Complex cultivation patterns
		2.4.3. Land principally occupied by agriculture, with
	2.4.Heterogeneous agricultural areas	significant areas of natural vegetation
		2.4.4. Agro-forestry areas
3. Forest and semi natural areas	3.1. Forests	3.1.1. Broad-leaved forest
		3.1.2. Coniferous forest
		3.1.3. Mixed forest
	3.2. Scrub and/or herbaceous vegetation associations	3.2. 1. Natural grasslands
		3.2. 2. Moors and heathland
		3.2. 3. Sclerophyllous vegetation
		3.2. 4. Transitional woodland-shrub
	3.3. Open spaces with little or no vegetation	3.3. 1. Beaches, dunes, sands
		3.3.2. Bare rocks
		3.3. 3. Sparsely vegetated areas
		3.3. 4. Burnt areas
		3.3. 5. Glaciers and perpetual snow
4. Wetlands	4.1. Inland wetlands	4.1. 1.Inland marshes
		4.1. 2.Peat bogs
	4.2. Maritime wetlands	4.2.1. Salt marshes
		4.2.2. Salines
		4.2.3. Intertidal flats
5. Water bodies	5.1. Inland waters	5.1.1. Water courses
		5.1.2. Water bodies
	5.2. Marine waters	5.2.1. Coastal lagoons
		5.2.2. Estuaries
		5.2.3. Sea and ocean

Source:(EEA, 2000)

This study adopts the Level 3 land use nomenclature with some modifications which was necessary as SWAT input land use data is expected to match land use in the SWAT database, in addition, it was observed that some classes were absent from the CORINE nomenclature. Prior to using the data for SWAT modelling, the basin boundary created from the 30 m resample DEM during watershed configuration was used to clip CORINE map of Portugal. This study recommends the use of the basin boundary to ensure reasonable overlay during HRU analysis. At successful loading of the land use map to the watershed boundary, 99.91% of overlap was achieved. ESRI ArcGIS was used to prepare and reclassify the land use maps into 9 classes: discontinuous urban fabric; eucalyptus forest; mixed agricultural areas; mixed forest; natural grasslands; non-irrigated arable land; olive groves; permanently irrigated land; water bodies. Discontinuous urban fabric (artificial surfaces with built up areas) were generalized as urban residential-medium to low density and water bodies was classified as water bodies, natural grassland was reclassified as pasture and mixed forest class was also retained in the database. The land use classes: eucalyptus, olive groves, permanently irrigated land, non-irrigated arable land, and mixed agricultural areas did not exist in SWAT database and was thus created and assigned appropriate SWAT land use codes. The non irrigated arable land forms the most dominant land (68.8%) use in the Roxo reservoir watershed. Figure 3-6 and Table 3-3 shows the reclassified land cover/use data used for SWAT simulations.

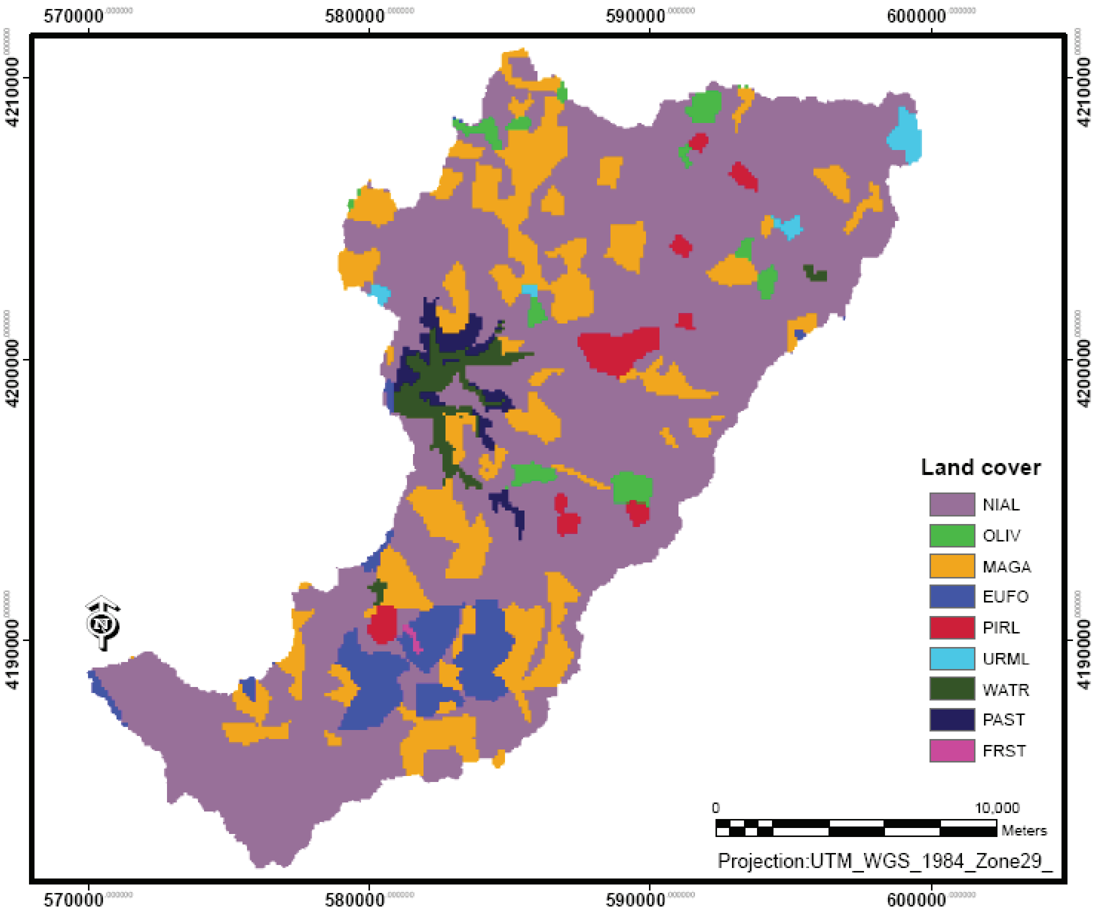


Figure 3-6: Land cover classification for Roxo reservoir watershed

Table 3-3: Matching of CORINE land use classes with the SWAT land use classes

Land use class	SWAT land use class	% of watershed area	Dominancy rank
Non Irrigated Arable land	Non Irrigated Arable land **(NIAL)**	68.8	1
Mixed Agricultural Areas	Mixed Agricultural Areas **(MAGA)**	17.8	2
Eucalyptus Forest	Eucalyptus Forest **(EUFO)**	4.7	3
Water bodies	Water bodies **(WATR)**	2.2	4
Permanently Irrigated Land	Permanently Irrigated Land **(PIRL)**	2.1	5
Olive groves	Olive groves **(OLIV)**	1.9	6
Natural Grasslands	Pasture **(PAST)**	1.5	7
Discontinuous Urban Fabric	Residential-Med/Low Density **(URML)**	0.8	8
Mixed Forest	Mixed Forest **(FRST)**	0.1	9

3.3.1.7. Soil data

The soils data required by SWAT comprise of different physical and chemical properties. The physical properties include soil hydrologic group (which is used in runoff generation with permeability and infiltration characteristics); maximum rooting depth, soil profile depth; from soil surface to bottom of layer; moist bulk density; available water capacity of the soil layer; saturated hydraulic conductivity; and the textural properties of soil (% clay, sand, silt and rock fragment content) required in stream flow computation and others such as USLE_K required to compute sediment yield. Chemical properties required by SWAT to determine transformation and movement of chemicals are fraction of porosity(void space), from which anions are excluded; and organic carbon content (% soil weight) and the initial concentrations of chemicals in the soil (Geza and McCray, 2008).

These data were obtained from previous ITC soil analysis research in the study area by Gokmen (2006) and from the Portuguese soil database. A digital soil map of 1:50,000 with complete tiles was acquired from Centro Operativo e de Technologia de Regadio (COTR) during the field campaign from 29/09/08 to 12/10/08 in Roxo reservoir watershed. Soil names were derived from the soil maps; soil hydrologic group were derived from S.H.G. Table from United States Soil Conservation Service; soil depth was derived from Soil Portugal report. Based on the laboratory analysis of Gokmen (2006), the following parameters were derived, soil depth; saturated hydraulic conductivity; soil carbon and textural properties of the soils; and available water content was derived from the SPAW Hydrology software; USLE_K was derived from Spreadsheet on Geometric mean particle diameter by Christ Mannaerts of the Water Resources Department, ITC. Table 3-4 shows some of these parameters. Due to non availability of data on soil layer, a single soil layer was assumed for SWAT modelling.

Table 3-4: Initial soil parameters

Soil Type	Soil group	BD (g/cm3)	AWC (mm/mm)	Ks (mm/hr)	CBN (%)	Clay (%)	Silt (%)	Sand (%)	Rock (%)	K-factor	Soil_Z(cm)
AH	D	1.52	0.12	1.02	0.9	44.8	21.6	33.7	16.6	0.324	200
BPC	D	1.87	0.12	0.78	0.9	46.9	22.6	30.5	2.6	0.318	250
CPH	C	1.51	0.12	2.16	1.6	42.5	23.1	34.4	5.8	0.329	200
PAG	B	1.69	0.12	5.88	0.8	25.3	34.8	39.9	26.1	0.321	100
PB	C	1.55	0.12	4.08	0.9	37.4	31.4	31.1	17.6	0.331	150
PS	B	1.66	0.13	5.52	1.3	27.0	36.0	37.0	15.5	0.330	250
PX	C	1.81	0.13	3.12	1.3	40.6	32.1	27.3	14.3	0.320	175
PXD	A	1.59	0.13	11.8	1.7	29.0	32.4	38.6	23.3	0.331	150
SP	A	1.79	0.15	7.68	1.5	36.6	41.0	22.5	12.8	0.320	620
SR	A	1.97	0.13	17.1	0.9	35.5	29.5	35.0	16.8	0.333	360
VC	B	1.54	0.12	7.56	1.4	36.5	24.6	38.9	8.9	0.333	330
VX	B	1.87	0.13	7.44	1.1	35.5	31.9	32.7	17.5	0.333	165

The basin feature class was also used to clip the Portuguese Soil map to mask out the area of interest (AOI) i.e. the study area. After clipping the soil map to the watershed boundary, the percentage of overlap was 99.24%. The soil map comprised of 42 classes and was reclassified into 12 classes which formed one of the spatial layers during modelling. A simplification of the original soil map from 42 classes into 12 was done by merging soils of similar physical properties, especially the textural properties. This was done to reduce complexity and extensive data input during soil parameterization.

Prior to loading the classified soil map in the HRU analysis interface, it was necessary to create a user soil database with the new soil classes, and this was followed by parameterization of the soil classes in the SWAT database. Soil types of the study area, codes, description and texture are depicted on Figure 3-7 and Table 3-5. The soil code Vx is the most dominant soil type in the study area with total area coverage of (21.346%). The order of dominancy in percentage (%) is as follows Vx (21.35%), Sr (16.83%), Ps (11.21%), Vc (11.08%), Bpc (10.23%), Pxd (7.47%), Px (6.17%), Pb (5.26%), Ah (3.32%), Pag (2.81%), Cph (2.32%), Sp (1.95%).

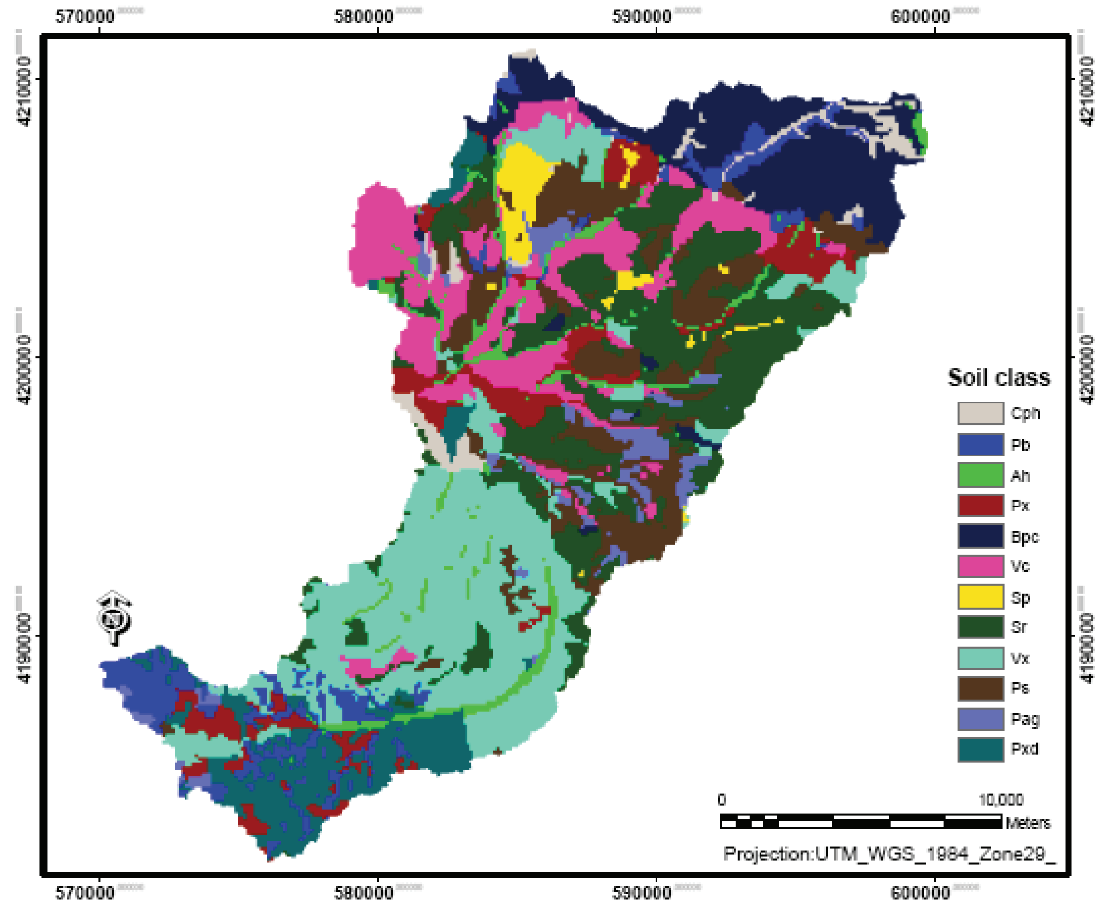


Figure 3-7: Soil map for Roxo reservoir watershed

Table 3-5: Soil classes description and area coverage

No	Soil code	SWAT Soil class	Description (Cardoso, 1965, Os Solos De Portugal)	Texture	Area (%)
1	AH	AH	Alluvial soils	Clay loam	3.3
2	BPC	BPC	Vertisols – calcareous black, strongly decarbonated	Clay	10.2
3	CPH	CPH	Vertisols – calcareous black, slightly decarbonated	Clay	2.3
4	PAG	PAG	Brown Mediterranean Soils from Non-calcareous rocks –para hydromorphic	Silty loam	2.8
5	PB	PB	Hydromorphic soils(without alluvial horizon –para not strongly unsaturated)	Clay loam	5.3
6	PS	PS	Hydromorphic soils – with alluvial horizon – planosols	Loam	11.2
7	PX	PX	Brown Mediterranean Soils from Non-calcareous rocks – normals	Clay loam	6.2
8	PXD	PXD	Brown Mediterranean Soils from Non-calcareous rocks – normals	Loam	7.5
9	SP	SP	Hydromorphic soils – hydromorphic organic soils	Silty clay	1.9
10	SR	SR	Red-yellow Mediterranean soils from non-calcareous rocks – normals	Loam	16.8
11	VC	VC	Red calcareous soils – red calcareous soils of semi-arid climates – normals	Clay loam	11.1
12	VX	VX	Red-yellow Mediterranean soils from non-calcareous rocks – normals	Clay loam	21.3

3.3.1.8. Slope definition

The slope was calculated from the DEM used in the study. The ArcGIS-SWAT calculates terrain slopes per HRU and run off curve numbers developed by USDA-SCS (1972). The division of HRU by slope is imperative in instances where there are wide ranges of slopes occurring in a watershed. However, in the ArcSWAT version, slope classification is a requirement that must be fulfilled for the modelling task. Slope descritization was carried out with multiple slope option during HRU analysis and 2 slope classes were selected by specification of an upper class limit. Multiple slope option permits a classification of slope into several classes. The option available in the combo box on the HRU analysis interface allows from 1 to 5 slope classes. It is advisable that more classes than 5 are found to be impractical while 3 or fewer slope classes are sufficient for most cases (Winchell et al., 2008). Therefore based on the suggestion above and the topographic conditions of the Roxo reservoir watershed, we used 2 classes for slope descritization. The result of the slope classification is shown in Figure 3-8.

3.3.1.9. Overlay and HRU definition.

Overlay operation was carried out on the classified grid layers (land use, soil and slope maps).This resulted in the generation of land use, soils, and slope distribution report as shown in Appendix A-5. The report provides detailed description of the distribution of the land use, soil, and slope classes in the watershed and the 13 sub-watershed delineated in the study area. The resulting FullHRU layer was used to define the HRU. HRU definition from the model interface was used to extract the dominant and critical landscape units for each sub watershed. An application of the HRU definition allows a subdivision of the basin into areas with unique land use and soil combinations and enables the model to reflect differences in evapotranspiration and other hydrologic conditions for different land covers/crops and soils. It is also used to make a separate prediction of runoff for each HRU and how it is routed to obtain the total runoff for the watershed. This enhances the accuracy of load predictions and provides a much a better physical description of the water balance of the study area (Winchell et al., 2008). In the HRU definition interface, three options are available: dominant land use, soils, slope; dominant HRU; multiple HRUs. In this study, dominant land use, soils, slope option which allows modeling of the sub-watershed while using single land use and main soil unit of each sub-watershed was employed.

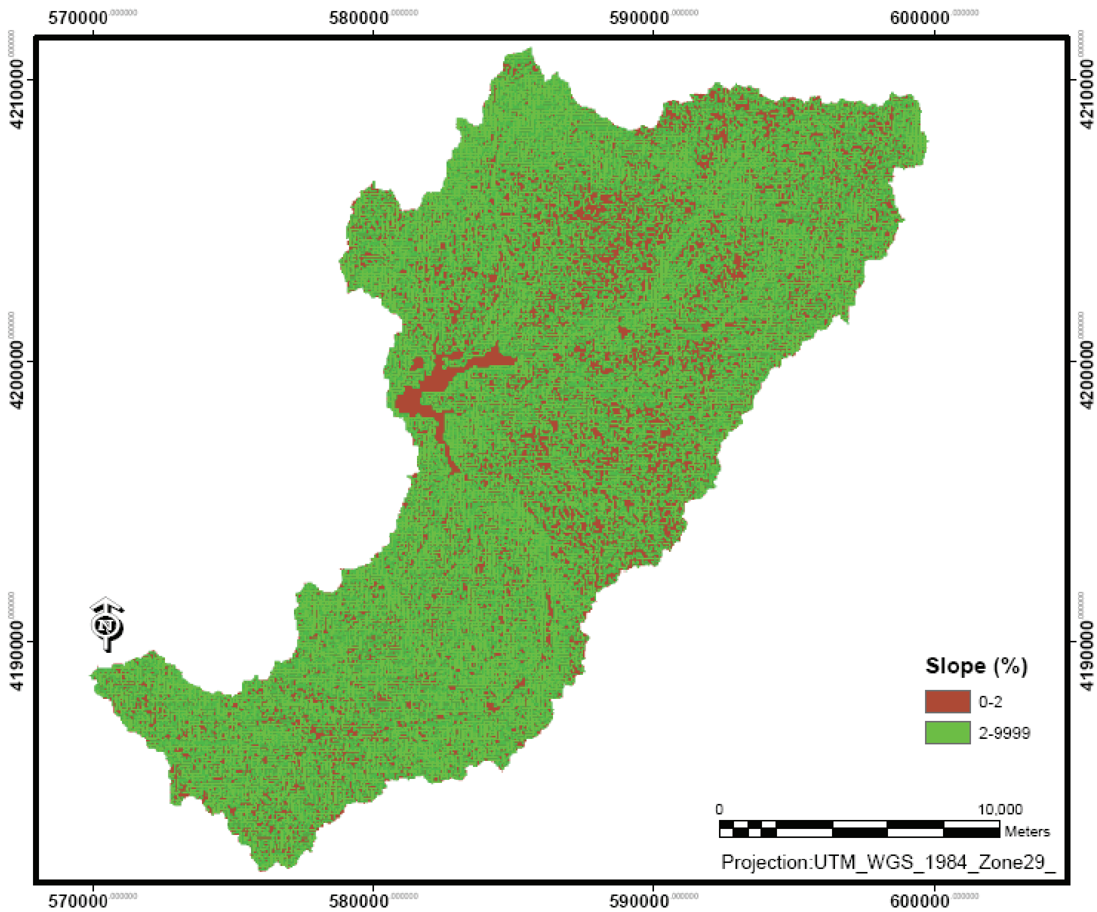


Figure 3-8: Slope map for Roxo reservoir watershed

3.3.2. Weather data definition

SWAT requires daily values of weather data as an input. These data are daily precipitation, maximum/minimum air temperature, solar radiation, wind speed and relative humidity. We present here, the definition of weather data input for rainfall and temperature weather data. In order to run the SWAT model, it is recommended to either prepare a file or location tables that contains observed data, or use daily values simulated by the SWAT model weather generator from monthly average data, summarize over a number of years (Neitsch et al., 2005). This research used observed and simulated data. SWAT modelling was carried out by using three types of weather data: SWAT weather generator simulated data; gauge data from ground stations; and satellite data.

Observed weather data from *Centro Operativo e de Technologia de Regadio* (COTR) (http://www.cotr.pt/sagranet/sagranet) were utilized to create daily precipitation, minimum/ maximum temperatures, dew point temperature, wind velocity and solar radiation statistics (minimum, maximum, average and standard deviation) for Beja and Aljustrel weather stations for the period 2001 - 2008. Similarly daily precipitation data for the same period were derived from *Sistema Nacional De Informacao De Recursos Hidricos* (SNIRH) (http://snirh.pt) for Castro Verde weather station. The spatial distribution of these weather stations is shown in Figure 3-9. Monthly weather parameters were derived from these series of observed daily data. Precipitation data of year 2007 to 2008 were derived from MSGMPE for 18 artificial rainfall stations.

3.3.2.1. Weather generation (Wgn)

SWAT has the potential to generate synthetic time series of precipitation, temperature, solar radiation, wind speed, and relative humidity for each sub-basin. ArcGIS-SWAT includes a point feature class of weather stations in a static geodatabase. User weather stations was established firstly for observed time series at Beja, Aljustrel and Castro Verde weather stations and later established for the time series data from satellite observation. With respect to observed time series data, the weather generator capability of the SWAT model was used to assign a station to each sub-watershed (see Table 3-6 & Figure 3-9) based on proximity to its centroid by storing the matches (SubPcp), (SubTmp) and time series in object classes, (Pcp), (Tmp) for precipitation and temperature respectively. All matched weather stations were appended to monitoring points and related to (time series); refer to Figure 3-5. It is recommended to fill -99.0 for all missing values to facilitate the generation of time series. SWAT uses a Markov chain concept developed by Nicks (1974) to statistically generate values and assigns them to a sub-watershed.

The weather generator data was first defined by creating a customize weather station in the static geodatabase because this is the recommended procedure. We started by customizing for three gauge stations (and later an inclusion of artificial station from satellite observation) by defining the number of rain years (8), elevation, geographical coordinates and all monthly weather parameters. The method used to generate the monthly parameters are all shown in Table 3-7 with description of required weather station parameters and mathematical equations used to derive values as specified in the SWAT input/output file documentation (Neitsch et al., 2004). Statistical functions in Microsoft excel were highly implored in the computation. In addition the computation of precipitation parameters and average dew point were carried out using a java edition of pcpSTAT, dew, and statistic programs develop by Liersch (2003). The program was designed to calculate the average daily dewpoint temperature per month using daily air temperature and humidity data. The result of the computation used as input monthly weather parameters for Aljustrel, Beja and Castro Verde weather stations are shown in Appendix A-6, A-7 & A-8.

Suffice to mention here that the customize weather generator data were entered into the weather stations before starting ArcSWAT project. We also prepared Wgn gage location tables to host the weather stations as well as daily precipitation and temperature gage location table. The location tables used are shown in Appendix A-9, A-10, and A-11. The step taken is shown in Figure 3-10 below.

Table 3-6: Description of ground weather stations

Station ID	Station Name	XPR(m)	YPR(m)	Elevation (masl)	Sub-basin
271	Castro Verde	579934.55	4172653.64	206	12,13
1005	Aljustrel	571119.64	4202949.77	104	3,4,5,7,8,9,11
1007	Beja	597845.65	4210562.41	217	1,2,6,10

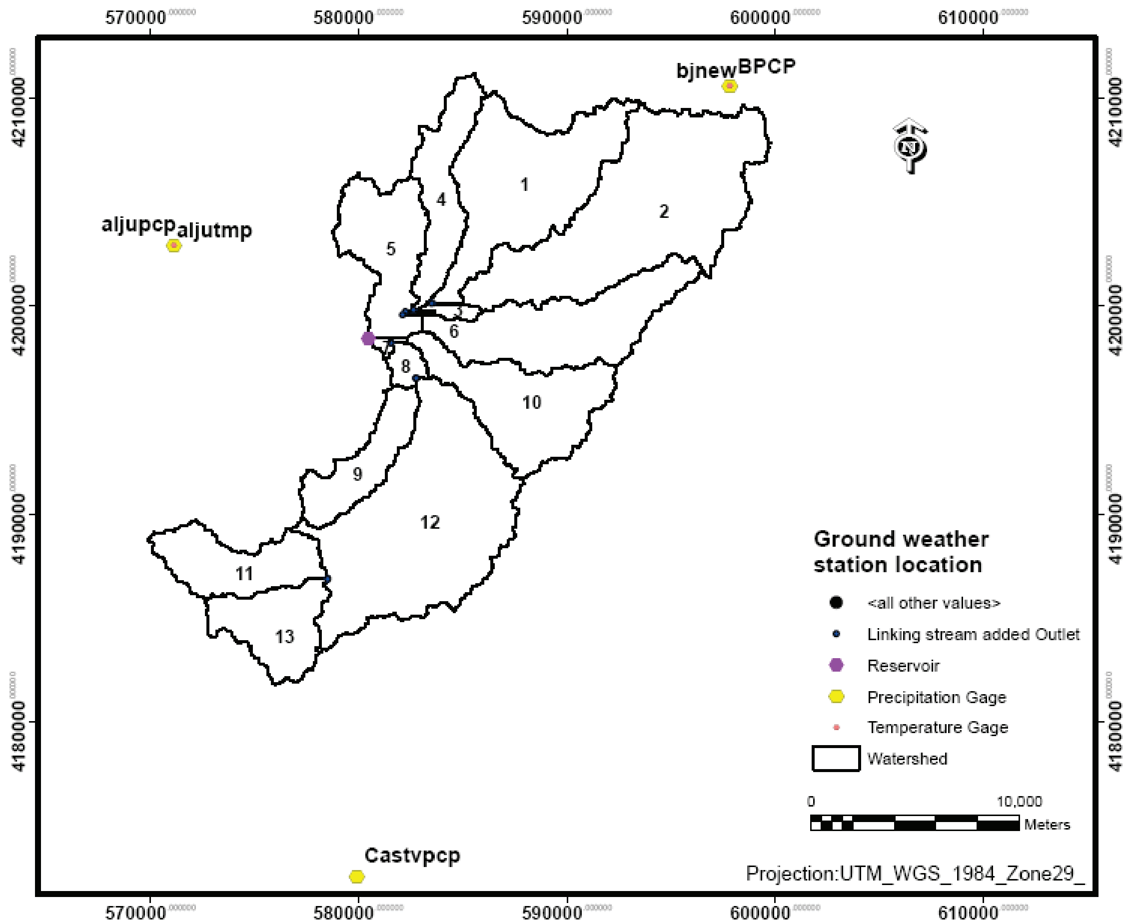


Figure 3-9: Spatial distribution of weather stations

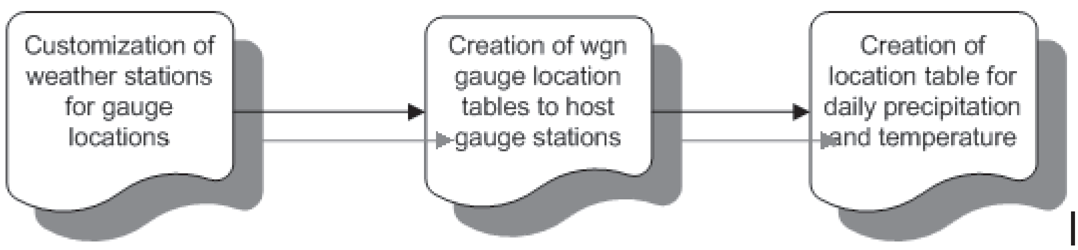


Figure 3-10: Sequence of creation of location tables

Table 3-7: Monthly weather parameters and definition

Average (mean) daily maximum air temperature for month (ºC)	This value was calculated by summing the maximum air temperature for every day in the month for all years of record and dividing by the number of days summed: $\mu mx_{mon} = \frac{\sum_{d=1}^{N} T_{mx,mon}}{N}$ Where μmx_{mon} is the mean daily maximum temperature for the month (^{O}C), *Tmx, mon* is the daily maximum temperature on record *d* in month *mon* (^{O}C), and *N* is the total number of daily maximum temperature records for month *mon*.
Average (mean) daily minimum air temperature for month (ºC)	This value was calculated by summing the minimum air temperature for every day in the month for all years of record and dividing by the number of days summed: $\mu mn_{mon} = \frac{\sum_{d=1}^{N} T_{mn,mon}}{N}$ Where μmn_{mon} is the mean daily minimum temperature for the month (^{O}C), *Tmn,mon* is the daily minimum temperature on record *d* in month *mon* (^{O}C), and *N* is the total number daily minimum temperature records for month *mon*.
Standard deviation for daily maximum air temperature in month (ºC)	This parameter quantifies the variability in maximum temperature for each month. The standard deviation is calculated as: $\sigma mx_{mon} = \sqrt{\left(\frac{\sum_{d-1}^{N}\left(T_{mx,mon}-\mu mx_{mon}\right)^2}{N-1}\right)}$ Where σmx_{mon} is the standard deviation for daily maximum temperature in month *mon* (ºC), *Tmx,mon* is the daily maximum temperature on record *d* in month *mon* (^{O}C), μmx_{mon} is the average daily maximum temperature for the month (ºC), and *N* is the total number of daily maximum temperature records for month *mon*
Standard deviation for daily minimum air temperature in month (ºC) {TMPSTDMN (mon)}	This parameter quantifies the variability in minimum temperature for each month. The standard deviation is calculated as: $\sigma mn_{mon} = \sqrt{\left(\frac{\sum_{d-1}^{N}\left(T_{mn,mon}-\mu mn_{mon}\right)^2}{N-1}\right)}$ Where σmn_{mon} is the standard deviation for daily minimum temperature in month *mon* (ºC), *Tmn,mon* is the daily minimum temperature on record *d* in month *mon* (°C), μmn_{mon} is the average daily minimum temperature for the month (ºC),and *N* is the total number of daily minimum temperature records for month *mon*.
Average (mean) total monthly precipitation (mm H2O) {PCPMM (mon)}:	It is given as: $\bar{R}_{mon} = \frac{\sum_{d=1}^{N} R_{day,mon}}{yrs}$ Where $\bar{R}_{mon}$ is the mean monthly precipitation (mm H2O), *Rday,mon* is the daily precipiation for record *d* in month *mon* (mm H2O), *N* is the total number of records in month *mon* used to calculate the average, and *yrs* is the number of years of daily precipitation records used in calculation.
Standard deviation for daily precipitation in month (mmH2O/day) {PCPSTD (mon)}:	This parameter quantifies the variability in precipitation for each month. The standard deviation is calculated: $\sigma_{mon} = \sqrt{\left(\frac{\sum_{d=1}^{N}\left(R_{day,mon}-\bar{R}_{mon}\right)^2}{N-1}\right)}$

	where σ_{mon} is the standard deviation for daily precipitation in month *mon* (mm H2O), *Rday,mon* is the amount of precipitation for record *d* in month *mon* (mm H2O), $\bar{R}_{mon}$ is the average precipitation for the month (mm H2O), and *N* is the total number of daily precipitation records for month *mon*. (Note: daily precipitation values of 0 mm are included in the standard deviation calculation).
Skew coefficient for daily precipitation in month {PCPSKW (mon)}:	This parameter quantifies the symmetry of the precipitation distribution about the monthly mean. The skew coefficient is calculated as: $g_{mon} = \frac{N.\sum_{d=1}^{N}(R_{day,mon}-\bar{R}_{mon})^3}{(N-1).(N-2).(\sigma_{mon})^3}$ where *gmon* is the skew coefficient for precipitation in the month, *N* is the total number of daily precipitation records for month *mon*, *Rday,mon* is the amount of precipitation for record *d* in month *mon* (mm H2O), $\bar{R}_{mon}$ is the average precipitation for the month (mm H2O), and σ_{mon} is the standard deviation for daily precipitation in month *mon*(mm H2O). (Note: daily precipitation values of 0 mm are included in the skew coefficient calculation).
Probability of a wet day following a dry day in the month {PR_W (1, mon)}.	This is the Probability of a wet day following a dry day in the month. It is calculated as: $P_i\ (W/D) = \frac{days_{W/D,i}}{days_{dry,i}}$ Where *Pi (W/D)* is the probability of a wet day following a dry day in month *i*, *daysW/D,i* is the number of times a wet day followed a dry day in month *i* for the entire period of record, and *daysdry,i* is the number of dry days in month *i* during the entire period of record. A dry day is a day with0 mm of precipitation. A wet day is a day with > 0 mm precipitation.
Probability of a wet day following a wet day in the month {PR_W (2, mon)}	This is the Probability of a wet day following a wet day in the month. It is calculated as: $P_i\ (W/W) = \frac{days_{W/W,i}}{days_{wet,i}}$ Where *Pi (W/W)* is the probability of a wet day following a wet day in month *i*, *daysW/W,i* is the number of times a wet day followed a wet day in month *i* for the entire period of record, and *dayswet,i* is the number of wet days in month *i* during the entire period of record. A dry day is a day with 0 mm of precipitation. A wet day is a day with > 0 mm precipitation.
Average number of days of precipitation in month {PCPD (mon)}	This parameter is calculated as: $\bar{d}_{wet,j} = \frac{days_{wet,j}}{yrs}$ Where $\bar{d}_{wet,j}$, is the average number of days of precipitation in month *i*, *dayswet,i* is the number of wet days in month during the entire period of record, and *yrs* is the number of years of record.
Maximum 0.5 hour rainfall in entire period of record for month (mm H2O) *{RAINHHMX (mon)}*.	This value represents the most extreme 30-minute rainfall intensity recorded in the entire period of record. It was estimated by Chris Mannaerts from relattorio_prec_intensa document which describes analysis of extreme precipitation intensity for Portugal.
Average daily solar radiation for month (MJ/m2/day) *{SOLARAV (mon)}*.	This value is calculated by summing the total solar radiation for every day in the month for all years of record and dividing by the number of days summed:

	$\mu rad_{mon} = \frac{\sum_{d=1}^{N} H_{day,mon}}{N}$ Where μrad_{mon} is the mean daily solar radiation for the month (MJ/m2/day), *Hday,mon* is the total solar radiation reaching the earth's surface for day *d* in month *mon* (MJ/m2/day), and *N* is the total number of daily solar radiation records for month ,*mon.*
Average daily dew point temperature in month (ºC) {DEWPT (mon)}	The dew point temperature is the temperature at which the actual vapour pressure present in the atmosphere is equal to the saturation vapour pressure. This value is calculated by summing the dew point temperature for every day in the month for all years of record and dividing by the number of days summed: $\mu dew_{mon} = \frac{\sum_{d=1}^{N} T_{dew,mon}}{N}$ Where μdew_{mon} is the mean daily dew point temperature for the month (ºC), *Tdew, mon* is the dew point temperature for day *d* in month *mon* (ºC), and *N* is the total number of daily dew point records for month *mon*.
Average daily wind speed in month (m/s) {WNDAV (mon)}.	This value is calculated by summing the average or mean wind speed values for every day in the month for all years of record and dividing by the number of days summed: $\mu wnd_{mon} = \frac{\sum_{d=1}^{N} \mu_{wnd,mon}}{N}$ Where µ*wndmon* is the mean daily wind speed for the month (m/s), µ*wnd,mon* is the average wind speed for day *d* in month *mon* (m/s), and *N* is the total number of daily wind speed records for month *mon*.

Source: After Neitsch et al., (2004)

3.3.2.1. Creation of artificial weather stations from satellite observation

Artificial point rainfall stations were created from the satellite observation data. A visit was made to the Eumetsat archive on September 2008 with the purpose of obtaining rainfall data, after a careful search, only datasets of 2007 were available and retrieved. The data were further processed in ITC (Maathius et al., 2008). ILWIS GIS software was employed to derive precipitation time series from the satellite map by randomly selecting pixel values in all sub-catchment. Thus time series for 18 point (i.e. 3 X 3 km^2 pixel) stations for the period 1/1/2007 to 23/05/2008 were generated. During implementation in the model, 10 of these stations were utilized.

The process of using MSGMPE time series data in SWAT model involves a first step of cleaning the data since there were some missing data which needed to be replaced with a -99 value that allow the model to interpolate for missing values. Thus time series data with dates and precipitation amount were created for the 10 artificial weather stations which formed the content of the satellite data location table required by the SWAT model to write weather station input tables. All artificial stations were attributed with names, elevation, rain years, and geographic coordinates on the user weather stations database edit interface. Precipitation values derived from the satellite observation was used to compute monthly weather parameters with all precipitation variables (PCPMM, PCPST, PCPSKW, PR_W (1), PR_W (2), and PCPD) while default values were assume for the other weather parameters. The location of artificial gauge stations used in the model are shown in Figure 3-13 below while the location table used is shown in Appendix A-12.

Table 3-8: Description of satellite weather stations

ID	Name	XPR(m)	YPR(m)	Elevation (masl)	Sub-basin
1	Aba	579940.86	4191480.73	178	9
2	Aca	582572.05	4191052.4	180	12
3	Ada	576636.57	4185790.01	183	13
4	Afa	584285.39	4187503.35	162	-
5	Aga	587222.53	4194968.59	152	10
6	Aha	591628.25	4198272.88	169	6
7	Aja	587344.92	4198517.65	152	-
8	Aka	594198.26	4203841.22	177	2
9	Ala	591383.49	4202005.51	165	-
10	Ama	595299.69	4207818.61	217	-
11	Ana	592301.35	4206533.61	190	-
12	Ara	587895.63	4201454.79	145	-
14	Aza	586059.91	4203963.6	147	1
15	Asa	584652.53	4208675.28	197	-
16	Ata	583734.67	4204269.56	157	4
17	Ava	580552.77	4204024.79	151	5
18	Aya	582816.82	4198395.26	128	6

NB: The (-) signs refers to the unselected artificial stations by the model

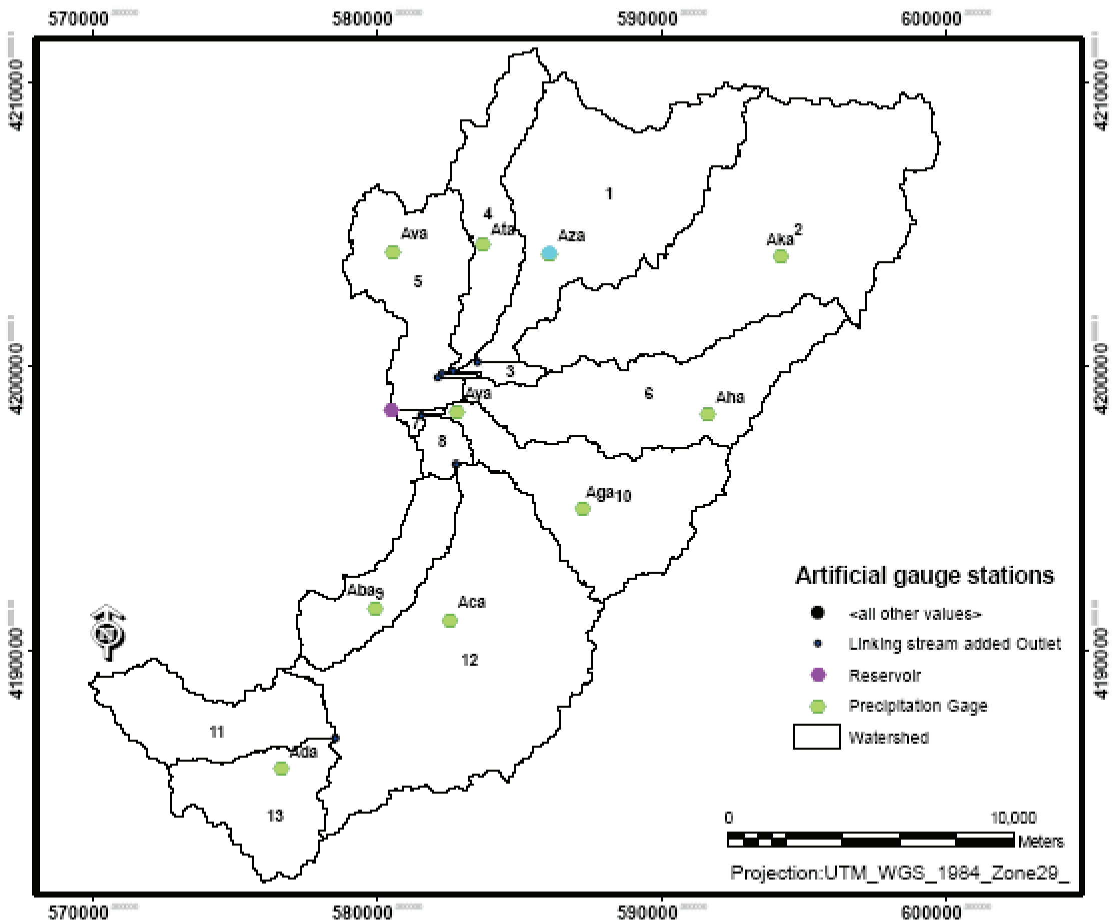


Figure 3-11: Location of artificial weather stations (satellite observation) in Roxo watershed

3.3.3. Management practices

ArcGIS-SWAT allows a user to define management practices taking place in every HRU that may affect simulation. Thus a user can define the starting and ending of the growing season, specify timing and amount of fertilizer, pesticides and irrigation application, timing of tillage and grazing operations as well as other agricultural practices. SWAT uses five databases to store information related to plant growth, urban land characteristics, tillage implementation, fertilizer components and pesticide properties. The Information required to simulate plant growth is stored by plant species in the plant growth database file supplied with the SWAT model. The fertilizer database summarizes the relative fractions of nitrogen and phosphorus pools in the different fertilizers and was updated with types of fertilizers used in the catchment. According to Paralta et al., (2007) sources of nitrogen to the watershed are fertilizers from atmospheric nitrogen with a composition of 0% to 3% and animal manure with nitrate values of +10 to +25 %.

The plant growth database distributed with SWAT includes parameters for most of the common plant species. Thus datasets available from COTR and recommendation from relevant literature (Neitsch et al., 2005; Pawan and Gieske, 2006) were used to parameterize specific crop type in the land cover/plant growth database. Information with respect to planting and fertilization for the main agricultural crop types (MAGA, PIAL, NIAL) are shown in table 3-8. In this study, sunflower, maize and winter wheat were used to characterize Mixed Agricultural Land (MAGA), Permanently Irrigated Arable Land (PIAL), and Non-irrigated Arable Land (NIAL) respectively. Other plant types were found not to be fertilized. Information on fertilizer date was obtained during fieldwork from the Instituto Polytechnico de Beja.

After preparing all required input data, updating databases and parameterization, ArcGIS-SWAT was ready to run.

Table 3-9: Agricultural Crop types and Fertilization

Crop types	Dates	Fert. Name	Fert. Amount
MAGA(sunflower)	April/may	Soil fertilizer level	NA
PIAL(maize)	Summer months	At planting:15-35-00	100kg/ha
		At boost:6-20-18 or 8-24-24	300/400kg/ha
		At mid/maturity: Nitro 32N	600kg/ha
NIAL(winter wheat)	End_Oct/start_Nov.	At planting:10-30-00(NPK)	300kg/ha
		At development: Nitro 27%	250kg/ha

3.4. Summary

This chapter provided a short description of the study area as well as a description of ArcSWAT as modelling tool for the research. Our test bed was the Roxo reservoir located in Portugal. The dataset used to carry out the modelling task include a 90m X 90m SRTM DEM that was resample into 30m X 30m; the level 3 land cover of CORINE2000; Soil map of study area was extracted from Portuguese soil map, provided by COTR. Meteorological and precipitation data were obtained with permission from COTR and SNIRH database and archived satellite data from Eumetsat as well as already existing satellite precipitation data from ITC. Land management data were also obtained from COTR and finally ITC research archive was also used to fill gaps of missing data. The chapter also elaborated on methods used to prepare the dataset and model setup.

4. Model simulations

4.1. Introduction

Simulation was carried out in three phases by driving the model with three sources of weather and climatic data: (1). SWAT weather generator (Wgn); (2). Observed ground rainfall data; (3). Satellite rainfall estimate. The simulation options used the Curve number (CN2) method for calculating the surface runoff (USDA-SCS, 1972), a first order Markov chain for rainfall distribution estimation, Penman–Monteith method for evaporation and Muskingum channel routing. The output frequency was on monthly basis while the model gave observed yearly summaries. The model outputs were compared to observed data, visual and statistical interpretations of the model behaviour to different sources were made and remarks were given on the model performance. After the visual observation, sensitivity analysis of parameters, calibration and validation were carried out for observed gage data simulations. The model was calibrated with the observed ground rainfall station data on rainfall input.

4.1.1. Simulating with SWAT weather generator (Wgn)

To carry out this simulation, a SWAT project was setup and input data and parameters were entered. The weather data definition dialogue box was used to define a custom database for this simulation. The custom database was already prepared before start of the SWAT project. As no gauge data was used, SWAT was allowed to generate all weather data. The period of simulation was from 9/1/2001 to 10/29/2008. Rainfall distribution used was skewed normal and printout setting was set for monthly. After running the model, it was saved as a scenario for further analysis.

4.1.2. Simulating with observed rain gauge data

This simulation was also carried out by input of prepared datasets and parameterization. Prior to running the simulation, gauge data for precipitation and temperature were created. During weather data definition, these gauge location tables of the weather data were loaded in the interface. The period of simulation was from 9/1/2001 to 10/29/2008. The rainfall distribution used was skewed normal and printout setting was set for monthly. The model result was also saved as a scenario for further analysis.

4.1.3. Simulating with satellite rainfall data

This simulation was also carried out by input of prepared datasets and parameterization. During the weather data definition, an already prepared gauge location table of the weather data was loaded at the user weather database interface. The period of simulation was from 1/1/2007 to 05/23/2008. The rainfall distribution used was skewed normal and printout setting was set for monthly. The model result was also saved as a scenario for further analysis.

4.1.4. Processing of SWAT output files

After running the SWAT model, five output files in text format are created: basins.sbs; basins.bsb; basins.rch; basins.wtr; and basins.rsv. The basins.rch file was highly utilized in this thesis. Each of the files contains summary information of a specific type of hydrologic element which is stored as an object class in the dynamic geodatabase, see Appendix B-1. In addition, time series data included in the five output files are also stored in <Time series> with fields that stores where each time series record was calculated, what as calculated, and how much was calculated. Thus all SWAT outputs were stored in the dynamic geodatabase and <Time series>. Each of these files was created for both scenarios. However a manual extraction of outputs was carried out in sub-basin 5. Sub-basin 5 was chosen because of availability of observed data for stream flow and nutrient, the model outputs were compared with the observed data. But for the purpose of this comparison, only stream flow was used. Figure 5-2 shows the location of sub-basin 5 in the watershed.

4.1.5. Visual and statistical comparison before model calibration

The comparison of using uncalibrated models is a useful way of evaluating the differences in model prediction since calibration conceals the differences in model predictions. Calibration itself is the fine tuning of model parameters to faithfully represent observed conditions. A definition of model calibration was given by Moriasi et al.(2007) as *"the process of estimating model parameters by comparing model predictions (output) for a given set of assumed conditions with observed data for the same condition"*. Uncalibrated model results also known as cold simulation result (results produced by the model before any calibration can be carried out) can reveal how good each dataset predicts stream flow before calibration which would indicate the effort needed for calibration when using specific dataset.

It is highly recommended that graphical techniques and quantitative statistics should be used in model evaluation (ASCE, 1993; Legates and McCabe, 1999; Moriasi et al., 2007). The graphical techniques provide a visual comparison of simulated and measured constituent data and a first synopsis of model performance (ASCE, 1993) and according to Legates and McCabe (1999), they are appropriate and vital to model evaluation. Two commonly used graphical techniques; hydrographs and percent exceedance probability curves have proved very useful. Bar graphs and box plots have also been used to examine data distribution. Hydrographs help identify model bias and can identify differences in timing and magnitude of peak flows and the shape of recession curves. Hydrographs and bar graphs were fully explored in this research. Quantitative statistics include standard regression, dimensionless, and error index. Standard regression statistics determine the strength of the linear relationship between simulated and measured data. Dimensionless techniques provide a relative model evaluation assessment, and error indices quantify the deviation in the units of the data of interest (Legates and McCabe, 1999). In this research we used a combination of graphical technique, standard regression statistic dimensionless technique (**Nash-Sutcliffe efficiency (NSE))** and an error index (**Percent bias (PBIAS)).** The NSE is a normalized statistic that determines the relative magnitude of the residual variance ("noise") when compared to the measured data variance ("information") (Nash and Sutcliffe, 1970). The NSE is a good indicator of how well the plot of observed versus simulated data fits the 1:1 line. NSE is calculated as shown in equation 4-1.

$$\mathbf{NSE} = 1-\left(\frac{\sum_{i=1}^{n}\left(Y_i^{obs}-Y_i^{sim}\right)^2}{\sum_{i=1}^{n}\left(Y_i^{obs}-Y^{mean}\right)^2}\right) \qquad \textbf{(4-1)}$$

Where Y_i^{obs} is the *i*th observation for the constituent being evaluated, Y_i^{sim} is the *i*th simulated value for the constituent being evaluated, Y^{mean} is the mean of observed data for the constituent being evaluated, and *n* is the total number of observations. NSE ranges between ∞ and 1.0 (1 inclusive), with NSE = 1 being the optimal value. Values between 0.0 and 1.0 are generally viewed as acceptable levels of performance, whereas values < 0.0 indicates that the mean observed value is a better predictor than the simulated value, which indicates unacceptable performance. An acceptable value should be greater than 0.5 while a good value should be greater than 0.7. We use here NSE based on the recommendations of ASCE (1993) and Legates and McCabe (1999) and due to its common usage with myriads of extensive information on reported values.

Percent bias (PBIAS) measures the average tendency of the simulated data to be larger or smaller than their observed counterparts (Gupta et al., 1999). The optimal value of PBIAS is 0.0, with low-magnitude values indicating accurate model simulation. Positive values indicate model underestimation bias, and negative values indicate model overestimation bias. Predicted flow that deviates less than 10 percent from measured flow is considered acceptable PBIAS is calculated with equation 4-2:

$$\mathbf{PBIAS} = \left(\frac{\sum_{i=1}^{n}\left(Y_i^{obs} - Y_i^{sim}\right) * (100)}{\sum_{i=1}^{n}\left(Y_i^{obs}\right)}\right) \qquad \textbf{(4-2)}$$

Where PBIAS is the deviation of data being evaluated, expressed as a percentage. PBIAS was chosen because of its ability to clearly indicate poor model performance.

Our findings revealed that the simulations with observed gage data predicted stream flow reasonably well before calibration and would therefore need less effort in calibration as compared to Wgn (weather generator) and MSGMPE data simulations. Figures (4-1) - (4-2) and Table 4-1, shows the result of monthly stream flow predictions from uncalibrated model and Figure (4-3) - (4-4) also show yearly comparisons before calibration.

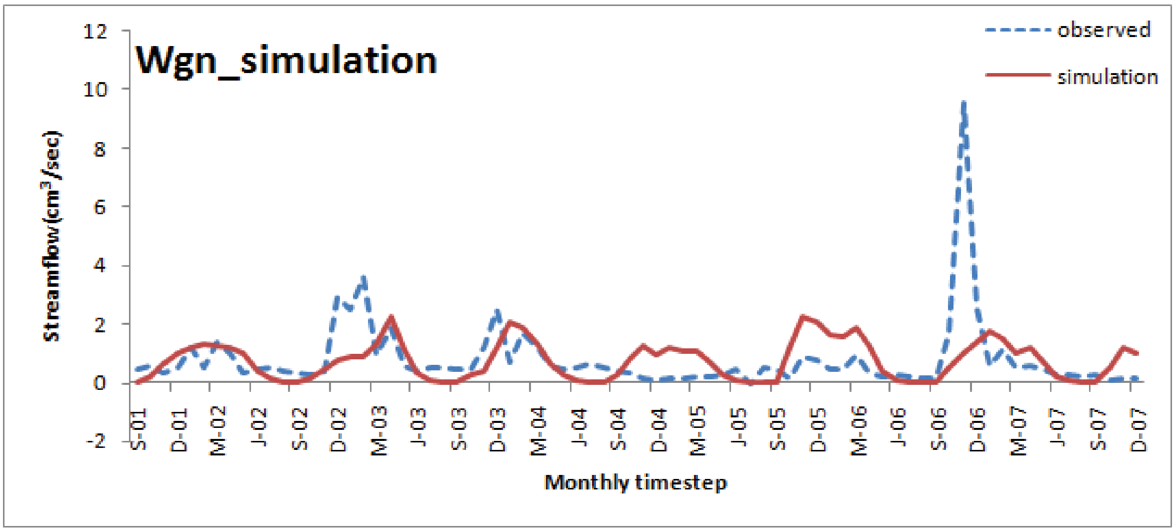


Figure 4-1: Hydrographs of observed stream flow with simulation using the weather generator (Wgn) before calibration for period Sep. 2001 to Dec. 2007.

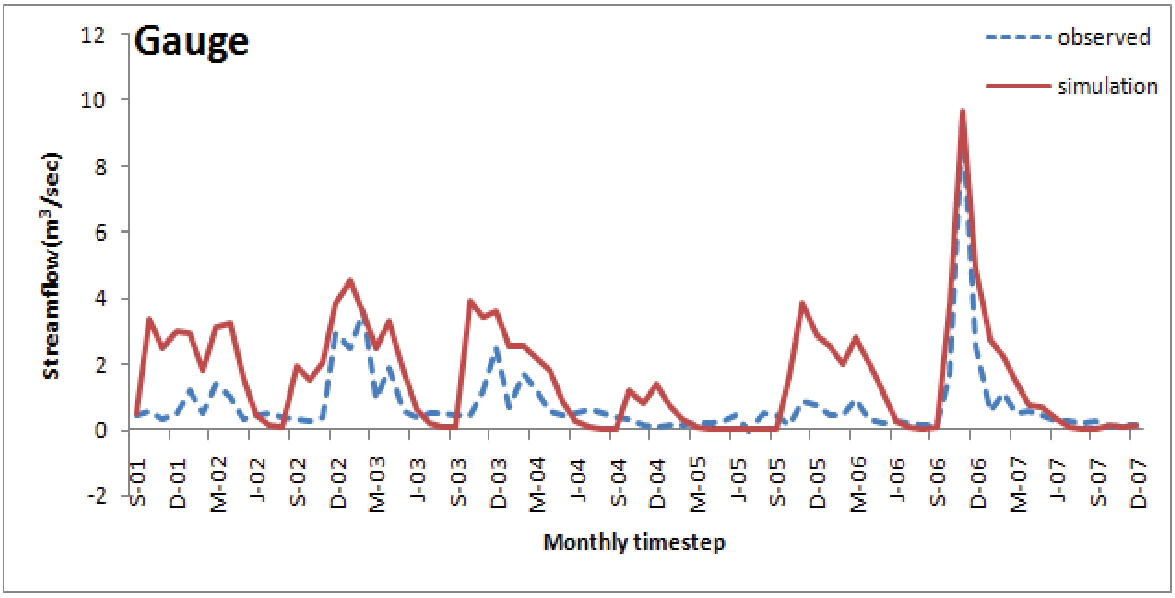


Figure 4-2: Hydrographs of observed stream flow with simulation using observed meteorological data before calibration for period Sep. 2001 to Dec. 2007.

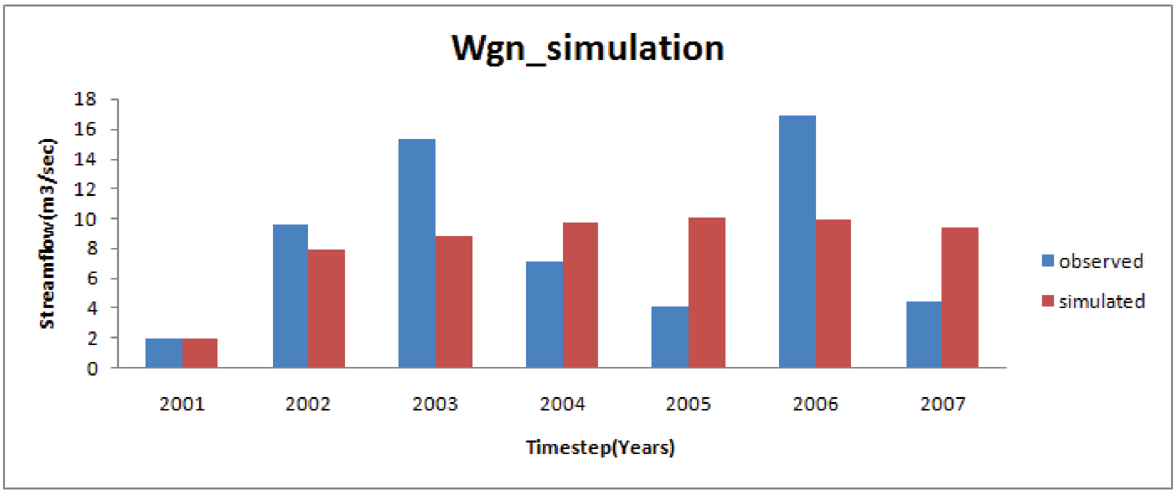


Figure 4-3: Annual comparison of observed and simulated stream flow using Wgn data before calibration.

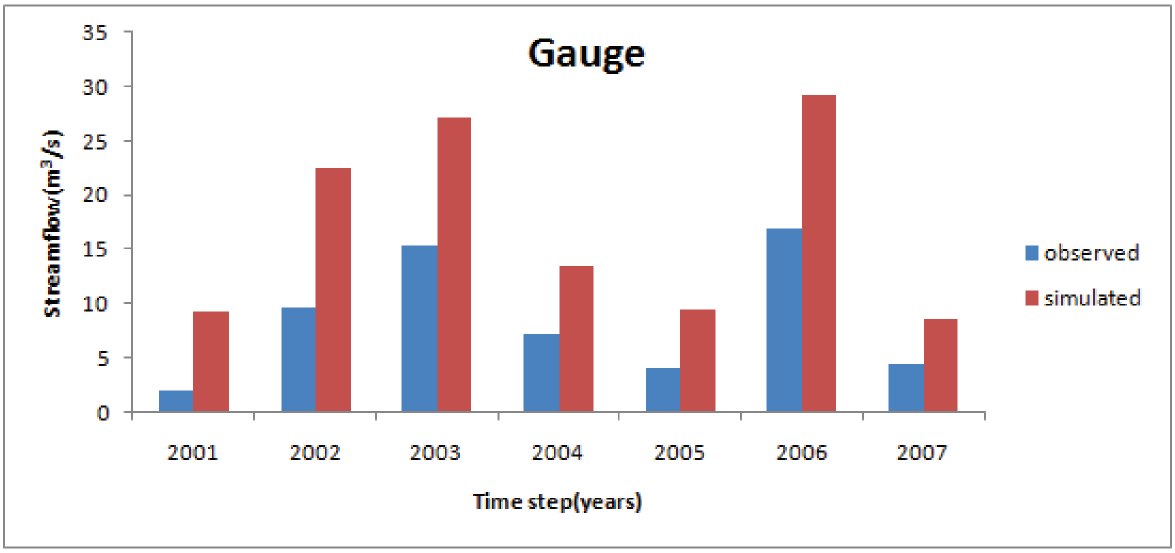


Figure 4-4: Annual comparison of observed and simulated stream flow using observed gauge data before calibration.

Table 4-1: Statistical evaluation of uncalibrated model runs

Model Run for monthly time step	NSE	PBIAS	R2
Wgn_simulation	-0.04	3.36	0.05
Gauge observation	-0.10	-101.75	0.63

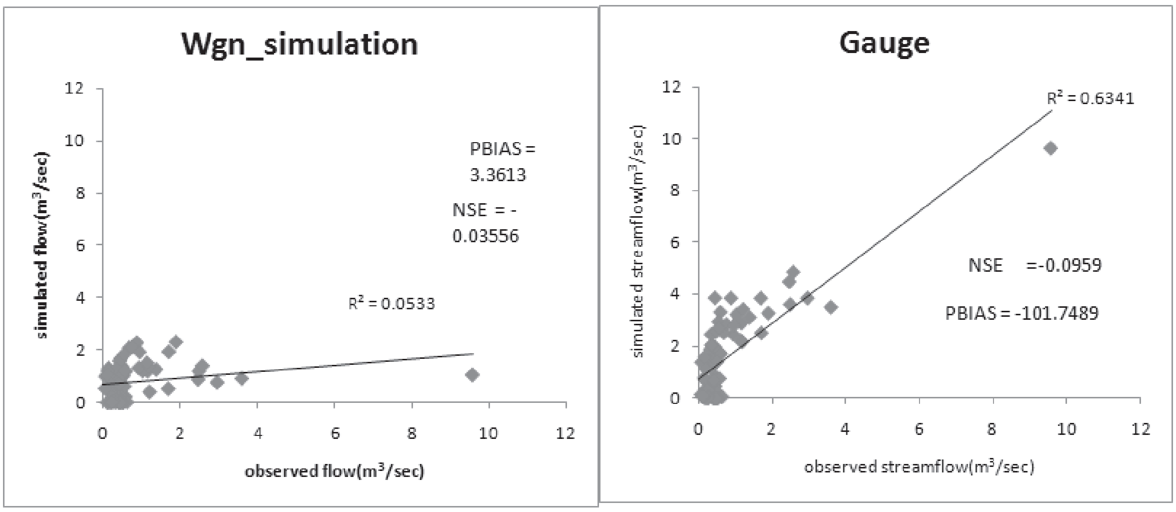


Figure 4-5: Plot of 1:1 line between observed and simulated flow using observed gauge & Wgn weather data before calibration.

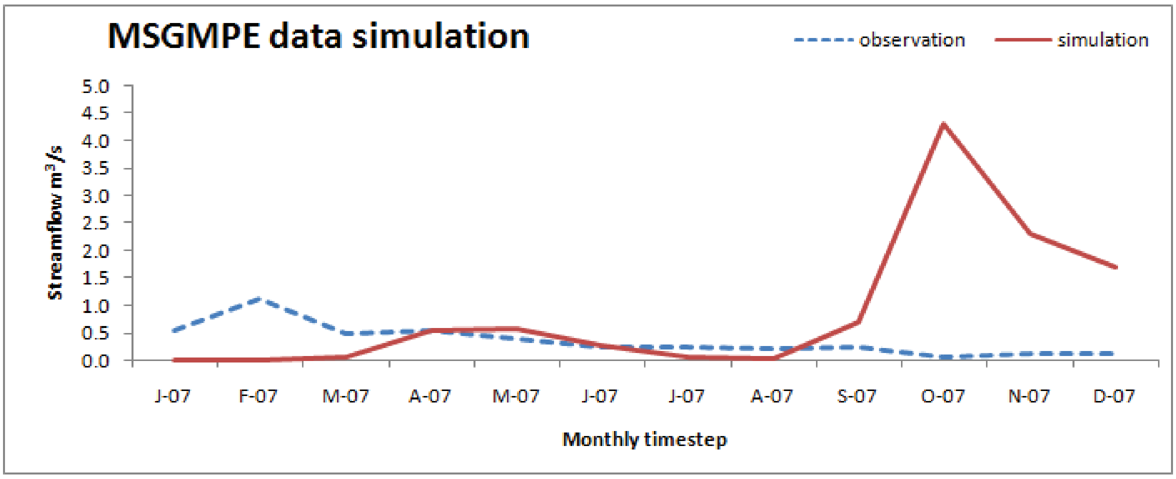


Figure 4-6: Hydrographs of observed and simulated stream flow using MSGMPE satellite rainfall data for year 2007.

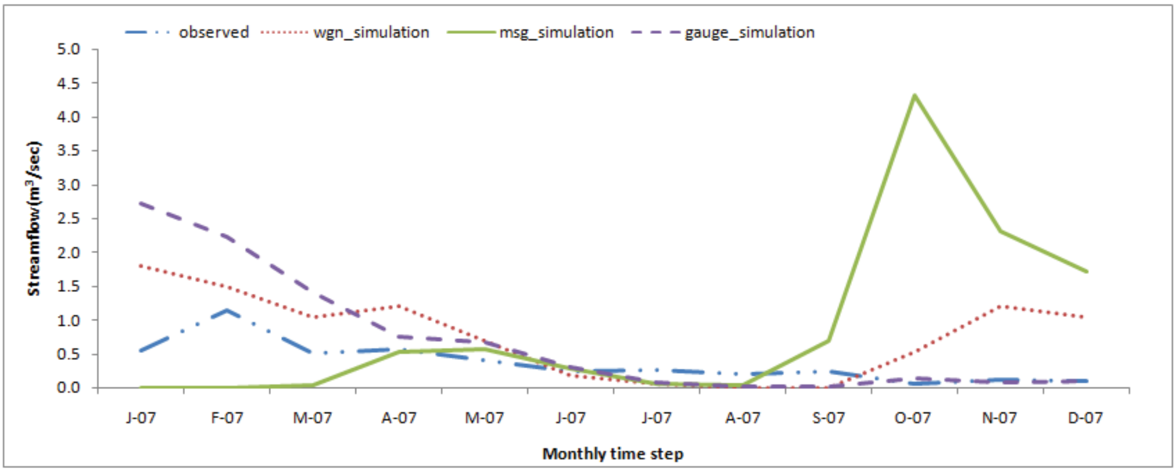


Figure 4-7: Comparison of monthly streamflow using different rainfall input methods for year 2007.

Table 4-2: Statistical comparison between 3 types of simulations for year 2007

Model Simulations	PBIAS (%)	NSE	R^2
Weather generator(WGN)	-112	-4.04	0.32
MSGMPE	-154.7	-27.31	0.29
Gauge	-112	-4.04	0.65

4.1.6. Interpretation of simulation results and model efficiency

From both graphical and statistical analysis of simulation results, SWAT simulations using the weather generator (Wgn) led to under prediction of stream flow for both monthly and annual time steps as shown in Figures (4-1, 4-3) and Table 4-1. Stream flow was high during wettest months for all the years of observation except 2004 which was generally a dry year but SWAT prediction is very contrary to this. The model performance was unacceptable according to the values of NSE computed which was about -0.04. The PBIAS values computed resulted in a positive value of 3.36 which indicated that model simulation resulted in an underestimation bias; this is also very evident from graphical display. The 1:1 line of the scatter plot in Figure 4-6 gave an R^2 value of 0.05, thus showing a poor model performance.

From the graphical and statistical analysis of simulation results from gauge data, SWAT over predicted stream flow as shown in Figures (4-2, 4-4) and Table 4-1. NSE calculated resulted in a -0.09 value which meant that the mean observed value was a better predictor than the simulated value, thereby indicating an unacceptable performance of the SWAT model. The PBIAS computed was in a negative range which indicated a model overestimation bias and this was very evident from the monthly hydrographs (Figure 4-3) and annual representation in Figure 4-4. A 1:1 line of the scatter plot in Figure 4-5 gave an R^2 of 0.63 which shows that observed gauge data predicted stream flow better than the Wgn data; also PBIAS and NSE for gage simulation appear to be better than the Wgn simulation. It can be concluded that the Wgn has climatic anomalies problem as it cannot capture extreme weather like drought or extreme wet conditions.

Stream flow prediction using the satellite observation shows unacceptable result from NSE statistical indicator result (with a value of -27.31) and the PBIAS shows that the simulation over predicted stream flow (with value of -154) as shown on Table 4-2. A visual glance validates the statistical comparison between observed and prediction of SWAT using MSGMPE satellite observation as shown in Figure 4-6. A 1:1 plot shows a relatively low correlation of 0.3. However it is imperative to bear in mind that the poor result derived from the satellite products must have accrued from some factors. To start with there were lots of missing data from the raw precipitation data; the simulation period was reasonably too short as such time steps are always used to allow for model stability in normal situation. Based on the poor performance of the model with respect to this input data, the simulation was not used for any further analysis in this study. We only show here the behaviour of the SWAT model when using MPEMSG satellite product for a short time frame as have been demonstrated.

Finally, a comparison between stream flow predictions using the three types of weather data (from different rainfall sources) was perform for year 2007 as shown in Figure 4-7 and Table 4-2 and base on the result, gauge simulation was chosen for model calibration. Year 2007 was chosen for such comparison because the satellite observation from MSG/MPE products were only available for 2007 - 2008 while observed stream flow data was available up to 2007.

4.2. Summary

In this chapter the response of the SWAT model to different rainfall inputs was examined. To do this we carried out three simulations and thus concluded that the model is indeed very sensitive to precipitation forcing. We analyzed model output by graphical and statistical techniques. It was thus evident that sources of rainfall data can lead to SWAT under prediction and/or over prediction or "*no prediction*". The analysis of model output is important before calibration as it helps to evaluate the differences in model predictions. The cold simulation result gave an idea of parameters to adjust during calibration. The next chapter therefore focus on sensitivity analysis, calibration and validation of the Arc SWAT model used in this study.

5. Sensitivity analysis, calibration and validation

5.1. Introduction

After analysis of uncalibrated SWAT model, we proceeded to carry out a calibration task because calibration improves the reliability of a model predictive capability. The SWAT model by itself is an intricate model that employs several parameters which complicates manual calibration. This fact is further buttressed by the distributed nature of the SWAT model which is characterized by HRUs representation, for instance, given a 200 HRUs and 20 parameters, the model calibration will involve fine-tuning of 200 * 20 = 4000 parameters, thus requiring an auto-calibration technique. The SWAT model incorporates an auto calibration procedure (Srinivasan and van Griensven, 2005) which is based on Shuffled Complex Evolution-University of Arizona algorithm (SCE-UA), developed by Duan et al. (1992). An investigation of Van Liew et al.(2005) reveals that the auto-calibration option in SWAT provides a powerful, labour saving tool that can be used to substantially reduce the frustration and uncertainty which often characterizes manual calibration. Hence this study uses the auto calibration procedure in conjunction with manual calibration.

SWAT model has twenty six parameters for flow, six parameters for sediment and nine parameters for water quality, only the flow component is considered here while water quality component will be consider in a further study. The evaluation of 26 flow parameters and 9 water quality parameters inclusion in auto calibration can be first determine by performing a sensitivity analysis. Sensitivity analysis is very important as it forms the first step to help pick sensitive parameters for calibration.

The model was first calibrated for hydrology by using data that was computed from the Roxo Reservoir water balance: stream flow data were made available from 2001 - 2007, therefore 2001-2004 stream flow data were used for model calibration and 2005 - 2007 stream flow data were used for model validation. In addition, we tested the sensitivity of auto-calibration technique to calibration time step by using flow data from 2001- 2007.As no data was available for validation, no validation was perform. We compared the results of 7 years and 4 years calibration time steps. The model should be calibrated for nitrate at the same point by using chemical data from Beja municipal water supply (EMAS) which are readily available in any further study of the Roxo watershed using SWAT water quality and hydrologic model. The water quality variable that would be included in the calibration could be nitrate: 2001 - 2004 water quality data could be used for model calibration while 2005 – 2007 water quality data could be use also for model validation. Hydrologic flow model calibration and validation was carried out for gauge observations and the findings are all presented in this chapter.

5.2. Sensitivity analysis and parameter selection

A sensitivity analysis (Green and van Griensven, 2008) is performed to limit the number of optimized parameters to obtain a good fit between the simulated and measured data. The optimization of parameters allows for models to better match realistic conditions. The sensitivity analysis tool in SWAT2005 (van Griensven, 2005) uses Latin Hypercube (LH) (McKay, 1988; McKay et al., 1979) sampling method combined with One-factor-At-a-Time (OAT) (Morris, 1991) to study the effect of change in individual parameters on model output. Two types of objective functions used by SWAT for sensitivity analysis are sum of squares of the residual (SSQ) and sum of the squares of the differences of the measured and simulated values after ranking (SSQR). The sum of square of residual (SSQ) was used here. SSQ is used to match simulated series to measure time series and is expressed in equation (5-1) below as:

$$\text{SSQ} = \sum_{i=1,n}\left[x_{i,measured} - x_{i,simulated}\right]^2 \quad (5\text{-}1)$$

Where $x_{i,measured}$ refers to measured or observed daily stream flow and $x_{i,simulated}$ is the daily model stream flow and n is the number of pairs of measured and simulated variables.

Sensitivity analysis was first carried out for flow because the model calibration was done for stream flow first which is the recommended technique for calibrating the SWAT model. During sensitivity analysis three variation methods are often used to define how the parameter values can be changed during analysis. These methods are: replace by value; add to value; and multiply by value. During sensitivity analysis, default values that came with the chosen parameters were used, this is recommended in the ArcSWAT manual (Winchell et al., 2008). For instance SWAT suggested 'multiply by value' which means a change by percentage of initial value was used for CN2 (SCS runoff curve number for moisture condition II) parameter. Increasing or decreasing parameters by using any of the variation methods can influence simulation results. For instance an increase of CN2 leads to increase of surface runoff while increase of Gwqmn (threshold depth of water in the shallow aquifer required for return flow to occur) and Esco (soil evaporation compensation factor) decreases base flow and evapotranspiration respectively.

At the completion of the sensitivity analysis, several sets of output files were produced and the names of these files are shown in Appendix B-2a. The files that were fully utilized here were the *sensresult.out* and *sensout.out*. The *sensresult.out* contains the final ranked set of parameters with highest rank assigned to the most sensitive parameter while other parameters are ranked in descending order. The sensout describes all detailed results that were achieved during sensitivity analysis such as the parameters initial values, lower and upper bound, ranking, mean, variance, etc. Table 5-1 gives a description of all parameters that were used for sensitivity analysis, while Table 5-2 shows the ranking order of the sensitivity parameters. Figure 5-1 shows the statistical output (rank and mean) of the sensitivity analysis. We adopted the ranking procedure of van Griensven et al. (2006) with a little modification to suit this specific modelling task. Ranks 1-6 signify very important parameters that must be considered during calibration and ranks > 28 were considered not to be important. However, the result of our sensitivity analysis was classified into 4 ranking groups; very important, important, slightly important and not important as shown in Table 5-1.

The result indicated that CN2 (SCS runoff curve number for moisture condition II) was the most important parameter with a mean of 1.86, this was followed by Gwqmn and Alpha_Bf parameters with means of 0.77 and 0.66 respectively. Parameters like Revapmn, Esco, and Sol_Awc were the next group to be considered as very important, and was followed by Sol_Z; Sol_K; Blai; Canmx;

Ch-K2; Surlag; Gw-Revap; Gw_delay; Epco; Slope; Ch_N2; Biomix and Slsubbsn parameters which classified as slightly important while the remaining parameters classified as not important as they did not have any impact on the model output and thus were not considered further. The sensitive parameters and processes they are related to are all depicted on Table 5-1 below. Finally the result shows that the six most important parameters involve the hydrology (runoff, soil and groundwater) of the watershed:

It is important to mention here that result of a sensitivity analysis can be affected by a number of factors. According to Rao and Han (1987), the results of sensitivity analysis depends on the objective function used for the analysis which may or may not represent all watershed response uniformly well. A study conducted by Mutela and Nicklow (2005) shows that the objective function SSQ, as we have used here is biased towards peak flow by underestimating groundwater contribution in total flow results and we found this to be so in this study as estimation of the PBIAS analysis gave a value of +2 which signifies an underestimation of groundwater. Other factors that can also affect sensitivity analysis results are usage of default parameter ranges as was done here and the Latin Hypercube sampling method with a limited number of 10 sampling points. We however selected 19 parameters (shown in Appendix B-2b) - that were ranked as important for the calibration process.

Table 5-1: Flow parameters used in sensitivity analysis

Parameter	Lower bound	Upper bound	Variation value	Definition	Processes
Alpha_Bf	0	1	1*	Baseflow alpha factor (days)	Groundwater
Biomix	0	1	25*	Biological mixing efficiency	Soil
Blai	0	1	61*	Leaf area index for crop	Crop
Canmx	0	10	7*	Maximum canopy index	Runoff
Ch_K2	0	150	54*	Effective hydraulic conductivity in main channel alluvium (mm/hr)	Channel
Ch_N2	0	1	51*	Manning coefficient for channel	Channel
Cn2	-25	25	10**	SCS runoff curve number for moisture condition II	Runoff
Epco	0	1	28*	Plant evaporation compensation factor	Evaporation
Esco	0	1	27*	Soil evaporation compensation factor	Evaporation
Gw_Delay	-10	10	2***	Groundwater delay (days)	Groundwater
Gw_Revap	-0.036	0.036	3***	Groundwater 'revap' coefficient.	Groundwater
Gwqmn	0	1000	6***	Threshold depth of water in the shallow aquifer required for return flow to occur (mm)	Soil
Revapmn	-100	100	5***	Threshold depth of water in the shallow aquifer for 'revap' to occur (mm).	Groundwater
Sftmp	0	5	36*	Snowfall temperature (oC)	Snow
Slope	-25	25	23**	Average slope steepness (m/m)	Geomorphology
Slsubbsn	-25	25	24**	Average slope length (m).	Geomorphology
Smfmn	0	10	35**	Minimum melt rate for snow during the year (occurs on winter solstice) (mm/8C/day)	Snow
Smfmx	0	10	34*	Maximum melt rate for snow during (mm/oC/day)	Snow
Smtmp	-25	25	37**	Snow melt base temperature (0C)	Snow
Sol_Alb	-25	25	22**	Soil albedo	Evaporation
Sol_Awc	-25	25	17**	Available water capacity of the soil layer (mm/mm soil)	Soil
Sol_K	-25	25	15**	Soil conductivity (mm/h)	Soil
Sol_Z	-25	25	16**	Soil depth	Soil
Surlag	0	10	33*	Surface runoff lag coefficient	Runoff
Timp	0	1	38*	Snow pack temperature lag factor	Snow
Tlaps	0	50	52*	Temperature laps rate (8C/km)	Geomorphology

NB:(*, **, *** are the different types of variation method used during sensitivity analysis of parameters)*: replace by value

**: multiply by value (%)

***: add by value

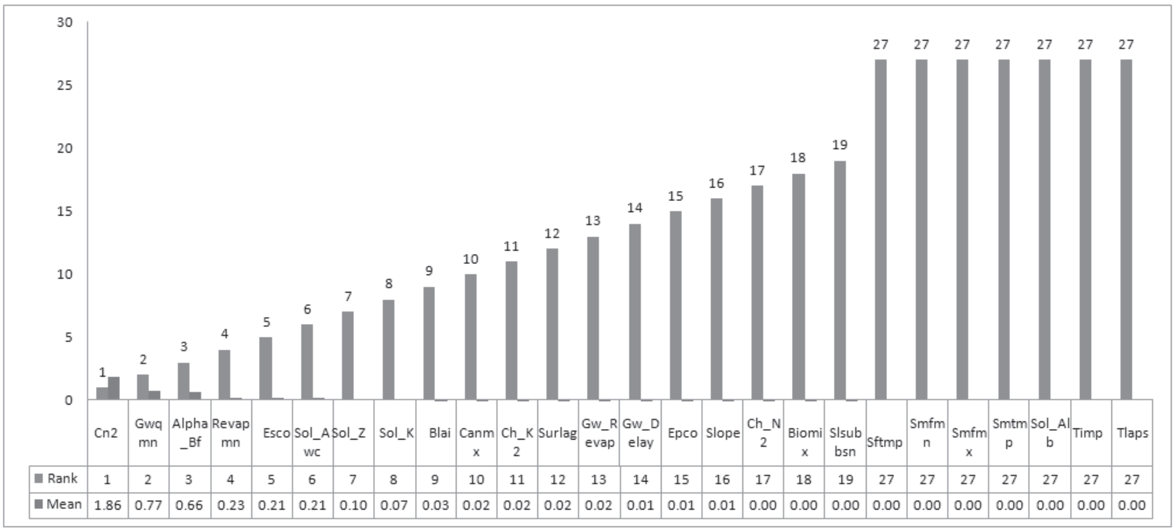


Figure 5-1: Output of sensitivity analysis

Table 5-2: Parameter level of importance and selection

Parameters	Rank	Parameter mean sensitivity	Sensitivity category
Cn2	1	1.86	Very important
Gwqmn	2	0.768	Very important
Alpha_Bf	3	0.657	Very important
Revapmn	4	0.226	important
Esco	5	0.209	important
Sol_Awc	6	0.206	important
Sol_Z	7	0.0984	slightly important’
Sol_K	8	0.0684	slightly important’
Blai	9	0.0267	slightly important’
Canmx	10	0.0236	slightly important’
Ch_K2	11	0.023	slightly important’
Surlag	12	0.0197	slightly important’
Gw_Revap	13	0.0196	slightly important’
Gw_Delay	14	0.0128	slightly important’
Epco	15	0.00863	slightly important
Slope	16	0.00564	slightly important
Ch_N2	17	0.00245	slightly important
Biomix	18	0.00128	slightly important
Slsubbsn	19	0.00116	slightly important
Sftmp	27	0	Not important
Smfmn	27	0	Not important
Smfmx	27	0	Not important
Smtmp	27	0	Not important
Sol_Alb	27	0	Not important
Timp	27	0	Not important
Tlaps	27	0	Not important

5.3. Model calibration and validation

One of the main purposes of hydrologic (H) or water quality (WQ) modelling is to generate accurate estimates of flows and concentrations where measured data are deficient, costly or forecasting into the future is required. H and WQ models like SWAT are based on field observations and the calibration of parameter values that cannot be measured directly. The combination of field data and calibrated model can provide an important investigative and planning tool in environmental analysis.

The Roxo reservoir watershed model was first calibrated with flow data for a four year period (2001-2004) by adjusting parameters until observed flow match with model predicted flow while validation was carried out for years 2005-2007 by comparing the calibrated model predicted flows with measured flows without adjusting any input parameters. It is proposed that at the completion of flow, the model should be calibrated and validated for nitrate. 2001 -2004 water quality data could use for model calibration while 2005 – 2007 water quality data could use for model validation. Figure 5-2 shows the calibration point in sub-basin #5 for both stream flow and could also be used for nitrate or any of the chemical data available later. Finally we tested the sensitivity of auto calibration to calibration time step using flow data for 2001 - 2007.

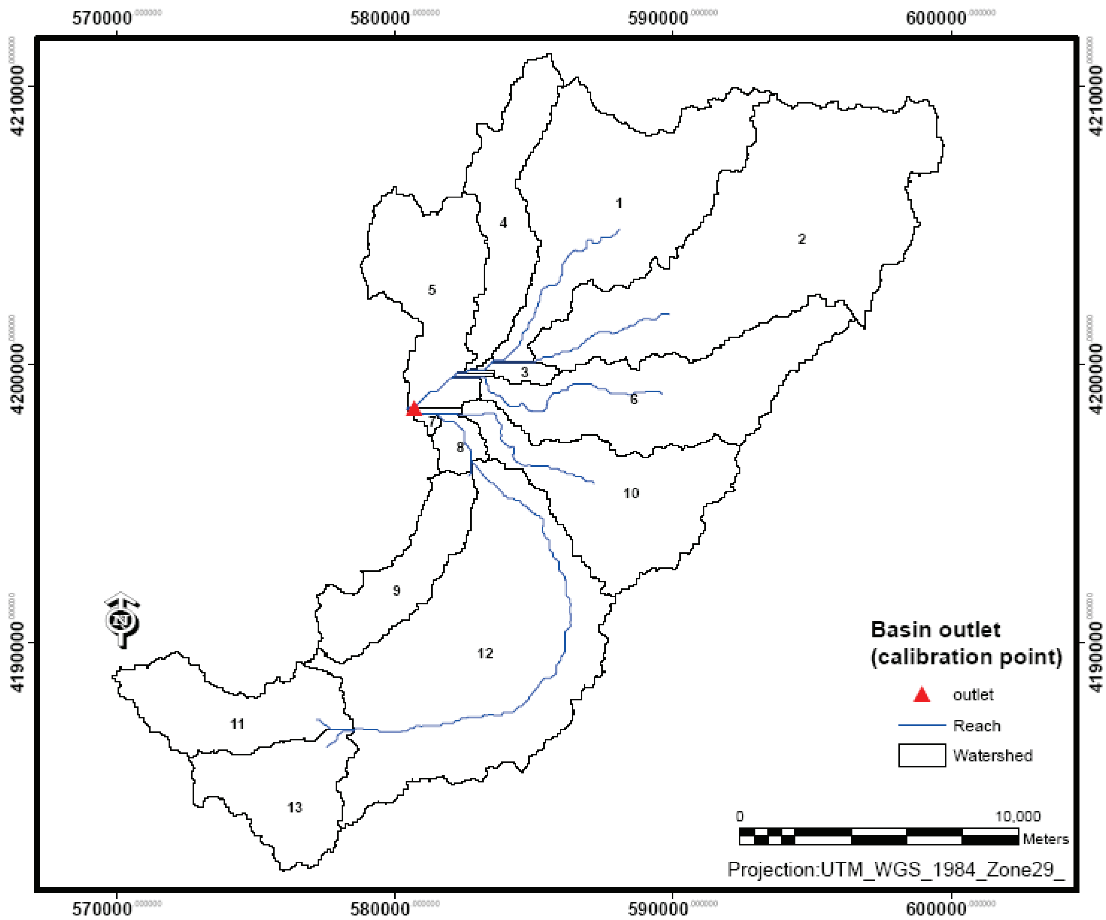


Figure 5-2: Calibration Point

5.3.1. **Manual calibration**

In this study a combination of manual and auto calibration technique were used. We started by assessing some of the major components of estimated basin values as shown in Appendix C-1. After gaining an impression of the model processes, we attempted manual calibration by manually adjusting CN, Gwqmm, Alpha_Bf, Revapmm and Esco parameters by editing the specific SWAT input files to match the observed data. Some of the values used for adjustment were taken from literature and clues were also taken from the SWAT sensitivity analysis output. The manual calibration was repeated a number of times until a positive NSE value (0.3) was achieved. All time steps used were monthly based. Experience has thus shown that manual calibration may be time intensive, but it helps to get a better auto calibration result.

5.3.2. **Auto-calibration**

An auto-calibration tool has been embedded in SWAT2005 version of the SWAT model by van Griensven (2005). This auto calibration tool uses the Shuffled Complex Evolution (SCE-UA) algorithm developed by Duan et al. (1992). SCE-UA is most widespread in hydrology because it is very efficient and effective. It combines the strength of Nelder-Mead (simplex), controlled random search, genetic algorithms and complex shuffling. As a first step, initial population (parameter space defined by its upper and lower bound) is partitioned into several communities called complexes. In each complex, different combinations of individual parameters produces offspring using simplex procedure. The probability of individual set taking part in the reproduction is proportional to its fitness. Individuals of lower fitness are replaced by their offspring to direct the search in an improvement direction. These complexes are shuffled at periodic interval and points are re-distributed among different complexes to ensure the sharing of information. As the search progresses, entire population converges towards the global optimum value (Duan et al., 1992).

The calibration was first carried out for monthly stream flow at the watershed outlet located in sub-basin #5 as shown in Figure 5-2 using sum of square of residual (SSQ) as an objective function in equation (5-1) above. The calibration results like in sensitivity analysis are also dependent upon the objective function chosen. We used the whole range of retained parameters for optimal screening as the watershed was being calibrated for the first time with the SWAT model. The parameters range was modified either by replacement of the initial value, addition of an absolute change or multiplication of a relative change. The calibration method used was Parasol with uncertainty analysis. Since calibration involves the testing of model with known input, we then created an observation file that was carefully prepared and set in the appropriate format as required by the auto calibration and uncertainty analysis window, an example of this file is shown in Appendix B-3b. Every other input was defined at the interface. The outputs of calibration result are shown in Appendix B-5 & B-6. To evaluate the model performance, we use NSE and PBIAS both described in Equations (4-1) and (4-2) respectively above. To validate the model, a new simulation for different time frame was initiated on the already calibrated model; the result was saved as a new scenario and predicted flow was compared with observed flow data.

We carried out the auto calibration run on a Microsoft Windows XP professional laptop computer with a 2.000GHz processor and 1.00GB of RAM. The average CPU (Central Processing Unit) run time for flow calibration was 15:00 to 24:00 hours for the 4 years and 3 days for the 7 years. The results of the auto calibration process are shown in the next section.

5.3.3. Flow calibration and validation results

A visual evaluation of the model was made by comparing observed and calibrated hydrographs with time to ascertain goodness of fit for model performance. Figure 5-3 shows the comparison between observed data and calibration output while Figure 5-4 shows a comparison between observed data and validation output. To support the visual judgment, two calibration indicators; NSE and PBIAS were used to quantify the strength of the model in reproducing observed values and they are presented in Table 5-3. Although the model was calibrated for a period of four years (2001-2004) for stream flow, first year (2001) of simulation was use for model priming or stabilization and as a result it was not used in any computation. The PBIAS estimates are within acceptable range for both calibration and validation, although it is evident that the positive values of 1% indicate that the model under predicts flow during calibration (2001-2004) period while the negative value of -0.61% shows that SWAT overestimated flow during validation (2005-2007) period. A possible cause for model underestimation during calibration would be the choice of objective function used which is biased towards high flow. However other errors for model under prediction can be attributed to input uncertainty of rainfall and some other unknown activities in the watershed. Figure 5-3 also shows that SWAT is predicting better for surface flow than base flow. In general simulations matched observed stream flow as the NSE estimates gave good range of values for calibration (about 0.77) period (2001-2004) and validation (about 0.64) period (2005-2007).The trend lines and scattered points in Figure 5-5 shows a visual comparison of predicted and observe d flow, the closer the scattered points to 1:1 line (y=x line), the closer the predicted values to the observed. A strong correlation was found between observed and simulated as the regression R^2 gave 0.77 and 0.75 for calibration and validation respectively. Thus with satisfactory results of flow calibration, we recommend calibration of water quality variables for the Roxo reservoir.

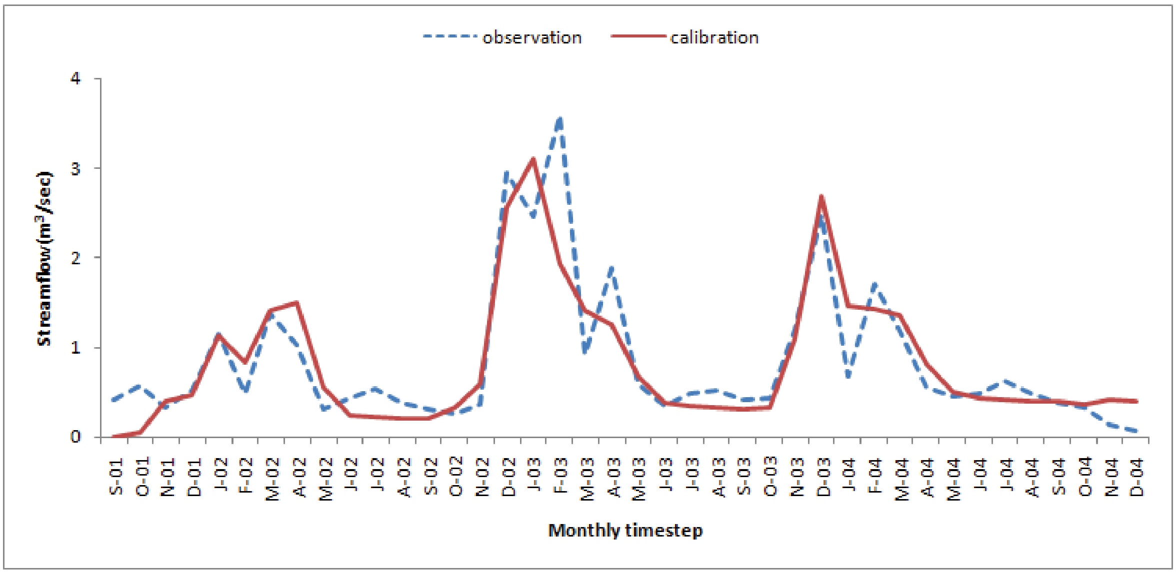


Figure 5-3: Observed and simulated stream flow for calibration years (2001-2004)

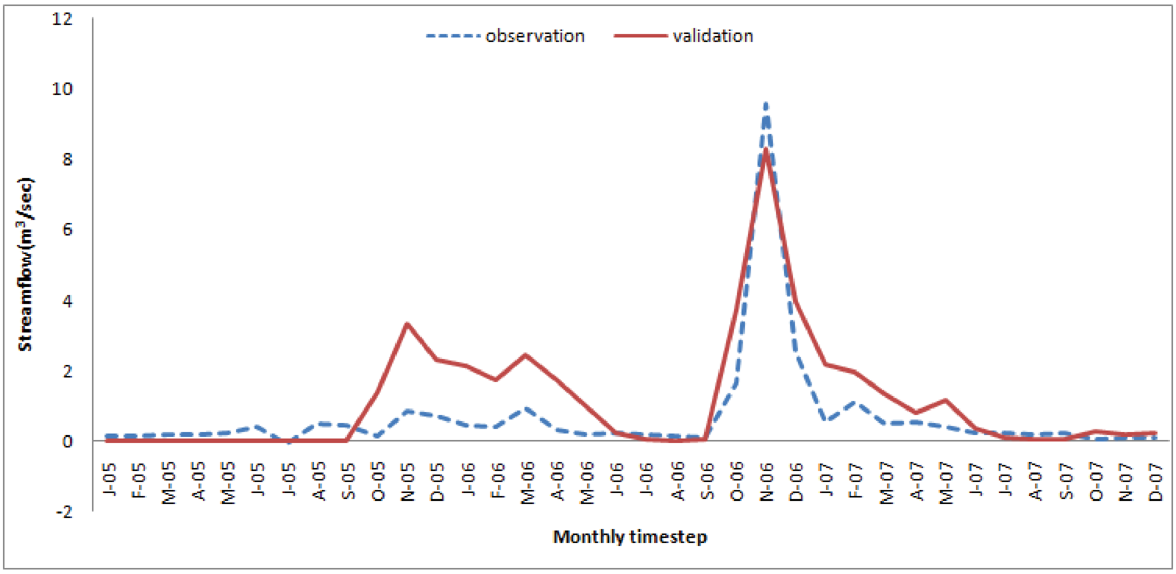


Figure 5-4: Observed and simulated stream flow for validation years (2005-2006)

Table 5-3: Model Performance after flow calibration

Process	NSE	PBIAS	Regression
Calibration	0.77	100	0.77
Validation	0.64	-61	0.75

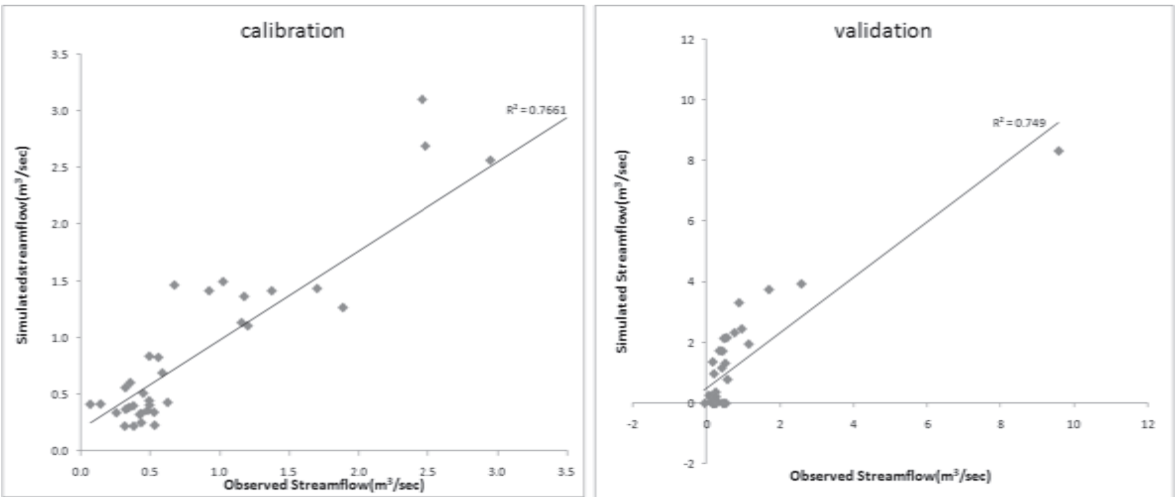


Figure 5-5: 1:1 line of observed and simulated stream flow for calibration and validation

5.4. Sensitivity of auto-calibration to calibration period (time step)

The model was also calibrated for a seven years period to test if it is sensitive to calibration time step. Our findings show that there is small difference with the length (4 or 7 years) of hydrologic model calibration as shown in the hydrographs in Figures 5-6 and 5-7 as well as Table 5-4.

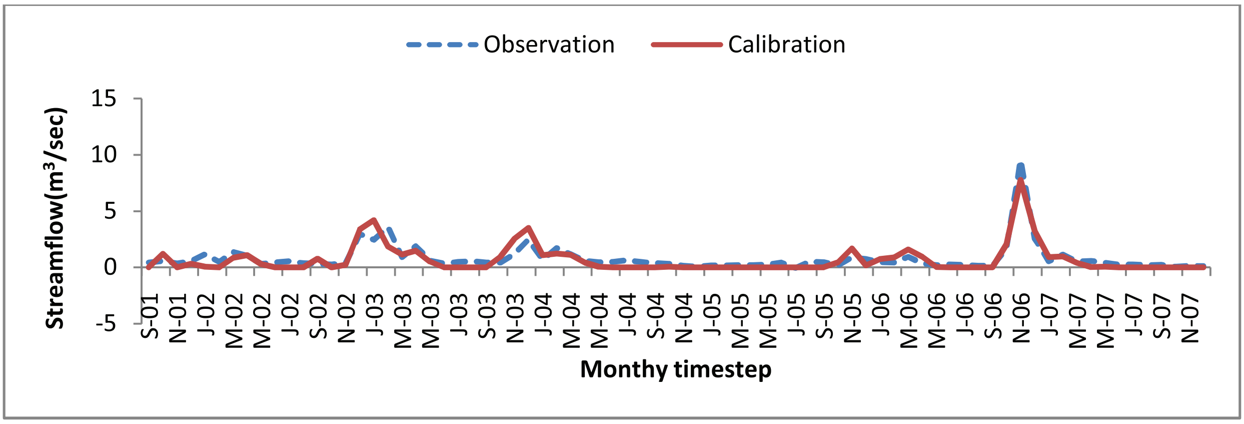


Figure 5-6: 7 years calibration

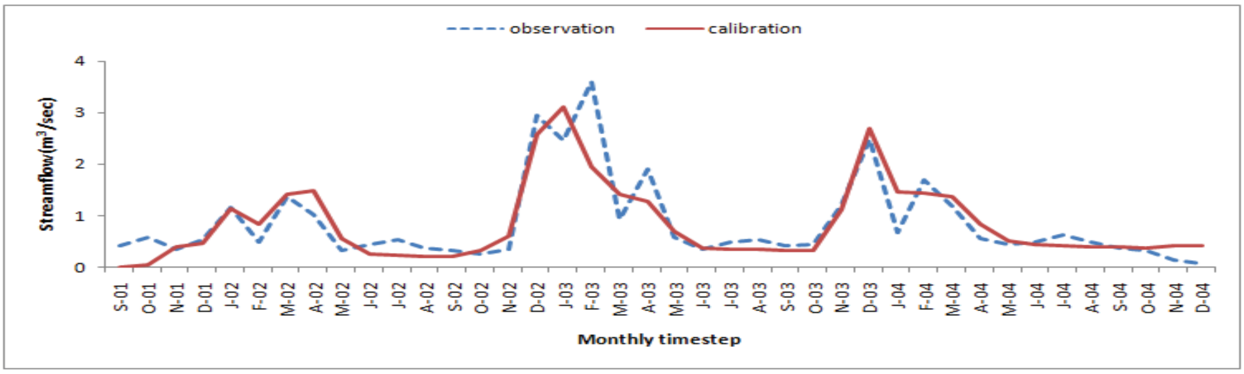


Figure 5-7: 4 years calibration

Table 5-4: model performance for different time step

Calibration	NSE	PBIAS	R^2
2001-2007	0.81	100	0.82
2001-2004	0.77	100	0.77

5.5. Summary

This chapter show results and discusses sensitivity, calibration and validation of the SWAT model for hydrology component (flow) as applied to the Roxo reservoir watershed in Beja, Portugal. The most sensitive parameters of the catchment's hydrology were examined. The CN2 (SCS runoff curve number for moisture condition II) was found to be at the top of these most sensitive parameters. A manual calibration follow by auto-calibration was employed and the results have been discussed in this chapter. The calibration result shows that SWAT is efficient in representing the hydrologic components of the watershed and generated outputs from the calibration task would be discussed in the preceding chapter.

6. SWAT model outputs

The goal of a calibrated model is to help make reliable and sound predictions. Thus this section examines some outputs generated from the calibration task. Some interesting outputs of the auto-calibration tasks include estimation of the basin values (i.e. hydrologic parameters), detail output of reaches and nutrient export; reservoir and water quality output; sediment output among others. The model output was also used to identify some critical source area of the watershed.

6.1. Basin values (hydrology)

The knowledge about hydrologic condition is important because it provides the foundation for understanding the behaviour of nutrient fluxes that eventually end up in the reservoir. Table 6-1 and Figure 6-1 below shows the water balance of the watershed for the simulation years.

From Figure 6-1, it is obvious that the summer months are very dry while the highest evaporation takes place during this time of the year. Since there is little or no runoff during this period, it can be concluded that the nutrient loading transported into the lake are from base flow. The sources of these nutrients loadings are groundwater and waste treatment plant. The figure also shows that most rain occur during winter months (October to December). Because rainfall events have a direct relationship with the transport of nutrients through overland flow and percolation to groundwater, nutrients loading to the reservoir would naturally reach the highest level during this period of the year. Thus the preceding section examines some of this nutrients pattern with respect to seasonal changes.

Table 6-1: Model estimated monthly average basin values for Roxo watershed (period 2001-2004)

Months	Rain (mm)	Runoff (mm)	Water yield (mm)	PET (mm)	ET (mm)	SED YLD (t/ha)
1	46.13	3.27	27.95	24.4	17.67	0.05
2	47.52	3.1	19.2	41.78	24.29	0.05
3	63.92	3.46	22.35	63.34	32.18	0.06
4	61.34	3.65	19.76	101.73	38.69	0.06
5	18.62	3.77	9.19	142.89	21.65	0.07
6	2.79	3.53	3.88	190.16	3.2	0.06
7	0.86	3.53	3.61	227.43	1.31	0.06
8	4.59	3.42	3.41	204.49	4.71	0.06
9	47.51	2.48	2.39	139.23	16.7	0.04
10	102.27	2.82	4.28	77.02	38.14	0.05
11	59.8	3.11	12.17	46.41	25.73	0.05
12	62.3	3.42	25.53	22.57	17.65	0.06
Total	**517.65**	**39.56**	**153.72**	**1281.45**	**241.92**	**0.67**

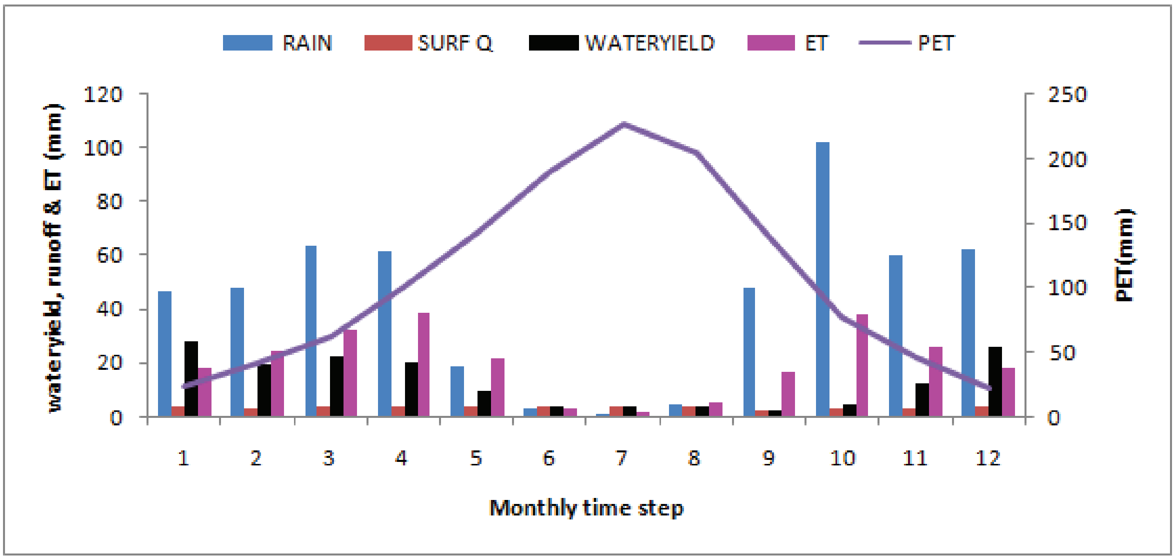


Figure 6-1: Estimated monthly average basin values for the Roxo reservoir (2001-2004 periods)

6.1.1. Nutrient export

The key nutrients controlling the trophic status of freshwater are nitrogen and phosphorus. Nutrient export from agricultural land is an important source of nutrient enrichment in almost all farming areas. With the exception of point sources such as sewage works discharges, which are fairly easily controlled, the export of N and P as diffuse discharges from agricultural land are the main target for measures to control the symptoms of eutrophication (Heathwaite, 1995). Roxo reservoir watershed is mainly dominated by agricultural activities with relatively low human population density. Thus agricultural input from high fertilization has been the main source of nutrient loads into Roxo reservoir (Almeida and Silva, 1987; Chisha, 2005).This research therefore tries to analyze nutrient export and loadings into the reservoir. To do this, we compared nutrients (N & P) fluxes with water fluxes as shown in Figures 6-1 to 6-6. A period of 7 years was used to examine these fluxes. SWAT nutrient load outputs (shown in Appendix C-4) were converted to concentration outputs by dividing simulated nutrient load (kg) with simulated flow out of reach at sub basin 5 using the concentration load relationship shown in Equation (6-1):

$$C = F/Q \qquad (6\text{-}1)$$

Where C is nutrient concentration in stream water (g/l), F is nutrient load (kg) transported with water out of reach during simulation time step and Q is stream flow (m^3/s) out of reach during time step.

An examination of temporal dynamics of N and P in the Roxo reservoir watershed shows nutrient concentration to be quite high for most seasons except for the very dry years of 2005 and 2007. Generally high stream flow resulted in high concentrations. However a decrease in concentration was observed during the summer period for all components of N and P. The amount of concentration for organic N varies from 0-38 mg/l with an average of 5.16 mg/l for the 7 years period. Similarly, Org-P varies from 0-7 mg/l with average of 0.65 mg/l. For the other components of N, ($NO3^-$, NO_2^- and $NH_{4,}^+$) the concentration range from 0-45mg/l, 0-3mg/l, 0-10mg/l and

6.61mg/l, 0.46mg/l and 1.99 mg/l average values respectively. The monthly concentration values are shown in Appendix C-3.

It is however important to mention here that though the SWAT model output seems to present very high nutrient loadings and concentrations from the reaches, this result can be further improved upon by calibrating the model for water quality before making a final conclusion on nature of the nutrient export and loading in the Roxo watershed.

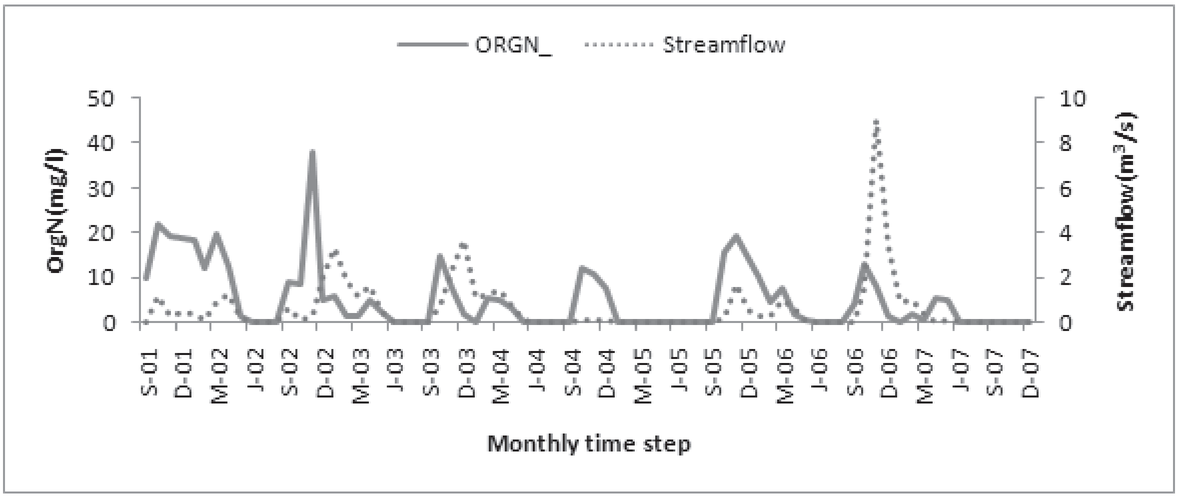


Figure 6-2: Monthly organic nitrogen flux with water flux.

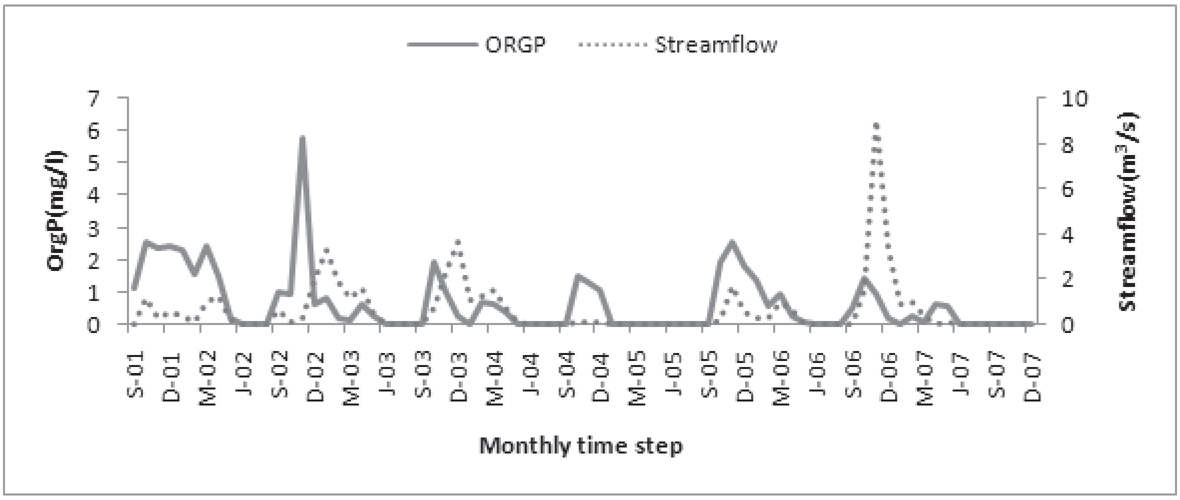


Figure 6-3: Monthly organic Phosphorus flux with water flux.

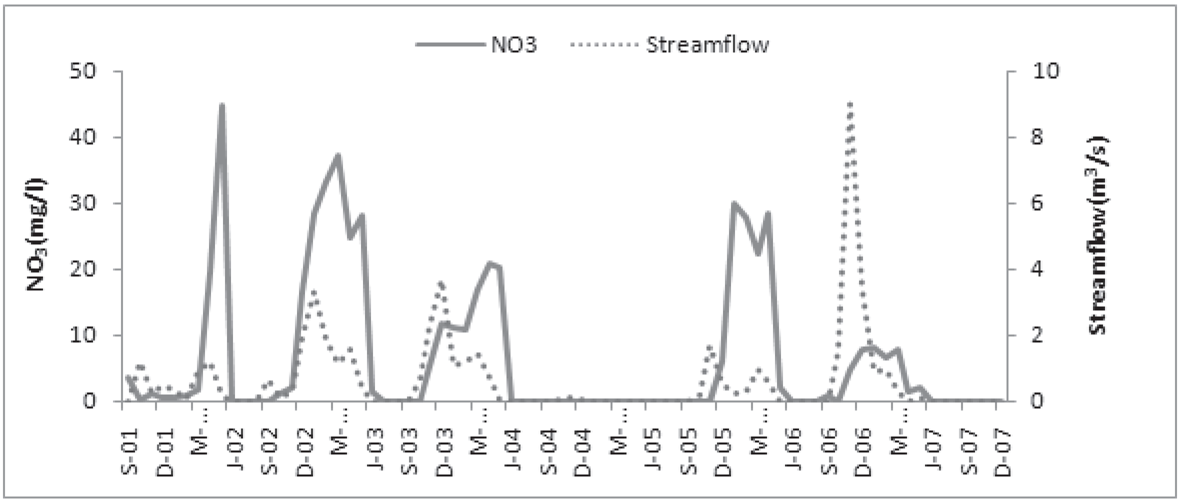


Figure 6-4: Monthly nitrate flux with water flux.

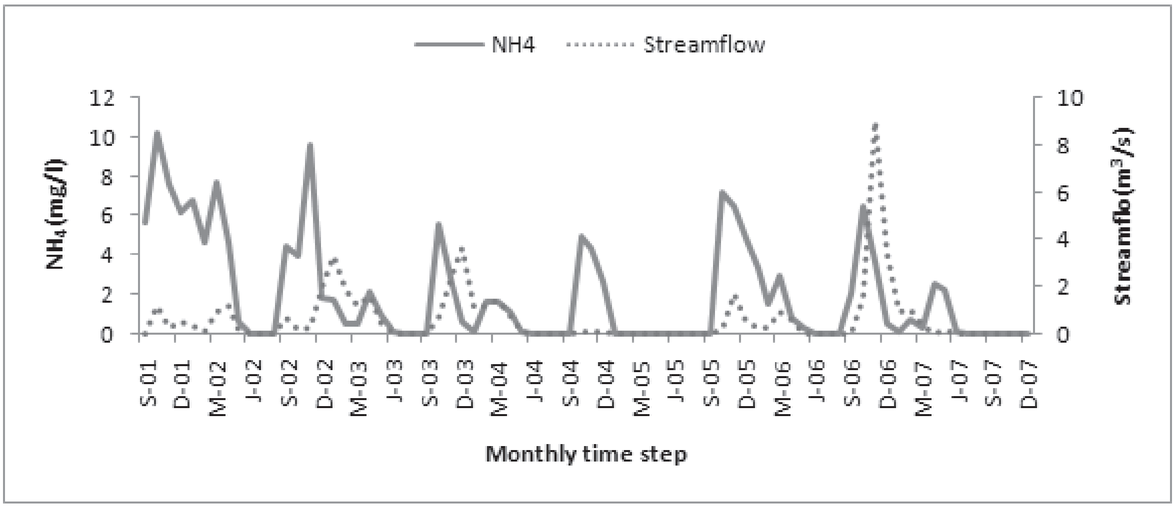


Figure 6-5: Monthly ammonia flux with water flux.

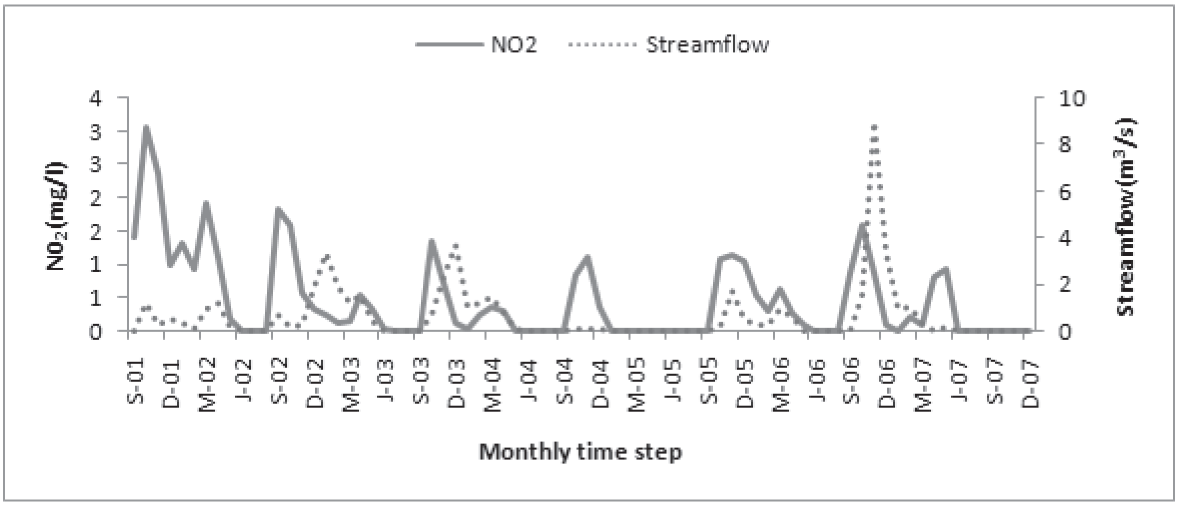


Figure 6-6: Monthly nitrite flux with water flux.

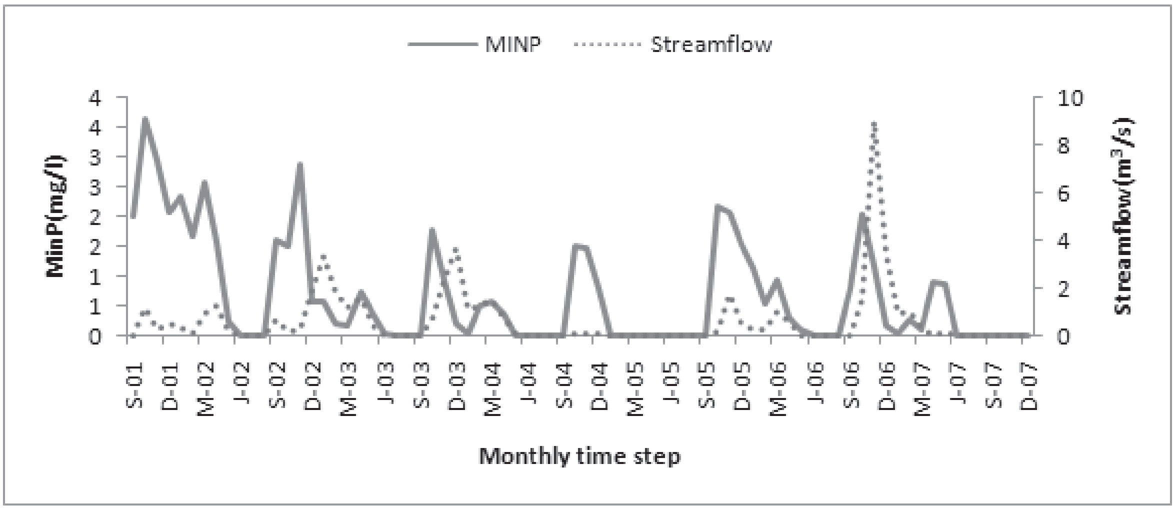


Figure 6-7: Monthly MinP flux with water flux.

From the graphs above, it is evidently clear that the lowest nutrient concentration occurs during May to June of each year because of low rainfall and stream flow. Previous studies have shown that the nutrient loads during this time of the year to be in dissolved form (Chisha, 2005) and this is also reflected on the graphs above (or graphs of nutrient loadings in Appendix C-4) as the nutrients loading have zero values. However the absence of nutrient loads is basically due to lack of runoff which is the mechanism for transport of the loads. But when the rain set in and runoff begins, load exportation increases. Thus the pattern of nutrient load in the study area is in agreement with similar study in literature. In a study carried out by Mitsch et al (2001), it was concluded that precipitation has a large influence on the timing of nutrient export from crop fields to the catchment outlet. The study reveals that high rainfall periods are normally associated with higher nutrient loadings when compared to low rainfall period.

6.1.2. Identification and prioritization of critical sub-watersheds

An attempt was also made to use the calibrated model to prioritize and identify the critical sub-watershed of Roxo reservoir catchment area. Critical areas are land areas were soil erosion rate exceed soil losses tolerance values and nutrient losses, were greatest improvement can be achieved with the least capital investment in best management practices. However real identification and prioritization are based on actual sediment rate, but the SWAT model simulation was used to identify and prioritized critical areas in the watershed, in the future, the simulation output can be compared with observed data before the identification of such critical area. The results from Table 6-2 show that all 13 sub-basins fall under slight erosion class with soil erosion range 0-5 t/ha (Tripathi et al., 2003). Since sub-watersheds 1, 2, and 8 were found to have the highest amount of sediment yield, they can be prioritized as critical areas of the watershed. The critical areas were also found to have the highest losses of Org-N and NO_3-N.

Table 6-2: Model annual output for identification of the critical sub-watersheds of Roxo catchment

Sub-watershed	landuse/soil	Area Km²	CN	SURQ mm	SED-YLD Ton/ha	ORGN Kg/ha	NO3 Kg/ha
1	NIALBpc	45.10	90	82.38	1.79	3.47	0.54
2	NIALBpc	70.30	90	77.3	1.54	2.97	0.51
3	NIALVc	1.73	80	37.8	0.56	1.88	0.31
4	NIALPs	18.50	80	31.83	0.2	0.64	0.22
5	NIALVc	23.40	36	0.35	0	0	0.06
6	NIALSr	34.10	69	7.32	0	0	0.32
7	WATRCph	0.79	95	0	0	0	0
8	NIALCph	3.15	86	80.21	4.04	11.48	0.19
9	NIALVx	15.10	80	32.16	0.36	0.96	0.32
10	NIALPs	30.80	80	33.89	0.15	0.48	0.21
11	NIALPb	19.20	86	61.45	1	2.06	0.18
12	NIALVx	71.30	80	8.8	0	0	0.18
13	NIALPxd	18.00	69	4.34	0	0.01	0.11

6.1.3. Reservoir output and water quality calibration

Observed water quality data from the Roxo reservoir was compared with the SWAT reservoir output to prepare the model for water quality calibration. The available water quality data used for this comparison was ammonium nitrogen and the result is shown in Figure 6-8. The procedure for the water quality calibration will be similar to that of the hydrologic calibration by running a sensitivity analysis to know the most sensitive parameters. From a visual analysis of the cold simulation result, one can say that the model has a tendency for simulating water quality. Although we admit, that the comparison in Figure 6-8 is quite poor, it must be noted that Ammonium-N is also a very dynamic water quality variable in general (subject to nitrification, gaseous ammonia losses, etc.), and no high correlations can be expected in reality. We also were not able to fully set up the reservoir model in SWAT as to simulate in reservoir biological and chemical processes. The figure is only shown for initial water quality model to reality comparison purposes.

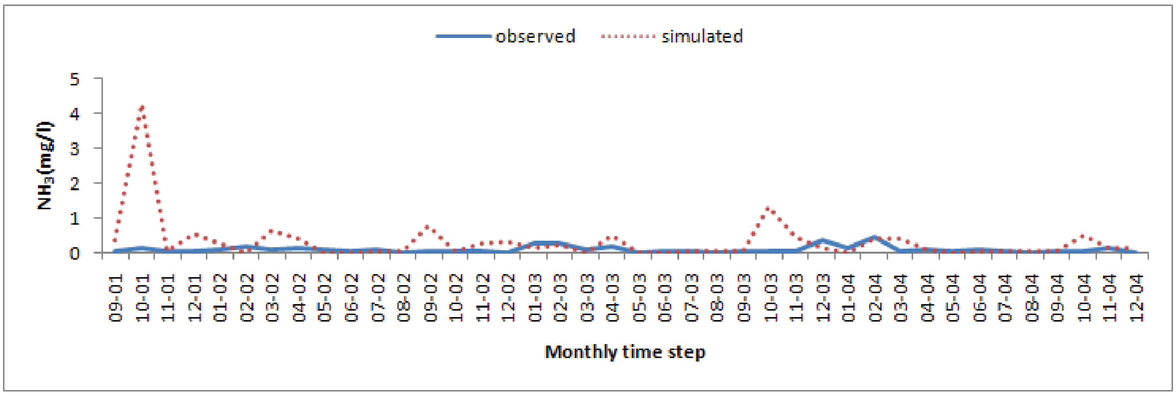


Figure 6-8: comparison of observed and simulated nitrogen ammonia in the reservoir.

6.2. **Summary**

The analysis of a watershed water quality model plays a very useful role in addressing the myriads of management problems present in most watersheds. One peculiar problem in the Roxo reservoir is the problem of eutrophication which is due to poor land management. Nutrients from agricultural lands are transported through streams into the Roxo reservoir, thus having knowledge of how much nutrient are transported into the reservoir can be used to curb their existence. Other relevant model outputs that can help in taking such useful management decisions are shown in Appendix C-2.

7. Overall summary

7.1. Cold simulations

Three types of rainfall data which include observed meteorological gauge data, SWAT weather generator (wgn) and Meteosat satellite MSG-MPE rainfall estimates were used to run the SWAT model. The simulation stream flow outputs were compared with 7 years observed stream flow. The simulations with the wgn and gauge data were carried out for a seven year period (2001-2007) on a monthly time step followed by yearly summary. The satellite rainfall data was carried out for a period of 15 months (January 2007- may 2008) on a monthly time step. In order to compare the model capability to represent observed stream flow, statistical and graphical techniques were employed. So for each simulation NSE and PBIAS statistical technique were used to evaluate SWAT model performance, hydrographs were also used to give an impression of the model performance. Figures 4-1 to 4-5, depict graphical display of model output and the observed stream flow with the weather generator and gauge rainfall data. The simulations using the SWAT weather generator (wgn) show tendency of underestimating stream flow while the gauge data simulation shows tendency of overestimating stream flow. In table 4-1, the statistical results show that the model performance was better with the rain gauge data when compared with wgn. This is expected as the gauge data are closer to reality than the wgn weather data, though none of the results were within acceptable range as the NSE values were -0.04 and -0.1 for wgn and gauge simulation respectively. The result of the Wgn simulation is also in agreement with the study of Tobin et al.,(2008). The 1:1 regression line shown in Figure 4-6 also gave a better impression for the gauge data when compared to the wgn the value computed were 0.6 and 0.053 for gauge and wgn respectively. The comparison of the satellite simulation was done for year 2007 as the observation data was not available beyond this year. In figure 4-7, the simulation of satellite MSGMPE is being compared with observed data and there is a very noticeable overestimation of stream flow. This is due to some high (apparently anomalies) rainfall events estimated by the Meteosat Seviri sensor combined with SSM/I sensor (on-board DMSP satellite), which were not fully confirmed with ground rainfall data.

Finally the stream output for year 2007 from the three simulations was compared with observation data of that same year as shown in Figure 4-9. From the graphical display (Figure 4-9) and statistical result (Table 4-2), the observed gauge data gave a better impression. But it is important to understand here that the satellite data performance must have been affected by other factors like processing errors since the use of this satellite product in hydrology is very new, the quality of the data is still undergoing some refinement as better algorithm are being researched to enhance data processing. More so, there were some missing data (which were filled in) which could also have influence the model simulation output using the satellite data. Based on the results of the cold simulation with the different rainfall data, the rain gauge simulation was chosen to be used for the SWAT model hydrologic calibration in the Roxo reservoir watershed.

7.2. Sensitivity analysis and hydrologic flow calibration

A sensitivity analysis was performed to limit the number of optimized parameters to obtain a good fit between the simulated and measured data. The SWAT2005 uses the Latin Hypercube (LH) (McKay, 1988; McKay et al., 1979) sampling method combined with One-factor-At-a-Time (OAT) (Morris, 1991) to study the effect of change in individual parameters on model output. Out of the two types of objective function of SWAT for sensitivity analysis, sum of square of residual as shown in equation (5-1) was used in this research. Out of the 26 flow parameters in SWAT, 19 parameters were considered to be sensitive in this study and the other of ranking of the parameters are shown in Figure 5-1 and Table 5-2. From the result, the curve number (CN) was found to be the most sensitive flow parameter. The CN parameters adjust the proportion of soil runoff and infiltration based on the watershed characteristics like the soil hydrologic group, land use, and antecedent moisture conditions. The parameter ranking was categorized into very important of which CN top the list and followed by Gwqmn (threshold depth of water in the shallow aquifer required for return flow to occur) and Álpha_Bf (i.e. the base flow alpha factor, similar to the recession constant). Parameters like Revapmn, Esco and Sol_Awc were considered to be important. The results of the sensitivity analysis were used to know the parameters to adjust during model calibration. In order to run the auto-calibration in SWAT2005, we started by manually adjusting the CN parameter, the values used for this manual adjustment were based on the range suggested from the sensitivity analysis results. In a similar manner the other parameters that were considered to be important were also manually adjusted by changing the values within the range suggested by the sensitivity results output, this was continued until a positive NSE (Nash & Sutcliff coefficient) was achieved and the auto calibration tool was then used to carry out the final calibration of the hydrologic flow parameter in the SWAT model. The purpose of the manual calibration was to save time during auto-calibration.

The calibration and the validation of ArcSWAT2005 applied to the Roxo reservoir watershed gave a satisfactory prediction of the monthly stream flow. NSE and PBIAS calibration indicators were used to quantify the strength of the model in reproducing observed values as they are presented in Table 5-3. Although the model was calibrated for a period of four years (2001-2004) for stream flow, the first year (2001) of simulation was used for model priming or stabilization and as a result it was not used in any computation. The PBIAS estimates are within acceptable range for both calibration and validation, although it is evident that the positive values of 1% indicate that the model under predicted flow during calibration period (2001-2004) while the negative value of -0.61% shows that SWAT overestimated flow during validation (2005-2007) period. A possible cause for model underestimation during calibration would be the choice of objective function used which is biased towards high flow. However other errors for model under prediction can be attributed to input uncertainty of rainfall and some other unknown activities in the watershed. Figure 5-3 also shows that SWAT is predicting better for surface flow than base flow. In general simulations matched observed stream flow as the NSE estimates gave good range of values for calibration (about 0.77) period (2001-2004) and validation (about 0.64) period (2005-2007).The trend lines and scattered points in Figure 5-5 shows a visual comparison of predicted and observed flow, the closer the scattered points to 1:1 line (y=x line), the closer the predicted values to the observed. A strong correlation was found between observed and simulated as the regression R^2 gave 0.77 and 0.75 for calibration and validation respectively.

In this study an effort was also made to verify the calibration length by simulating for the whole 7 years. The first purpose for this was to test the sensitivity of ArcSWAT2005 to calibration period while the second purpose was due to the fact that we used the model output to analyze the water quality issue in the catchment and it is recommended that water quality predictions in the SWAT model can estimate better with longer period. Thus to analyze the model output with respect to water quality variables, 7 years of the calibration output were used. We admit that in fact, the SWAT modelling would benefit from longer calibration and validation periods. However, in real case studies like this, it remains always difficult to obtain long term experimental data series for the important ca/val variables of the model.

7.3. Model output

An examination of nutrient exports (N and P) and their relationship to hydrologic conditions of the watershed shown in Figures 6-2 to 6-7 reveals that when stream flow is high, there is tendency for low nutrient concentration and vice versa, and with dry conditions, nutrient concentrations also decreases.

A visual comparison of simulated water quality (NH_3-N as example) and observation data from the Roxo reservoir was carried out to prepare the model for water quality calibration. The cold simulation gave indication of the water quality parameter to adjust during calibration. But a sensitivity analysis needs to be carried out first before a final conclusion can be drawn here.

A further analysis of the model output shows that it is possible to also identify and prioritized critical areas of the watershed using the SWAT model. Such priorities can be used to evaluate the management scenarios to reduce runoff rate, sediment yield and nutrient losses from the critical watershed areas and fields.

8. Conclusions and recommendations

8.1. Conclusions

Objective 1: Comparing the capabilities of the climate observation systems in watershed water quality modelling, by running the SWAT model with different rainfall/climate data inputs.

Three simulations with different sources of rainfall input data were used in the SWAT model. Our findings show that indeed the model is very sensitive to rainfall forcing. We observed that the model gets close to the real world situation when very accurate or close to accurate rainfall and other climate data forcing were used in simulation. Out of the three types used here, point based, SWAT weather generator and satellite rainfall forcing, the best simulation came from the ground rain gauge based simulations. However it should be noted that the duration and complete rainfall time series data all play a role here (as satellite daily rainfall time series only covered 1.5 year).

Objective 2: Calibrate and validate the SWAT model hydrological output using the Roxo reservoir water balance.

SWAT water quality and hydrologic model was applied to Roxo reservoir watershed. The result of calibration and validation for stream flow proved that the model can adequately simulate the hydrologic system of the study area. Stream flow was found to be most sensitive to curve number (CN), Threshold depth of water in the shallow aquifer required for return flow to occur (Gwqmn), baseflow alpha factor (Alpha_Bf), threshold depth of water in the shallow aquifer for 'revap' to occur (Revapmn), soil evaporation compensation factor (Esco) and available water capacity of the soil layer (Sol_Awc). The use of an inversion of the reservoir water balance, where the calculated reservoir inflows are used as catchment outflows gave adequate results for calibration of the SWAT model, without the use of typical river stream flow gauges.

Objective 3: Make a quantitative assessment of diffuse pollution load into Roxo reservoir from predictions of nutrient (N & P) loadings in runoff.

The result of the calibration was used to estimate nutrient loadings into the reservoir. High flow resulted in low nutrient concentration and low flow resulted in high concentration values which is in agreement with study of Shakak (2004). The output result was also used to prepare the model for the water quality calibration and for identification of critical source areas which need to be prioritize for effective management of the watershed.

This study shows that model outputs are relevant in identifying *critical* and *source areas* in the watershed. The information extracted from this can be used to evaluate management scenarios to reduce runoff, sediment and nutrient losses from watershed. Although hydrologic calibrations results reveal SWAT as a great tool for understanding the hydrologic component of the Roxo reservoir watershed, water quality calibration will always be needed to ascertain reliable nutrient loads to help in effective soil and water management, planning and decision making processes in the Roxo catchment and elsewhere.

8.2. Limitation

Insufficient satellite time series data for comparison and integration with gauge data was the main challenge in this thesis. Longer time series data are needed to get optimum result from SWAT simulations. The model performance also depends on high quality weather data with minimal missing values. But this was not the case with the MSGMPE satellite data used as data time series was too short. Some errors that were introduced during the process of converting pixel values to time series value obviously affected the model output. With respect to the time frame of this datasets, the period used for simulation is normally used for model priming and stabilization.

Although a reservoir was implemented in the SWAT project setup for this study, there were insufficient data to fully parameterize the reservoir thus very limited reservoir characteristics were described in the reservoir database.

8.3. Recommendations

After a successful calibration of the hydrologic model components, the next step would be sediment and water quality calibrations. It is therefore recommended that based on the hydrologic calibration; further efforts should be geared towards calibrating the SWAT model for water quality of the Roxo reservoir, using a full reservoir model. The standard SWAT model however accommodates only smaller reservoirs and the model needs some adaptations for simulating the Roxo reservoir.

Both satellite and rain gauge data could be assimilated (using data assimilation techniques) to derive more reliable data to be used as input to run the model. Based on the result of the satellite data simulation, it is recommended that when the database of the MSG time series data in ITC would have been updated for more number of years, the model should be simulated again with the MSGMPE satellite rainfall data and such result should be integrated with gauge data to get better rainfall input to drive the SWAT model.

Efforts should be made to extract all reservoir input data and the already implemented reservoir could be updated with this.

Bibliography

Almeida, C.C. and Silva, M.L., 1987. Incidence of agriculture on water quality at Campina de Faro (South Portugal), IV Simpósio de Hidrogeologia AEHS-GTH, 5-9 Out. Palma de Maiorca, pp. 249-257.

ASCE, 1993. Criteria for evaluation of watershed models. J. Irrigation Drainage Eng., 119)((3): 429-442.

Blackmore, T., Chadwick, R., Francis, P., Saunders, R. and David, G., 2006. Rainfall estimation over Africa using MSG, Improving the Nimrod nowcasting system's satellite precipitation estimates by introducing the new SEVIRI channels, Helsinki, Finland.

Caetano, M., Mata, F. and Freire, S., 2006. Accuracy assesment of the Portugues CORINE Land Cover map. Global Developments in Environmental Earth Observation from Space 459-467.

Chaplot, V., Saleh, A. and Jaynes, D.B., 2005. Effect of the accuracy of spatial rainfall information on the modeling of water, sediment, and NO3-N loads at the watershed level. Journal of Hydrology, 312(1-4): 223-234.

Chaubey, I., Haan, C.T., Grunwald, S. and Salisbury, J.M., 1999. Uncertainty in the model parameters due to spatial variability of rainfall. Journal of Hydrology, 220(1-2): 48-61.

Chisha, M., 2005. Assessment of nutrient pollution contribution of the Outeiro catchment to the Roxo lake in Portugal using the GWLF model, ITC, Enschede, 77 pp.

Collins, A.L. and McGonigle, D.F., 2008. Monitoring and modelling diffuse pollution from agriculture for policy support: UK and European experience. Environmental Science & Policy, 11(2): 97-101.

Cotter, A.S., Chaubey, I., Costello, T.A., Soerens, T.S. and Nelson, M.A., 2003. Water quality model output uncertainty as affected by spatial resolution of input data. Journal of the American Water Resources Association (JAWRA), 39((4)): 977-986.

Coutsoukis, P., 2003 CIA World Fact Book, pp. .

Dingman, S.L., 2002. Physical hydrology.

Drolc, A. and Zagorc Koncan, J., 2008. Diffuse sources of nitrogen compounds in the Sava river basin, Slovenia. Desalination, 226(1-3): 256-261.

Duan, Q., Sorooshian, S. and Gupta, V., 1992. Effective and Efficient Global Optimization for Conceptual Rainfall-Runoff Models. Water Resource. Research., 28(4): 1015-1031.

Easton, Z.M. et al., 2008. Re-conceptualizing the soil and water assessment tool (SWAT) model to predict runoff from variable source areas. Journal of Hydrology, 348(3-4): 279-291.

Eckhardt, K. and Arnold, J.G., 2001. Automatic calibration of a distributed catchment model. Journal of Hydrology, 251: 103-109.

EEA, 2000. Corine Landcover 2000 vector by country (CLC2000).European Environment Agency.

Euroharp, 2005. Towards European Harmonized Procedures for Quantification of Nutrient Losses from Diffuse Sources. Euroharp.org, pp. On-line document.

FitzHugh, T.W. and Mackay, D.S., 2000. Impacts of input parameter spatial aggregation on an agricultural nonpoint source pollution model. Journal of Hydrology, 236(1-2): 35-53.

Galbiati, L., Bouraoui, F., Elorza, F.J. and Bidoglio, G., 2006. Modeling diffuse pollution loading into a Mediterranean lagoon: Development and application of an integrated surface-subsurface model tool. Ecological Modelling, 193(1-2): 4-18.

Geerts, B., 98. Satellite-based rainfall estimation.

Geza, M. and McCray, J.E., 2008. Effects of soil data resolution on SWAT model stream flow and water quality predictions. Journal of Environmental Management, 88(3): 393-406.

Gokmen, M., 2006. Evaluation of the applicability of the GIS - coupled SWAT model for assessing non - point pollution in a European catchment (Roxo reservoir catchment, Portugal) in the perspective of EU water framework directive, ITC, Enschede.
Green, C.H. and van Griensven, A., 2008. Autocalibration in hydrologic modeling: Using SWAT2005 in small-scale watersheds. Environmental Modelling & Software, 23(4): 422-434.
Grizzetti, B., Bouraoui, F. and De Marsily, G., 2005. Modelling nitrogen pressure in river basins: A comparison between a statistical approach and the physically-based SWAT model. Physics and Chemistry of the Earth, Parts A/B/C, 30(8-10): 508-517.
Gupta, H.V., Sorooshian, S. and Yapo, P.O., 1999. Status of automatic calibration for hydrologic models: Comparison with multilevel expert calibration. Journal of Hydrologic Engineering, 4(2): 135-143.
Gurung, R.P., 2007. Modelling of Eutrophication in Roxo reservoir, Alentejo, Portugal : a system dynamic based approach, ITC, Enschede, 100 pp.
Heathwaite, L., 1995. Sourcesof Eutrohication:Hydrological Pathways of Catchment Nutrient Export. IAHS, 230: 161-175.
Henderson-Sellers, B. and Markland, H.R., 1987. Decaying Lakes: The Origins and Control of Cultural Eutrophication. . John Wiley & Sons Ltd., Great Britain.
Kalin, L. and Hantush, M.M., 2006. Hydrologic modeling of an eastern Pennsylvania watershed with NEXRAD and Rain Gauge Data. Journal of Hydrologic Engineering 11(6): 555-569.
Kamarianakis, Y., Chrysoulakis, N., Feidas, H., Kokolatos, G. and Kokolatos, G., 2006. Comparing rainfall estimates derived from rain gages and satellite images at the eastern Mediterranean region, 9th AGILE Conference on Geographic Information Science, , Visegrád, Hungary.
Kannan, N., White, S.M., Worrall, F. and Whelan, M.J., 2007. Hydrological modelling of a small catchment using SWAT-2000 - Ensuring correct flow partitioning for contaminant modelling. Journal of Hydrology, 334(1-2): 64-72.
Kummsa, A.A., 2006. Assessing relationships between stream water quality and watershed attributes using the SWAT2000 integrated watershed model : a case study in the Ronne river basin, Sweden, ITC, Enschede, 95 pp.
Legates, D.R. and McCabe, G.J., 1999. Evaluating the use of “goodness-of-fit” measures in hydrologic and hydroclimatic model validation. Water Resources Res., 35(1): 233-241.
Liersch, S., 2003. The Programs: dew.exe and dew02.exe User's Manual, Berlin.
Maathius, B.H.P., Mannaerts, C. and Retsios, B., 2008. The ITC Geonetcast-Toolbox Approach for Less Developed Countries. International Archves of the Photogrammetry, Remoe Sensing and Spatial Information Sciences., XXXVII(Part B7): 1302-1307.
Maidment, D.R. (Editor), 1992. Handbook of Hydrology. McGraw-Hill,Inc.
McKay, M.D., 1988. Sensitivity and Uncertaintity Analysis Using a staistical Sample of Input Values.Uncertaintity Analytsis. Uncertainty Analysis. CRC press, Inc. Boca Raton, Florida, 145-186.
McKay, M.D., Beckman, R.J. and Conover, W.J., 1979. Acomparison of three methods for selecting values of input variables in the Analysis of output from a computer code. Technometrics, 21(2): 239-245.
Mekonnen, S.C., 2005. Assessment of catchment water balance using GIS and remote sensing : Roxo, Portugal, ITC, Enschede, 109 pp.
Migliaccio, K.W., Chaubey, I. and Haggard, B.E., 2007. Evaluation of landscape and instream modeling to predict watershed nutrient yields. Environmental Modelling & Software, 22(7): 987-999.
Mitsch, W.J., Day, J.W. and Gilliam, J.W., 2001. Reducing Nitrogen Loading Loading to the Gulf of Mexico from the Mississippi River basin:Strategies to a Persistent Ecological Problem. Bioscience, 51(5): 373-388.
Moriasi, D.N. et al., 2007. Model Evaluation Guidlines for Systematic Quantification of accuracy in Watershed Simulations. Transactions of the ASABE 50(3): 885−900.
Morris, M.D., 1991. Factorial Samplng Plans for Preliminary Computational Experiments. Technometrics, 32(2): 161-174.

Mutela, M.K. and Nicklow, J.W., 2005. Sensitivity and uncertaintity analysis coupled with automatic calibration for a distributed watershed model. Journal of Hydrology, 10: 282-290.

Nash, J.E. and Sutcliffe, J.V., 1970. River flow forecasting through conceptual models: Part 1. A discussion of principles. Jounal of Hydrology, 10(3): 282-290.

Neitsch, S.L., Arnold, J.G., Kiniry, J.R., Srinivasan, R. and Willams, J.R., 2000. Soil and Water Assessment Tool-Theoretical Documentation-version2000. Grassland,Soil and Water Research Laboratory,Agricultural Research Service an Blackland Research Center,Texas Agricutultural Experiment Station, Temple,Texas.

Neitsch, S.L., Arnold, J.G., Kiniry, J.R., Srinivasan, R. and Williams, J.R., 2004. Soil and Water assessment tool-Input/Output File Documentaion-version2005. Grassland,Soil and Water Research Laboratory,Agricultural Research Service an Blackland Research Center,Texas Agricutultural Experiment Station, Temple,Texas.

Neitsch, S.L., Arnold, J.G., Kiniry, J.R. and Williams, J.R., 2005. Soil and Water Assessment Tool-Theoretical Documentation-version2005. Grassland,Soil and Water Research Laboratory,Agricultural Research Service an Blackland Research Center,Texas Agricutultural Experiment Station, Temple,Texas.

Neitsch, S.L., Arnold, J.G., Kiniry, J.R., Williams, J.R. and King, K.W., 2002a. Soil and Water Assessment Tool-Theoretical Documentation-version2000. Grassland,Soil and Water Research Laboratory,Agricultural Research Service an Blackland Research Center,Texas Agricutultural Experiment Station, Temple,Texas.

Nicks, A., 1974. Stochastic Generation of the Occurrence, Pattern and location of maximum amount of daily rainfall, In Proceedings Symposium on Statistical Hydrology, August-September 1971. Tucson, AZ. Miscellaneous Publication No. 1275, U.S. Department of Agriculture Washington, DC;, pp. 154-171.

OECD, 1982. Eutrophication of Waters: Monitoring, Assessment and Control. Organization of Economic Cooperation and Development., Paris.

Olivera, F., 2001. Extracting Hydrologic Information From Spatial Data for HMS Modeling. Journal of Hydrologic Engineering, 6(6): 524-530.

Olivera, F. et al., 2006. ARCGIS-SWAT: A GEODATA MODEL AND GIS INTERFACE FOR SWAT. Journal of the American Water Resources Association (JAWRA), 42(2): 295-309.

Paralta, E., P.M., C. and Ribeiro, L., 2007. Assessing agriculture pollution in the Beja aquifer using nitrogen isotopes (South Portugal), International Symposium on Advances in Isotope Hydrology and its role in Sustainable Water Resources Management, (IHS–2007), International Atomic Energy Agency Vienna International Centre (VIC) Building C IAEA Boardroom, 4th floor Wagramer Strasse 5 A-1400 Vienna, Austria, pp. 101.

Pawan, K.S., 2004. Diagnosing irrigation water resources with multi - sensor remote sensing and GIS techniques : a case study of the Roxo dam irrigation system, Portugal, ITC, Enschede, 116 pp.

Pawan, K.S. and Gieske, A.S.M., 2006. Multi - sensor remote sensing for computing actual evapotranspiration and its application for irrigation performance assessment in the Roxo irrigation command area, Portugal. In: Journal of hydrology and meteorology : SOHAM, Nepal, 3(2006)1, pp. 10-20.

Pohlert, T., Huisman, J.A., Breuer, L. and Frede, H.-G., 2005. Modelling of point and non-point source pollution of nitrate with SWAT in the river Dill. Adv. Geosci., 5: 7-12.

Rao, A.R. and Han, J., 1987. Analysis of urban runoff models. Advances in Water Resources, 10: 205-211.

Reintjes, T.H.M., 2007. Modeling in Hydrology.Part1, Lecture material, Enschede.

Santhi, C., Arnold, J.G., Williams, J.R., , Dugas, W.A., Sirinivasan, R. and Hauck, L.M., 2001. Validation of the SWAT model on a large river basin with point and nonpoint sources. Journal of the American Water Resources Association, 37(5): 1169-1188.

Shakak, N.B.I., 2004. Assessment of pollution risk using the AGNPS watershed model : case study of upper Roxo catchment, Portugal, ITC, Enschede, 117 pp.

Singh, V.P. (Editor), 1995. Computer Models of Watershed Hydrology Water Resources Pulications, Colorado, 1109 pp.

Sorooshian, S., Duan, Q.Y. and Gupta, V.K., 1993. Calibration of rainfall runoff models-Application of global optimization to the Sacramento Soil-Moisture Accounting Model. Water Resources Research, 29: 1185-1194.

Srinivasan, R. and van Griensven, A., 2005. ArcSWAT 2005Advanced Workshop.

Storm, D.E. and White, M.J., 2005. Development of Guidelines for TMDLs with Nonpoint Source Components Using SWAT, Biosystems and Agricultural Engineering Department Oklahoma State University, Oklahoma.

Tetra Tech Inc, 2004. Appendix C: Application of the Soil Water Assessment T ool (SWAT) to the Wabash River Watershed.

Texas Water Resources Institute, 2008. Soil and Water Assessment Tool (SWAT) watershed model. state of texas, pp. 2008 TexasOnline.com - Official Portal of Texas.

Tobin, K.J., Bennett, M.E. and Marvin, E., 2008. Comparison of SWAT Hydrological Model Results from TRMM 3B42, NEXRAD Stage III, and Oklahoma Mesonet Data. American Geophysical Union

Tong, S.T.Y. and Chen, W., 2002. Modeling the relationship between land use and surface water quality. Journal of Environmental Management, 66(4): 377-393.

Tripathi, M.P., Panda, R.K. and Raghuwanshi, N.S., 2003. Identification and Prioritisation of Critical Sub-watersheds for Soil Conservation Management using the SWAT Model. Biosystems Engineering, 85(3): 365-379.

Tripathi, M.P., Panda, R.K., Raghuwanshi, N.S. and Singh, R., 2004. Hydrological modelling of a small watershed using generated rainfall in the soil and water assessment tool model. Hydrological processes, 18 1811-1821.

USDA-SCS, 1972. USDA Soil Conservation Service, National Enginering Handbook Section 4:Hydrology.

USEPA, 2000. National Water Quality Inventory Report.

van Griensven, A., 2005. Sensitivity,auto-calibration, uncertainty and model evaluation in SWAT2005.Draft.

van Griensven, A., Francos, A. and Bauwens, W., 2002. Sensitivity analysis and autocalibration of an integral dynamic model for river water quality. Water Science and Technology, 45(9): 325-332.

Van Griensven, A. et al., 2006. A global sensitivity analysis tool for the paramters of multi-variable catchment models Journal of Hydrology, 324: 10-23.

Van Liew, M.W., Arnold, J.G. and Bosch, D.D., 2005. Problems ad potential of autocalibrating a hydrologic model. Soil and Water Division of ASAE 48(3): 1025-1040.

Williams, J.R., 1975. Sediment-yield prediction with universal equation using runoff energy factor.In Present and prospective technology for predicting sediment yield and sources. ARS, S(40): 244-252.

Winchell, M., Srinivasan, R., Di Luzio, M. and Arnold, J.G., 2008. ARCSWAT 2.0 interface for SWAT2005

User's guide. Blackland Research Center ,Texas Agricultural Experimental Stations,720 East Blackland Road-Tmple,Texas 76502

Grassland,Soil and Water Research Laboratory,USDA Agricultural Research Service,808 East Blackland Road-Temple,Texas 76502

Wischmeier, W.H. and Smith, D.D., 1978. Predicting rainfall losses:a guide to conservation planning. USDA Agricultural Handbook

Zomer, R., Jarvis, A. and Mohideen, S., 2008. Hole-filled seamless SRTM data-update- version4, available from http://srtm.csi.cgiar.org. International Centre for Tropical Agriculture (CIAT).

Appendices

Appendix A

A-1: Characteristics of hydrologic soil group

Soil Group	Characteristics	Minimum Infiltration Capacity (in./hr)
A	Sandy, deep, well drained soils; deep loess; aggregated silty soils	0.30-0.45
B	Sandy loams, shallow loess, moderately deep and moderately well drained soils	0.15-0.30
C	Clay loam soils, shallow sandy loams with a low permeability horizon impeding drainage (soils with a high clay content), soils low in organic content	0.05-0.15
D	Heavy clay soils with swelling potential (heavy plastic clays), water logged soils, certain saline soils, or shallow soils over an impermeable layer	0.00-0.05

Source: NRCS, 1972 as described in (Tetra Tech Inc., 2004)

A-2: Curve Number adjustments from Antecedent Moisture Conditions I, II, III

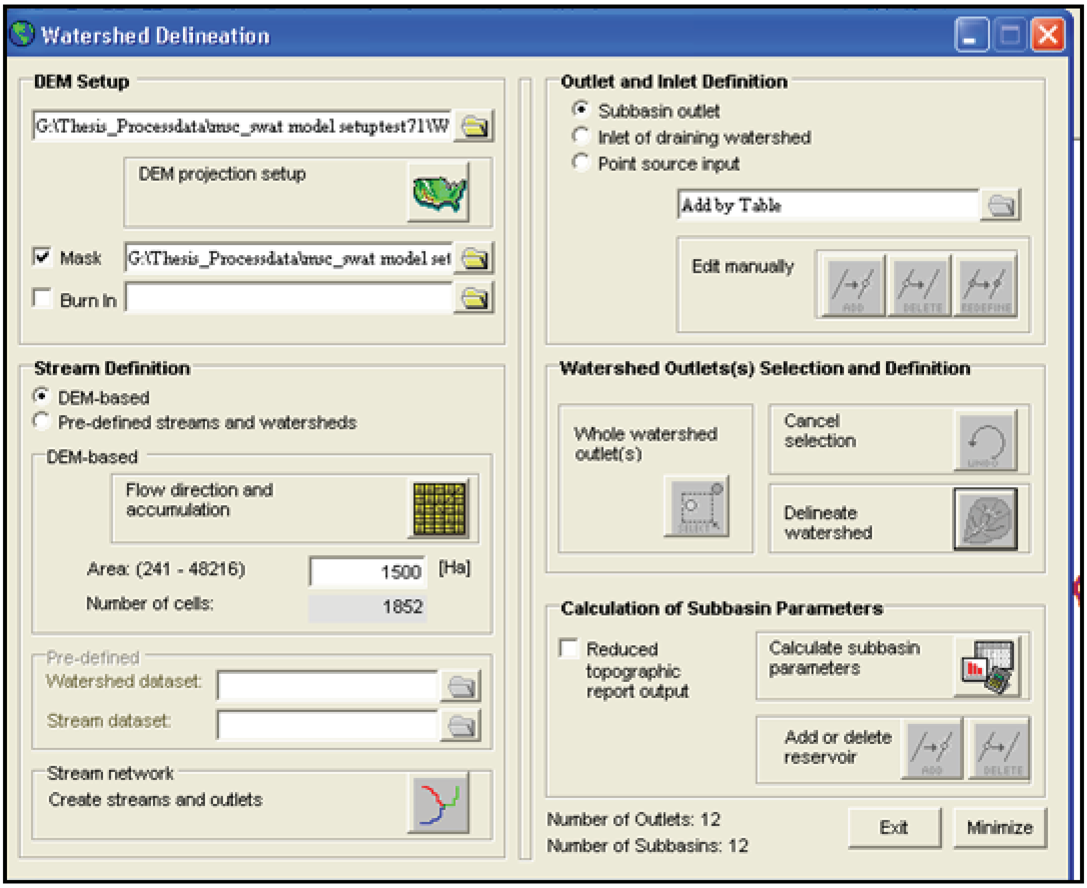
CN for AMC II	CN for AMC I	CN for AMC III
100	100	100
95	87	99
90	78	98
85	70	97
80	63	94
75	57	91
70	51	87
65	45	83
60	40	79
55	35	75
50	31	70
45	27	65
40	23	60
35	19	55
30	15	50
25	12	45
20	9	39
15	7	33
10	4	26
5	2	17
0	0	0

Source: NRCS, 1972 as described in (Tetra Tech Inc., 2004)

A-3: Topographic report

Elevation report for the watershed	Min. Elevation: 110m Max. Elevation: 293m Mean. Elevation: 177.07 Std. Deviation: 26.59
Elevation report for Subbasin # 1	Min. Elevation: 128m Max. Elevation: 272m Mean. Elevation: 17 Std. Deviation: 23.44
Elevation report for Subbasin # 2	Min. Elevation: 128m Max. Elevation: 293m Mean. Elevation: 193.07 Std. Deviation: 30.61
Elevation report for Subbasin # 3	Min. Elevation: 128m Max. Elevation: 153m Mean. Elevation: 137.4616 Std. Deviation: 8.57
Elevation report for Subbasin # 4	Min. Elevation: 128m Max. Elevation: 265m Mean. Elevation: 175.97 Std. Deviation: 32.21
Elevation report for Subbasin # 5	Min. Elevation: 110m Max. Elevation: 211m Mean. Elevation: 154.19 Std. Deviation: 18.62
Elevation report for Subbasin # 6	Min. Elevation: 128m Max. Elevation: 215m Mean. Elevation: 164.54 Std. Deviation: 17.83
Elevation report for Subbasin # 7	Min. Elevation: 110m Max. Elevation: 153m Mean. Elevation: 132.58 Std. Deviation: 6.85
Elevation report for Subbasin # 8	Min. Elevation: 123m Max. Elevation: 168m Mean. Elevation: 137.56 Std. Deviation: 8.65
Elevation report for Subbasin # 9	Min. Elevation: 128m Max. Elevation: 222m Mean. Elevation: 172.15 Std. Deviation: 21.35
Elevation report for Subbasin # 10	Min. Elevation: 125m Max. Elevation: 196m Mean. Elevation: 157.57 Std. Deviation: 10.04
Elevation report for Subbasin # 11	Min. Elevation: 173m Max. Elevation: 250m Mean. Elevation: 205.04 Std. Deviation: 14.64
Elevation report for Subbasin # 12	Min. Elevation: 128m Max. Elevation: 232m Mean. Elevation: 174.44 Std. Deviation: 17.18
Elevation report for Subbasin # 13	Min. Elevation: 173m Max. Elevation: 233m Mean. Elevation: 200.24 Std. Deviation: 10.63

A-4: Snap shot of the watershed delineation tool



A-5: Landuse, soil and slope distribution

```
____________________________________________________________________________

________________________________________________________

SWAT   model  simulation   Date: 12/16/2008 12:00:00 AM   Time:
00:00:00
DOMINANT  LandUse/Soil  OPTION
Number of HRUs: 13
Number of Subbasins: 13

____________________________________________________________________________
___________________________________________________________
                                                                  Area
[ha]          Area[acres]

Watershed
30639.3300           75711.3164

____________________________________________________________________________
___________________________________________________________
                                                                  Area
[ha]          Area[acres] %Wat.Area
LANDUSE:
```

Non-irrigated arable land --> NIAL
30560.6700 75516.9436 99.74
Water --> WATR
78.6600 194.3728 0.26

SOILS:
Bpc
7029.2700 17369.6776 22.94
Vc
2512.3500 6208.1425 8.20
Ps
4936.5900 12198.5607 16.11
Sr
3411.1800 8429.1963 11.13
Cph
393.8400 973.1983 1.29
Vx
8643.1500 21357.6558 28.21
Pb
1915.0200 4732.1102 6.25
Pxd
1797.9300 4442.7749 5.87

SLOPE:
2-9999
30560.6700 75516.9436 99.74
0-2
78.6600 194.3728 0.26

Area
[ha] Area[acres] %Wat.Area %Sub.Area

SUBBASIN # 1
4508.1000 11139.7405 14.71

LANDUSE:
Non-irrigated arable land --> NIAL
4508.1000 11139.7405 14.71 100.00

SOILS:
Bpc
4508.1000 11139.7405 14.71 100.00

SLOPE:
2-9999
4508.1000 11139.7405 14.71 100.00
HRUs
1 Non-irrigated arable land --> NIAL/Bpc/2-9999
4508.1000 11139.7405 14.71 100.00 1

Area
[ha] Area[acres] %Wat.Area %Sub.Area

```
SUBBASIN #                                        2
7029.2700          17369.6776     22.94

LANDUSE:
                  Non-irrigated arable land --> NIAL
7029.2700          17369.6776     22.94    100.00

SOILS:
                                                Bpc
7029.2700          17369.6776     22.94    100.00

SLOPE:
                                             2-9999
7029.2700          17369.6776     22.94    100.00
HRUs
 2       Non-irrigated arable land --> NIAL/Bpc/2-9999
7029.2700          17369.6776     22.94    100.00    1
_________________________________________________________________________
__________________________________________________________
_________________________________________________________________________
__________________________________________________________
                                                              Area
[ha]          Area[acres] %Wat.Area %Sub.Area

SUBBASIN #                                        3
172.7100             426.7750      0.56

LANDUSE:
                  Non-irrigated arable land --> NIAL
172.7100             426.7750      0.56    100.00

SOILS:
                                                 Vc
172.7100             426.7750      0.56    100.00

SLOPE:
                                             2-9999
172.7100             426.7750      0.56    100.00
HRUs
 3        Non-irrigated arable land --> NIAL/Vc/2-9999
172.7100             426.7750      0.56    100.00    1
_________________________________________________________________________
__________________________________________________________
_________________________________________________________________________
__________________________________________________________
                                                              Area
[ha]          Area[acres] %Wat.Area %Sub.Area

SUBBASIN #                                        4
1854.7200            4583.1059      6.05

LANDUSE:
                  Non-irrigated arable land --> NIAL
1854.7200            4583.1059      6.05    100.00

SOILS:
```

Ps
1854.7200 4583.1059 6.05 100.00

SLOPE:
2-9999
1854.7200 4583.1059 6.05 100.00
HRUs
4 Non-irrigated arable land --> NIAL/Ps/2-9999
1854.7200 4583.1059 6.05 100.00 1

___

Area
[ha] Area[acres] %Wat.Area %Sub.Area

SUBBASIN # 5
2339.6400 5781.3674 7.64

LANDUSE:
Non-irrigated arable land --> NIAL
2339.6400 5781.3674 7.64 100.00

SOILS:
Vc
2339.6400 5781.3674 7.64 100.00

SLOPE:
2-9999
2339.6400 5781.3674 7.64 100.00
HRUs
5 Non-irrigated arable land --> NIAL/Vc/2-9999
2339.6400 5781.3674 7.64 100.00 1

___

Area
[ha] Area[acres] %Wat.Area %Sub.Area

SUBBASIN # 6
3411.1800 8429.1963 11.13

LANDUSE:
Non-irrigated arable land --> NIAL
3411.1800 8429.1963 11.13 100.00

SOILS:
Sr
3411.1800 8429.1963 11.13 100.00

SLOPE:
2-9999
3411.1800 8429.1963 11.13 100.00
HRUs
6 Non-irrigated arable land --> NIAL/Sr/2-9999
3411.1800 8429.1963 11.13 100.00 1

```
_______________________________________________________________________
_____________________________________________________
_______________________________________________________________________
_____________________________________________________
                                                                  Area
[ha]          Area[acres] %Wat.Area %Sub.Area

SUBBASIN #                                                       7
78.6600             194.3728      0.26

LANDUSE:
                                       Water --> WATR
78.6600             194.3728      0.26    100.00

SOILS:
                                                    Cph
78.6600             194.3728      0.26    100.00

SLOPE:
                                                    0-2
78.6600             194.3728      0.26    100.00
HRUs
 7                          Water --> WATR/Cph/0-2
78.6600             194.3728      0.26    100.00    1
_______________________________________________________________________
_____________________________________________________
_______________________________________________________________________
_____________________________________________________
                                                                  Area
[ha]          Area[acres] %Wat.Area %Sub.Area

SUBBASIN #                                                       8
315.1800             778.8255      1.03

LANDUSE:
                   Non-irrigated arable land --> NIAL
315.1800             778.8255      1.03    100.00

SOILS:
                                                    Cph
315.1800             778.8255      1.03    100.00

SLOPE:
                                                 2-9999
315.1800             778.8255      1.03    100.00
HRUs
 8      Non-irrigated arable land --> NIAL/Cph/2-9999
315.1800             778.8255      1.03    100.00    1
_______________________________________________________________________
_____________________________________________________
_______________________________________________________________________
_____________________________________________________
                                                                  Area
[ha]          Area[acres] %Wat.Area %Sub.Area

SUBBASIN #                                                       9
1513.6200            3740.2307      4.94
```

LANDUSE:
Non-irrigated arable land --> NIAL
1513.6200 3740.2307 4.94 100.00

SOILS:
Vx
1513.6200 3740.2307 4.94 100.00

SLOPE:
2-9999
1513.6200 3740.2307 4.94 100.00
HRUs
9 Non-irrigated arable land --> NIAL/Vx/2-9999
1513.6200 3740.2307 4.94 100.00 1

____
____

Area
[ha] Area[acres] %Wat.Area %Sub.Area

SUBBASIN # 10
3081.8700 7615.4549 10.06

LANDUSE:
Non-irrigated arable land --> NIAL
3081.8700 7615.4549 10.06 100.00

SOILS:
Ps
3081.8700 7615.4549 10.06 100.00

SLOPE:
2-9999
3081.8700 7615.4549 10.06 100.00
HRUs
10 Non-irrigated arable land --> NIAL/Ps/2-9999
3081.8700 7615.4549 10.06 100.00 1

____
____

Area
[ha] Area[acres] %Wat.Area %Sub.Area

SUBBASIN # 11
1915.0200 4732.1102 6.25

LANDUSE:
Non-irrigated arable land --> NIAL
1915.0200 4732.1102 6.25 100.00

SOILS:
Pb
1915.0200 4732.1102 6.25 100.00

SLOPE:

```
                                                  2-9999
1915.0200           4732.1102      6.25    100.00
HRUs
 11      Non-irrigated arable land --> NIAL/Pb/2-9999
1915.0200           4732.1102      6.25    100.00    1
______________________________________________________________________
_____________________________________________________
______________________________________________________________________
_____________________________________________________
                                                                Area
[ha]          Area[acres] %Wat.Area %Sub.Area

SUBBASIN #                                              12
7129.5300          17617.4251     23.27

LANDUSE:
                   Non-irrigated arable land --> NIAL
7129.5300          17617.4251     23.27    100.00

SOILS:
                                                        Vx
7129.5300          17617.4251     23.27    100.00

SLOPE:
                                                  2-9999
7129.5300          17617.4251     23.27    100.00
HRUs
 12      Non-irrigated arable land --> NIAL/Vx/2-9999
7129.5300          17617.4251     23.27    100.00    1
______________________________________________________________________
_____________________________________________________
______________________________________________________________________
_____________________________________________________
                                                                Area
[ha]          Area[acres] %Wat.Area %Sub.Area

SUBBASIN #                                              13
1797.9300           4442.7749      5.87

LANDUSE:
                   Non-irrigated arable land --> NIAL
1797.9300           4442.7749      5.87    100.00

SOILS:
                                                       Pxd
1797.9300           4442.7749      5.87    100.00

SLOPE:
                                                  2-9999
1797.9300           4442.7749      5.87    100.00
HRUs
 13     Non-irrigated arable land --> NIAL/Pxd/2-9999
1797.9300           4442.7749      5.87    100.00    1
```

A-6: Aljustrel monthly weather Parameters used by the SWAT weather generator

TIME	TMPMX	TMPMN	TMPSTDMX	TMPSTDMN	PCPMM	PCPSTD	PCPSKW	PR_W1	PR_W2	PCPD	RAINHHMX	SOLARAV	DEWPOINT	WNDAVG
Months	°C	°C	°C	°C	mm (H_2O)	mm (H_2O/day)					(mm H_2O)	(mj/m2/ day)	°C	m/s
january	16.42	3.89	2.74	3.18	38.60	3.01	2.72	0.34	0.56	14.71	23.3	7.33	9.38	2.43
february	17.55	4.66	2.33	2.98	45.30	3.49	2.94	0.38	0.61	12.86	23.3	11.22	9.84	2.68
march	20.18	6.57	3.52	2.87	56.16	5.17	3.65	0.24	0.50	10.14	23.3	15.05	10.72	2.83
april	22.67	8.07	4.04	2.27	57.57	5.20	3.81	0.21	0.57	9.71	23.3	19.53	11.79	2.82
may	26.10	10.37	4.27	2.50	29.09	3.12	4.29	0.19	0.31	6.86	23.3	22.56	13.02	2.90
june	31.51	14.05	4.43	2.02	6.14	0.76	4.91	0.10	0.23	2.57	23.3	25.73	15.58	3.07
july	33.53	14.95	4.07	2.25	1.17	0.21	3.98	0.06	0.00	1.57	23.3	26.42	16.02	3.45
august	33.91	15.54	3.98	1.98	4.94	0.69	3.59	0.06	0.18	1.57	23.3	23.21	16.90	3.35
septembe	30.58	14.28	3.70	2.21	31.31	3.16	4.14	0.15	0.42	6.88	23.3	17.52	16.81	2.86
october	25.25	12.42	3.52	2.77	88.59	6.30	2.97	0.49	0.55	13.88	23.3	12.03	14.99	2.94
novembe	19.78	7.43	3.22	3.48	97.30	7.84	3.25	0.34	0.63	13.43	23.3	9.08	11.44	2.69
december	16.16	4.98	2.17	3.53	54.69	4.49	3.28	0.31	0.49	12.57	23.3	7.32	9.64	2.74

A-7: Beja monthly weather parameters used by the SWAT weather generator

TIME	TMPMX	TMPMN	TMPSTDMX	TMPSTDMN	PCPMM	PCPSTD	PCPSKW	PR_W1	PR_W2	PCPD	RAINHHMM	SOLARAV	DEWPT	WNDAV
Months	°C	°C	°C	°C	mm (H_2O)	mm (H_2O/day)					(mm H_2O)	(mj/m2/ day)	°C	m/s
january	15.7	4.9	2.8	2.9	40.5	1.8	3.1	0.3	0.6	12.3	23.3	9.5	8.6	1.8
february	16.8	5.4	2.5	2.5	49.7	1.8	3.3	0.4	0.6	13.3	23.3	12.4	9.2	2.0
march	19.4	6.9	3.7	2.7	46.4	2.3	3.0	0.2	0.6	11.9	23.3	16.0	10.2	2.1
april	22.1	8.4	4.2	2.2	50.3	2.6	3.3	0.2	0.6	10.3	23.3	22.2	11.4	2.1
may	25.6	10.5	4.3	2.4	30.4	2.1	3.9	0.2	0.4	8.1	23.3	25.4	12.8	2.1
june	31.4	14.1	4.3	2.2	10.9	1.9	3.5	0.1	0.3	3.1	23.3	25.1	15.2	2.2
july	32.4	15.1	3.8	2.7	1.0	0.2	2.9	0.1	0.1	1.0	23.3	29.8	15.6	2.4
august	33.7	15.8	3.9	2.2	4.9	0.8	3.2	0.1	0.2	2.0	23.3	26.1	15.9	2.3
septembe	30.2	14.6	3.7	2.1	42.6	2.8	4.0	0.2	0.5	9.8	23.3	19.9	15.7	2.0
october	24.5	12.7	3.6	2.5	95.4	3.7	3.4	0.3	0.7	15.0	23.3	13.7	14.3	2.1
novembe	19.0	8.7	3.3	3.0	79.5	4.1	3.0	0.3	0.7	12.4	23.3	10.9	10.7	2.0
december	15.7	5.5	2.9	2.8	52.3	1.5	3.0	0.3	0.5	12.4	23.3	8.4	9.0	2.1

A-8: Castro Verde monthly weather parameters used by the SWAT weather generator

TIME	TMPMX	TMPMN	TMPSTDMX	TMPSTDMN	PCPMM	PCPSTD	PCPSKW	PR_W1	PR_W2	PCPD	RAINHHMM	SOLARAV	DEWPT	WNDAV
Months	°C	°C	°C	°C	mm (H_2O)	mm (H_2O/day)				PCPD	(mm H_2O)	(mj/m2/ day)	°C	m/s
january					43.36	2.62	2.41	0.61	0.78	25.40	23.3			1.43
february					46.90	3.82	3.37	0.58	0.70	19.71	23.3			1.47
march					45.26	3.22	3.01	0.45	0.70	19.00	23.3			1.81
april					41.09	3.12	3.23	0.30	0.56	12.14	23.3			2.02
may					19.60	1.68	3.40	0.29	0.44	11.43	23.3			1.84
june					3.93	0.51	4.54	0.07	0.19	3.00	23.3			2.34
july					0.66	0.09	3.43	0.04	0.08	1.50	23.3			2.68
august					8.65	1.33	4.28	0.06	0.24	2.29	23.3			2.41
september					28.96	2.89	4.67	0.18	0.45	9.14	23.3			2.03
october					85.55	6.30	3.23	0.41	0.71	17.33	23.3			2.07
november					73.58	5.55	2.92	0.39	0.78	19.14	23.3			1.30
december					55.78	4.07	3.39	0.63	0.78	23.60	23.3			1.78

NB: (empty cells were left to be generated by SWAT)

A-9: Precipitation location table used in modeling

ID	NAME	XPR	YPR	elevation
1	BPCP	597845.652	4210562.415	206
2	Aljupcp	571119.64	4202949.775	104
3	Castvpcp	579934.55	4172653.644	217

NB: BPCP (beja precipitation), Aljupcp (aljustrel precipitation), Castvpcp (CastroVerde precipitation)

A-10: Temperature location table used in modeling

ID	NAME	XPR	YPR	YPR
1	BPCP	597845.652	4210562.415	206
2	Aljupcp	571119.64	4202949.775	104

A-11: Weather station location table (gauge)

ID	NAME	XPR	YPR
1007	Beja	597845.652	4210562.415
1005	Aljustre	571119.64	4202949.775
271	Castrv	579934.55	4172653.644

A-12: Weather station location table (satellite)

ID	NAME	XPR	YPR	ELEVATION
1	Aba	579940.86	4191480.73	178
2	Aca	582572.05	4191052.4	180
3	Ada	576636.57	4185790.01	183
4	Afa	584285.39	4187503.35	162
5	Aga	587222.53	4194968.59	152
6	Aha	591628.25	4198272.88	169
7	Aja	587344.92	4198517.65	152
8	Aka	594198.26	4203841.22	177
9	Ala	591383.49	4202005.51	165
10	Ama	595299.69	4207818.61	217
11	Ana	592301.35	4206533.61	190
12	Ara	587895.63	4201454.79	145
14	Aza	586059.91	4203963.6	147
15	Asa	584652.53	4208675.28	197
16	Ata	583734.67	4204269.56	157
17	Ava	580552.77	4204024.79	151
18	Aya	582816.82	4198395.26	128

Appendix B

B-1: Output Files

Output Files	Summary Information	Object class in Dynamic Database
basins.sbs	HRU	<sbs>
basins.bsb	Sub-basins	<bsb>
basins.rch	Reaches	<rch>
basins.wtr	Pond, wetland and depressional/impoundment area in the HRUs	<wtr>
basins.rsv	Reservoirs	<rsv>

(Olivera et al., 2006)

B-2a: Output files of the sensitivity analysis.

File name	Description
sensresult.out	List of parameter ranks
sensout.out	Detailed output with mean, variance and partial sensitivities
senspar.out	Parameter values of each run
sensobjf.out	Value of objective function for each run
sensrespons.out	Model output values for each run
lathyppar.out	Normalized Latin-Hypercube sampling points
oatpar.out	Normalized OAT sampling points

Extracted form van Griensven et al.(2002)

B-2b: Initial parameter value and bounds & other variables used for calibration

```
PARAMETER     INITIAL VALUE     LOWER BOUND     UPPER BOUND
---------     -------------     -----------     -----------
 1    0.00000    1.00000    1     1 2001  Alpha_Bf
 2    0.00000    1.00000   25     1 2001    Biomix
 3    0.00000    1.00000   61     1 2001      Blai
 4    0.00000   10.00000    7     1 2001     Canmx
 5    0.00000  150.00000   54     1 2001     Ch_K2
 6    0.00000    1.00000   51     1 2001     Ch_N2
 7  -25.00000   25.00000   10     3 2001       Cn2
 8    0.00000    1.00000   28     1 2001      Epco
 9    0.00000    1.00000   27     1 2001      Esco
10  -10.00000   10.00000    2     2 2001  Gw_Delay
11   -0.03600    0.03600    3     2 2001  Gw_Revap
12**********1000.00000    6     2 2001     Gwqmn
13-100.00000  100.00000    5     2 2001   Revapmn
14  -25.00000   25.00000   23     3 2001     Slope
15  -25.00000   25.00000   24     3 2001  Slsubbsn
16  -25.00000   25.00000   22     3 2001   Sol_Alb
17  -25.00000   25.00000   17     3 2001   Sol_Awc
18  -25.00000   25.00000   15     3 2001     Sol_K
19  -25.00000   25.00000   16     3 2001     Sol_Z
20    0.00000   10.00000   33     1    0    Surlag
 Objective functions are (objmet.dat):
OBJECTIVE FUNCTION  1 =
SSQ   for flow            (m^3/s) at location  1
 Response functions are (responsmet.dat):
OUTPUT   1 =
aver. for flow            (m^3/s) at location  1
  sce control parameters


  SCE CONTROL     MAX TRIALS     REQUIRED IMPROVEMENT     RANDOM
   PARAMETER        ALLOWED      PERCENT     NO. LOOPS      SEED
  -----------     ----------     -------     ---------     ------
                     20000          1.0          5          1667


                  SCE ALGORITHM CONTROL PARAMETERS
                  ================================

  NUMBER OF     POINTS PER     POINTS IN     POINTS PER     EVOL. STEPS
  COMPLEXES      COMPLEX       INI. POPUL.   SUB-COMPLX     PER COMPLEX
  ---------     ----------     -----------   ----------     -----------
     10             33             330           17              33
```

B-3a: SWAT calibration output variables (procedures used in producing the observation files for calibration)

Nr.	Variable
1	Flow [m3/s]
2	Sediment concentration [g/l]
3	Organic N concentration [mg N/l]
4	Organic P concentration [mg P/l]
5	Nitrate concentration [mg N/l]
6	Ammonia concentration [mg N/l]
7	Nitrite concentration [mg N/l]
8	CBOD concentration [mg/l]
9	Dissolved oxygen concentration [mg/l]
10	Mineral P concentration [mg P/l]
11	Chlorophyll-a concentration [μg/l]
12	Soluble pesticide concentration [mg/l]
13	Sorbed pesticide concentration [mg/l]
14	Temperature [°C]
20	Kjeldahl nitrogen concentration [mg N/l]
21	Total nitrogen concentration [mg N/l]
22	Total phosporus concentration [mg P/l]

Extracted form van Griensven et al.(2002)

B-3b:Observation data used for 4-year period

2001	9	0.422	-99	-99	-99	-99	-99
2001	10	0.581	-99	-99	-99	-99	-99
2001	11	0.337	-99	-99	-99	-99	-99
2001	12	0.53	-99	-99	-99	-99	-99
2002	1	1.157	-99	-99	-99	-99	-99
2002	2	0.494	-99	-99	-99	-99	-99
2002	3	1.375	-99	-99	-99	-99	-99
2002	4	1.025	-99	-99	-99	-99	-99
2002	5	0.322	-99	-99	-99	-99	-99
2002	6	0.436	-99	-99	-99	-99	-99
2002	7	0.532	-99	-99	-99	-99	-99
2002	8	0.381	-99	-99	-99	-99	-99
2002	9	0.317	-99	-99	-99	-99	-99
2002	10	0.257	-99	-99	-99	-99	-99
2002	11	0.357	-99	-99	-99	-99	-99
2002	12	2.951	-99	-99	-99	-99	-99
2003	1	2.459	-99	-99	-99	-99	-99
2003	2	3.589	-99	-99	-99	-99	-99
2003	3	0.924	-99	-99	-99	-99	-99
2003	4	1.887	-99	-99	-99	-99	-99
2003	5	0.587	-99	-99	-99	-99	-99
2003	6	0.347	-99	-99	-99	-99	-99
2003	7	0.481	-99	-99	-99	-99	-99
2003	8	0.528	-99	-99	-99	-99	-99
2003	9	0.425	-99	-99	-99	-99	-99
2003	10	0.435	-99	-99	-99	-99	-99
2003	11	1.203	-99	-99	-99	-99	-99
2003	12	2.482	-99	-99	-99	-99	-99
2004	1	0.675	-99	-99	-99	-99	-99
2004	2	1.701	-99	-99	-99	-99	-99
2004	3	1.176	-99	-99	-99	-99	-99
2004	4	0.559	-99	-99	-99	-99	-99
2004	5	0.45	-99	-99	-99	-99	-99
2004	6	0.493	-99	-99	-99	-99	-99
2004	7	0.625	-99	-99	-99	-99	-99
2004	8	0.495	-99	-99	-99	-99	-99
2004	9	0.379	-99	-99	-99	-99	-99
2004	10	0.324	-99	-99	-99	-99	-99
2004	11	0.143	-99	-99	-99	-99	-99
2004	12	0.069	-99	-99	-99	-99	-99

B-4: Output file for parasol (calibration technque used in the thesis)

File name	Description
Sceobjf.out	Objective functions values for each optimization run
scerespons.out	Model output values for all simulation runs
scepar.out	Parameter values of all simulation runs
sceparobj.out	Parameter values of all simulation runs and global optimization criterion
Uncobjf.good	Objective function values for the good parameter sets in "goodpar.out"
Senspar.out	Parameter values

Extracted form van Griensven et al.(2002)

B-5: Raw calibration output (from the 4-year period)

2001	m	9	9.50E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
2001	m	10	4.53E-02	2.20E-02	3.37E-01	3.17E-02	1.60E+01	4.26E-01	2.16E-01	2.69E-01	0.00E+00	4.28E+02	0.00E+00	0.00E+00	0.00E+00	7.63E-01	1.70E+01	3.00E-01
2001	m	11	3.94E-01	7.69E-02	4.87E+00	5.16E-01	4.18E+03	3.32E+00	1.37E+00	1.63E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.18E+00	4.19E+03	2.14E+00
2001	m	12	4.68E-01	9.24E-02	4.34E+00	4.51E-01	4.62E+03	3.30E+00	1.10E+00	1.45E+00	0.00E+00	2.11E+02	0.00E+00	0.00E+00	0.00E+00	7.64E+00	4.63E+03	1.90E+00
2002	m	1	1.13E+00	1.16E+00	6.96E+00	6.81E-01	1.42E+04	5.61E+00	2.14E+00	2.40E+00	0.00E+00	1.20E+03	0.00E+00	0.00E+00	0.00E+00	1.26E+01	1.43E+04	3.09E+00
2002	m	2	8.33E-01	8.87E-01	8.84E+00	8.54E-01	8.28E+03	7.08E+00	2.81E+00	3.02E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.59E+01	8.29E+03	3.88E+00
2002	m	3	1.41E+00	1.95E+00	1.28E+01	1.16E+00	1.13E+04	1.02E+01	5.10E+00	4.63E+00	0.00E+00	3.89E+03	0.00E+00	0.00E+00	0.00E+00	2.30E+01	1.13E+04	5.78E+00
2002	m	4	1.49E+00	2.05E+00	1.79E+01	1.58E+00	7.60E+03	1.43E+01	7.49E+00	6.43E+00	0.00E+00	1.79E+03	0.00E+00	0.00E+00	0.00E+00	3.23E+01	7.64E+03	8.01E+00
2002	m	5	5.53E-01	6.31E-01	1.75E+01	1.46E+00	1.17E+03	1.44E+01	8.50E+00	6.80E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.19E+01	1.21E+03	8.27E+00
2002	m	6	2.42E-01	2.55E-01	1.38E+01	9.89E-01	3.29E+01	1.14E+01	9.36E+00	6.77E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.52E+01	6.74E+01	7.76E+00
2002	m	7	2.18E-01	2.64E-01	1.16E+01	7.23E-01	1.78E+01	9.31E+00	9.59E+00	6.77E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.10E+01	4.83E+01	7.49E+00
2002	m	8	2.11E-01	2.58E-01	1.17E+01	7.52E-01	1.63E+01	9.61E+00	9.34E+00	6.55E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.13E+01	4.70E+01	7.30E+00
2002	m	9	2.13E-01	2.45E-01	1.65E+01	1.29E+00	1.31E+01	1.36E+01	1.01E+01	7.05E+00	0.00E+00	9.35E+02	0.00E+00	0.00E+00	0.00E+00	3.01E+01	5.34E+01	8.34E+00
2002	m	10	3.32E-01	2.85E-01	1.87E+01	1.47E+00	5.09E+01	1.52E+01	1.01E+01	7.69E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.39E+01	9.49E+01	9.16E+00
2002	m	11	5.99E-01	4.73E-01	3.22E+01	3.27E+00	2.17E+02	2.11E+01	9.01E+00	8.47E+00	0.00E+00	1.22E+03	0.00E+00	0.00E+00	0.00E+00	5.33E+01	2.79E+02	1.17E+01
2002	m	12	2.57E+00	4.91E+00	3.00E+01	2.84E+00	2.16E+03	2.23E+01	9.29E+00	8.95E+00	0.00E+00	1.08E+04	0.00E+00	0.00E+00	0.00E+00	5.23E+01	2.22E+03	1.18E+01
2003	m	1	3.10E+00	6.53E+00	4.29E+01	4.37E+00	9.08E+03	2.94E+01	1.03E+01	1.10E+01	0.00E+00	9.03E+03	0.00E+00	0.00E+00	0.00E+00	7.23E+01	9.16E+03	1.53E+01
2003	m	2	1.94E+00	3.85E+00	4.48E+01	4.49E+00	8.49E+03	3.13E+01	1.13E+01	1.18E+01	0.00E+00	2.07E+03	0.00E+00	0.00E+00	0.00E+00	7.61E+01	8.58E+03	1.63E+01
2003	m	3	1.41E+00	2.67E+00	4.24E+01	3.84E+00	5.67E+03	3.26E+01	1.57E+01	1.35E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.50E+01	5.76E+03	1.73E+01
2003	m	4	1.26E+00	2.21E+00	4.48E+01	3.97E+00	4.11E+03	3.45E+01	1.74E+01	1.47E+01	0.00E+00	1.19E+03	0.00E+00	0.00E+00	0.00E+00	7.93E+01	4.20E+03	1.87E+01
2003	m	5	6.83E-01	9.40E-01	3.91E+01	2.99E+00	1.06E+03	3.13E+01	2.29E+01	1.63E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.04E+01	1.15E+03	1.93E+01
2003	m	6	3.75E-01	5.23E-01	3.24E+01	2.14E+00	7.76E+01	2.51E+01	2.42E+01	1.67E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.75E+01	1.59E+02	1.88E+01
2003	m	7	3.49E-01	4.86E-01	3.13E+01	2.05E+00	5.19E+01	2.44E+01	2.31E+01	1.62E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.56E+01	1.31E+02	1.83E+01
2003	m	8	3.33E-01	4.55E-01	2.52E+01	1.39E+00	6.50E+01	1.67E+01	1.94E+01	1.64E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.19E+01	1.26E+02	1.77E+01
2003	m	9	3.23E-01	4.68E-01	3.01E+01	1.98E+00	4.63E+01	2.43E+01	2.28E+01	1.53E+01	0.00E+00	7.13E+02	0.00E+00	0.00E+00	0.00E+00	5.44E+01	1.23E+02	1.73E+01
2003	m	10	3.25E-01	4.37E-01	4.97E+01	4.29E+00	3.54E+01	3.84E+01	2.18E+01	1.69E+01	0.00E+00	1.91E+03	0.00E+00	0.00E+00	0.00E+00	8.81E+01	1.45E+02	2.12E+01
2003	m	11	1.10E+00	9.92E-01	6.01E+01	5.57E+00	4.29E+02	4.34E+01	2.03E+01	1.76E+01	0.00E+00	8.15E+02	0.00E+00	0.00E+00	0.00E+00	1.04E+02	5.52E+02	2.32E+01
2003	m	12	2.69E+00	5.90E+00	7.32E+01	7.25E+00	1.52E+03	5.14E+01	1.91E+01	1.92E+01	0.00E+00	5.42E+03	0.00E+00	0.00E+00	0.00E+00	1.25E+02	1.67E+03	2.64E+01
2004	m	1	1.46E+00	2.74E+00	7.45E+01	7.42E+00	5.09E+02	5.18E+01	1.99E+01	1.90E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.26E+02	6.55E+02	2.64E+01
2004	m	2	1.43E+00	2.78E+00	7.33E+01	7.14E+00	9.61E+02	5.23E+01	2.07E+01	1.99E+01	0.00E+00	1.71E+03	0.00E+00	0.00E+00	0.00E+00	1.26E+02	1.11E+03	2.70E+01
2004	m	3	1.36E+00	2.62E+00	7.66E+01	7.34E+00	1.31E+03	5.53E+01	2.30E+01	2.13E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.32E+02	1.46E+03	2.87E+01
2004	m	4	8.21E-01	1.53E+00	7.12E+01	6.44E+00	3.85E+02	5.36E+01	2.63E+01	2.21E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.25E+02	5.36E+02	2.85E+01
2004	m	5	5.04E-01	8.24E-01	6.35E+01	5.35E+00	6.57E+01	4.92E+01	2.94E+01	2.24E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.13E+02	2.08E+02	2.77E+01
2004	m	6	4.35E-01	6.72E-01	4.25E+01	2.56E+00	6.31E+01	3.10E+01	3.51E+01	2.40E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.36E+01	1.72E+02	2.65E+01
2004	m	7	4.20E-01	6.29E-01	4.14E+01	2.53E+00	6.18E+01	3.02E+01	3.25E+01	2.31E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.16E+01	1.66E+02	2.57E+01
2004	m	8	3.97E-01	5.92E-01	4.21E+01	2.64E+00	5.40E+01	3.21E+01	3.38E+01	2.25E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.42E+01	1.62E+02	2.51E+01
2004	m	9	3.92E-01	6.02E-01	4.38E+01	2.92E+00	4.66E+01	3.50E+01	3.26E+01	2.16E+01	0.00E+00	4.34E+02	0.00E+00	0.00E+00	0.00E+00	7.89E+01	1.58E+02	2.45E+01
2004	m	10	3.62E-01	5.30E-01	5.33E+01	4.30E+00	3.44E+01	4.35E+01	2.71E+01	2.02E+01	0.00E+00	1.77E+03	0.00E+00	0.00E+00	0.00E+00	9.68E+01	1.58E+02	2.45E+01
2004	m	11	4.10E-01	6.00E-01	6.98E+01	6.59E+00	2.58E+01	5.19E+01	2.19E+01	1.96E+01	0.00E+00	9.54E+02	0.00E+00	0.00E+00	0.00E+00	1.22E+02	1.69E+02	2.62E+01
2004	m	12	4.08E-01	5.96E-01	7.67E+01	7.80E+00	2.27E+01	5.28E+01	1.77E+01	1.86E+01	0.00E+00	9.18E+02	0.00E+00	0.00E+00	0.00E+00	1.29E+02	1.70E+02	2.64E+01

B-6: 4-year period calibration output (prepared for analysis)

2001	m	9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2001	m	10	0.05	0.02	0.34	0.03	16.00	0.43	0.22	0.27	0.00	428.00	0.00	0.00	0.00	0.76	17.00	0.30
2001	m	11	0.39	0.08	4.87	0.52	4180.00	3.32	1.37	1.63	0.00	0.00	0.00	0.00	0.00	8.18	4190.00	2.14
2001	m	12	0.47	0.09	4.34	0.45	4620.00	3.30	1.10	1.45	0.00	211.00	0.00	0.00	0.00	7.64	4630.00	1.90
2002	m	1	1.13	1.16	6.96	0.68	14200.00	5.61	2.14	2.40	0.00	1200.00	0.00	0.00	0.00	12.60	14300.00	3.09
2002	m	2	0.83	0.89	8.84	0.85	8280.00	7.08	2.81	3.02	0.00	0.00	0.00	0.00	0.00	15.90	8290.00	3.88
2002	m	3	1.41	1.95	12.80	1.16	11300.00	10.20	5.10	4.63	0.00	3890.00	0.00	0.00	0.00	23.00	11300.00	5.78
2002	m	4	1.49	2.05	17.90	1.58	7600.00	14.30	7.49	6.43	0.00	1790.00	0.00	0.00	0.00	32.30	7640.00	8.01
2002	m	5	0.55	0.63	17.50	1.46	1170.00	14.40	8.50	6.80	0.00	0.00	0.00	0.00	0.00	31.90	1210.00	8.27
2002	m	6	0.24	0.26	13.80	0.99	32.90	11.40	9.36	6.77	0.00	0.00	0.00	0.00	0.00	25.20	67.40	7.76
2002	m	7	0.22	0.26	11.60	0.72	17.80	9.31	9.59	6.77	0.00	0.00	0.00	0.00	0.00	21.00	48.30	7.49
2002	m	8	0.21	0.26	11.70	0.75	16.30	9.61	9.34	6.55	0.00	0.00	0.00	0.00	0.00	21.30	47.00	7.30
2002	m	9	0.21	0.25	16.50	1.29	13.10	13.60	10.10	7.05	0.00	935.00	0.00	0.00	0.00	30.10	53.40	8.34
2002	m	10	0.33	0.29	18.70	1.47	50.90	15.20	10.10	7.69	0.00	0.00	0.00	0.00	0.00	33.90	94.90	9.16
2002	m	11	0.60	0.47	32.20	3.27	217.00	21.10	9.01	8.47	0.00	1220.00	0.00	0.00	0.00	53.30	279.00	11.70
2002	m	12	2.57	4.91	30.00	2.84	2160.00	22.30	9.29	8.95	0.00	10800.00	0.00	0.00	0.00	52.30	2220.00	11.80
2003	m	1	3.10	6.53	42.90	4.37	9080.00	29.40	10.30	11.00	0.00	9030.00	0.00	0.00	0.00	72.30	9160.00	15.30
2003	m	2	1.94	3.85	44.80	4.49	8490.00	31.30	11.30	11.80	0.00	2070.00	0.00	0.00	0.00	76.10	8580.00	16.30
2003	m	3	1.41	2.67	42.40	3.84	5670.00	32.60	15.70	13.50	0.00	0.00	0.00	0.00	0.00	75.00	5760.00	17.30
2003	m	4	1.26	2.21	44.80	3.97	4110.00	34.50	17.40	14.70	0.00	1190.00	0.00	0.00	0.00	79.30	4200.00	18.70
2003	m	5	0.68	0.94	39.10	2.99	1060.00	31.30	22.90	16.30	0.00	0.00	0.00	0.00	0.00	70.40	1150.00	19.30
2003	m	6	0.38	0.52	32.40	2.14	77.60	25.10	24.20	16.70	0.00	0.00	0.00	0.00	0.00	57.50	159.00	18.80
2003	m	7	0.35	0.49	31.30	2.05	51.90	24.40	23.10	16.20	0.00	0.00	0.00	0.00	0.00	55.60	131.00	18.30
2003	m	8	0.33	0.46	25.20	1.39	65.00	16.70	19.40	16.40	0.00	0.00	0.00	0.00	0.00	41.90	126.00	17.70
2003	m	9	0.32	0.47	30.10	1.98	46.30	24.30	22.80	15.30	0.00	713.00	0.00	0.00	0.00	54.40	123.00	17.30
2003	m	10	0.33	0.44	49.70	4.29	35.40	38.40	21.80	16.90	0.00	1910.00	0.00	0.00	0.00	88.10	145.00	21.20
2003	m	11	1.10	0.99	60.10	5.57	429.00	43.40	20.30	17.60	0.00	815.00	0.00	0.00	0.00	104.00	552.00	23.20
2003	m	12	2.69	5.90	73.20	7.25	1520.00	51.40	19.10	19.20	0.00	5420.00	0.00	0.00	0.00	125.00	1670.00	26.40
2004	m	1	1.46	2.74	74.50	7.42	509.00	51.80	19.90	19.00	0.00	0.00	0.00	0.00	0.00	126.00	655.00	26.40
2004	m	2	1.43	2.78	73.30	7.14	961.00	52.30	20.70	19.90	0.00	1710.00	0.00	0.00	0.00	126.00	1110.00	27.00
2004	m	3	1.36	2.62	76.60	7.34	1310.00	55.30	23.00	21.30	0.00	0.00	0.00	0.00	0.00	132.00	1460.00	28.70
2004	m	4	0.82	1.53	71.20	6.44	385.00	53.60	26.30	22.10	0.00	0.00	0.00	0.00	0.00	125.00	536.00	28.50
2004	m	5	0.50	0.82	63.50	5.35	65.70	49.20	29.40	22.40	0.00	0.00	0.00	0.00	0.00	113.00	208.00	27.70
2004	m	6	0.44	0.67	42.50	2.56	63.10	31.00	35.10	24.00	0.00	0.00	0.00	0.00	0.00	73.60	172.00	26.50
2004	m	7	0.42	0.63	41.40	2.53	61.80	30.20	32.50	23.10	0.00	0.00	0.00	0.00	0.00	71.60	166.00	25.70
2004	m	8	0.40	0.59	42.10	2.64	54.00	32.10	33.80	22.50	0.00	0.00	0.00	0.00	0.00	74.20	162.00	25.10
2004	m	9	0.39	0.60	43.80	2.92	46.60	35.00	32.60	21.60	0.00	434.00	0.00	0.00	0.00	78.90	158.00	24.50
2004	m	10	0.36	0.53	53.30	4.30	34.40	43.50	27.10	20.20	0.00	1770.00	0.00	0.00	0.00	96.80	158.00	24.50
2004	m	11	0.41	0.60	69.80	6.59	25.80	51.90	21.90	19.60	0.00	954.00	0.00	0.00	0.00	122.00	169.00	26.20
2004	m	12	0.41	0.60	76.70	7.80	22.70	52.80	17.70	18.60	0.00	918.00	0.00	0.00	0.00	129.00	170.00	26.40

Appendix C

C-1: Average annual basin values estimated by SWAT

PRECIP = 546.0 MM
SNOW FALL = 0.00 MM
SNOW MELT = 0.00 MM
SUBLIMATION = 0.00 MM
SURFACE RUNOFF Q = 39.06 MM
LATERAL SOIL Q = 1.74 MM
TILE Q = 0.00 MM
GROUNDWATER (SHAL AQ) Q = 112.88 MM
REVAP (SHAL AQ => SOIL/PLANTS) = 55.81 MM
DEEP AQ RECHARGE = 10.63 MM
TOTAL AQ RECHARGE = 212.55 MM
TOTAL WATER YLD = 151.14 MM
PERCOLATION OUT OF SOIL = 215.30 MM
ET = 246.5 MM
PET = 1237.0MM
TRANSMISSION LOSSES = 2.54 MM
TOTAL SEDIMENT LOADING = 0.670 T/HA
POND BUDGET
EVAPORATION = 0.000 MM
SEEPAGE = 0.000 MM
RAINFALL ON POOL = 0.000 MM
INFLOW
WATER = 0.000 MM
SEDIMENT = 0.000 T/HA
OUTFLOW
WATER = 0.000 MM
SEDIMENT = 0.000 T/HA
RESERVOIR BUDGET
EVAPORATION = 0.042 MM
SEEPAGE = 0.000 MM
RAINFALL ON RESERVOIR = 0.020 MM
INFLOW
WATER = 75.943 MM
SEDIMENT = 0.025 T/HA
OUTFLOW
WATER = 75.886 MM
SEDIMENT = 0.003 T/HA
YIELD LOSS FROM PONDS
WATER = 0.000 MM
SEDIMENT = 0.000 T/HA
YIELD LOSS FROM RESERVOIRS
WATER = 0.057 MM
SEDIMENT = 0.022 T/HA

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NUTRIENTS

ORGANIC N = 1.381 (KG/HA)
ORGANIC P = 0.171 (KG/HA)
NO3 YIELD (SQ) = 0.205 (KG/HA)
NO3 YIELD (SSQ) = 0.101 (KG/HA)
SOL P YIELD = 0.003 (KG/HA)
NO3 LEACHED = 96.614 (KG/HA)

P LEACHED = 0.059 (KG/HA)
N UPTAKE = 10.933 (KG/HA)
P UPTAKE = 1.738 (KG/HA)
NO3 YIELD (GWQ) = 48.921 (KG/HA)
ACTIVE TO SOLUTION P FLOW = -0.317 (KG/HA)
ACTIVE TO STABLE P FLOW = 0.033 (KG/HA)
N FERTILIZER APPLIED = 93.107 (KG/HA)
P FERTILIZER APPLIED = 0.000 (KG/HA)
N FIXATION = 0.000 (KG/HA)
DENITRIFICATION = 0.000 (KG/HA)
HUMUS MIN ON ACTIVE ORG N = 2.416 (KG/HA)
ACTIVE TO STABLE ORG N = -0.388 (KG/HA)
HUMUS MIN ON ACTIVE ORG P = 0.414 (KG/HA)
MIN FROM FRESH ORG N = 5.609 (KG/HA)
MIN FROM FRESH ORG P = 0.994 (KG/HA)
NO3 IN RAINFALL = 1.044 (KG/HA)
INITIAL NO3 IN SOIL = 25.716 (KG/HA)
FINAL NO3 IN SOIL = 1.724 (KG/HA)
INITIAL ORG N IN SOIL = 3675.814 (KG/HA)
FINAL ORG N IN SOIL = 3669.145 (KG/HA)
INITIAL MIN P IN SOIL = 205.678 (KG/HA)
FINAL MIN P IN SOIL = 203.430 (KG/HA)
INITIAL ORG P IN SOIL = 450.287 (KG/HA)
FINAL ORG P IN SOIL = 449.654 (KG/HA)
NO3 IN FERT = 93.107 (KG/HA)
AMMONIA IN FERT = 0.000 (KG/HA)
ORG N IN FERT = 0.000 (KG/HA)
MINERAL P IN FERT = 0.000 (KG/HA)
ORG P IN FERT = 0.000 (KG/HA)
N REMOVED IN YIELD = 2.830 (KG/HA)
P REMOVED IN YIELD = 0.323 (KG/HA)
AMMONIA VOLATILIZATION = 0.000 (KG/HA)
AMMONIA NITRIFICATION = 0.000 (KG/HA)
NO3 EVAP-LAYER 2 TO 1 = 25.271

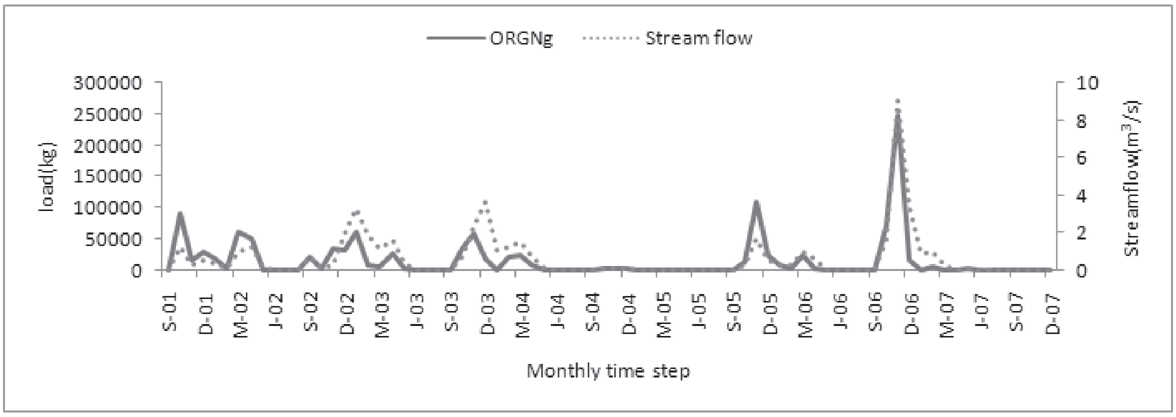
C-2:Landcover proportion in subbasin vs nutrient

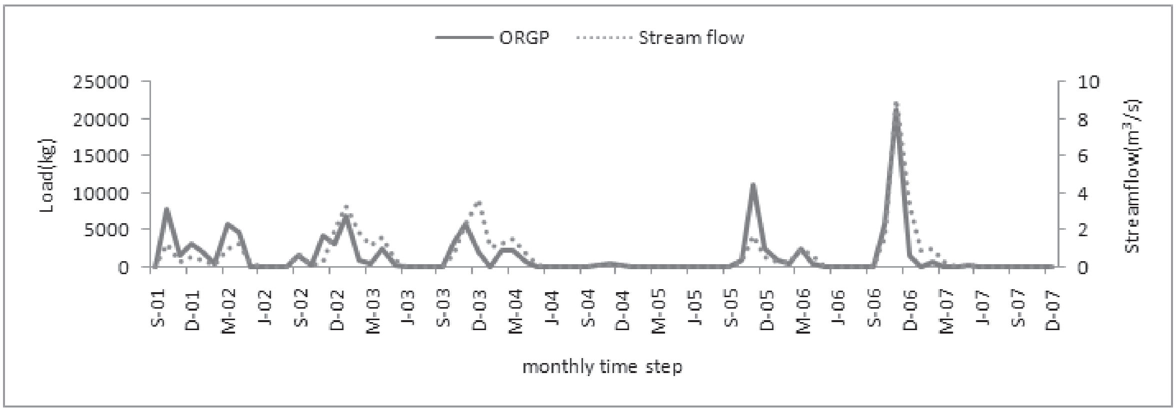
SUB	NIAL	OLIV	MAGA	PIRL	EUFO	URML	WATR	PAST	FRST	NO3	NSURQk g/ha	ORGNk g/ha	ORGP kg/ha
1	63.94	4.33	27.54	0.69		0.52	0.93	0.82		0.54	0.428	76.851	9.564
2	80.18	1.62	8.93	0.01		4.95	2.9	0.7		0.51	0.428	81.086	10.09
3	59.93						38.25	1.82		0.31	0.499	27.742	3.438
4	55.75	4.93	28.91		0.09		1.52	5.68		0.22	0.598	35.57	4.418
5	56.57	0.39	18.58		0.95	1.34	10.29	8.6		0.06	0.002	0.893	0.111
6	76.41	16.34		3.4	0.35		1.28	1.73		0.32	0.167	4.814	0.596
7	23				5.03		57.89	2.52		0	0	0	0
8	47.14		17.36				33.32			0.19	1.128	110.378	13.69
9	61.25		27.68	1.39	3.3		2.69			0.32	0.531	28.03	3.483
10	78.66	7.77	4.86	4.31			1.6	1.64		0.21	0.124	24.964	3.098
11	77.18		15.38		3.8					0.18	1.236	39.2	4.911
12	49.38	0.05	25.9	1.34	20.4		0.73	0.97	0.37	0.18	0.037	7.242	0.899
13	96.47		0.74							0.11	0.008	2.099	0.261

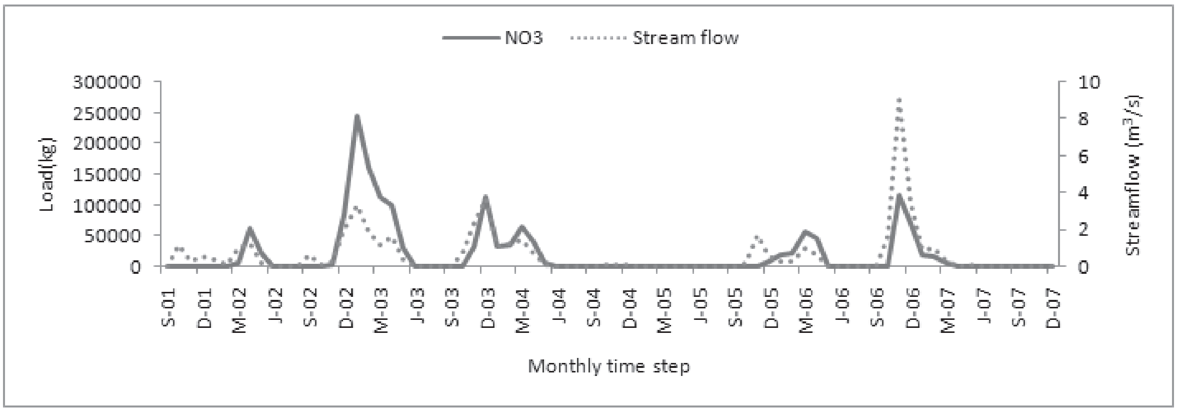
C-3: Monthly concentration.

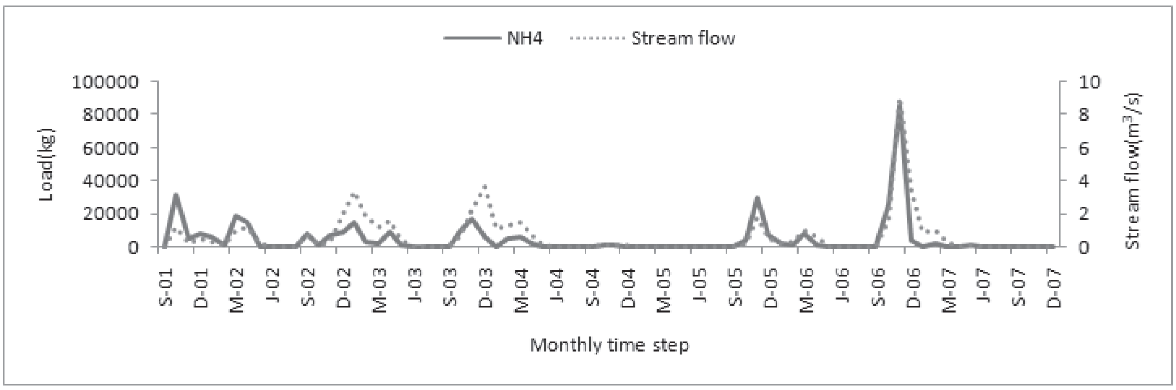
observed	timestep	Streamflo	NO3_mg/l	NH4_mg/l	NO2_mg/l	MINP_mg	ORGN_mg	ORGP_mg
-0.01	S-01	0.01	9.74	14.58	3.66	5.23	25.77	2.82
0.32	O-01	1.20	0.82	26.41	7.98	9.49	57.35	6.52
0.15	N-01	0.24	3.10	19.67	6.15	7.66	49.92	6.09
0.42	D-01	0.50	1.42	16.07	2.57	5.42	48.74	6.25
1.05	J-02	0.33	1.60	17.48	3.44	6.12	47.17	5.96
0.34	F-02	0.08	2.01	11.96	2.42	4.33	31.78	4.04
1.20	M-02	0.94	4.94	19.85	5.03	6.70	50.97	6.19
0.80	A-02	1.23	51.10	11.95	2.92	4.09	32.23	3.87
-0.09	M-02	0.18	116.14	1.60	0.49	0.59	3.69	0.45
-0.12	J-02	0.01	0.32	0.13	0.00	0.02	0.00	0.00
-0.06	J-02	0.01	0.00	0.00	0.00	0.00	0.00	0.00
-0.08	A-02	0.01	0.00	0.00	0.00	0.00	0.00	0.00
0.08	S-02	0.67	0.14	11.39	4.76	4.18	23.18	2.49
0.15	O-02	0.12	3.04	10.23	4.15	3.95	21.81	2.45
0.26	N-02	0.30	5.78	24.90	1.45	7.45	98.78	14.93
2.86	D-02	1.94	43.53	4.59	0.87	1.49	12.62	1.61
2.39	J-03	3.31	73.79	4.39	0.61	1.45	15.09	2.10
3.37	F-03	1.88	85.98	1.38	0.30	0.48	3.84	0.49
0.86	M-03	1.15	96.41	1.31	0.36	0.47	3.25	0.39
1.67	A-03	1.59	64.14	5.37	1.39	1.88	13.33	1.62
0.10	M-03	0.40	73.00	2.39	0.89	0.92	5.42	0.64
-0.17	J-03	0.02	3.63	0.36	0.09	0.11	0.45	0.05
-0.06	J-03	0.01	0.14	0.08	0.00	0.01	0.00	0.00
0.02	A-03	0.01	0.00	0.00	0.00	0.00	0.00	0.00
0.06	S-03	0.01	0.00	0.00	0.00	0.00	0.00	0.00
0.20	O-03	0.73	0.11	14.26	3.50	4.65	38.83	4.93
1.17	N-03	2.30	14.48	7.44	1.85	2.47	20.25	2.51
2.41	D-03	3.67	30.46	1.56	0.30	0.51	4.41	0.57
0.60	J-04	1.06	29.40	0.24	0.06	0.07	0.49	0.06
1.63	F-04	1.23	28.03	4.30	0.61	1.32	13.53	1.81
1.02	M-04	1.46	44.31	4.28	0.92	1.44	12.36	1.53
0.37	A-04	0.73	53.76	2.99	0.81	0.99	7.98	0.94
0.19	M-04	0.09	52.32	0.14	0.02	0.02	0.02	0.00
0.02	J-04	0.01	0.01	0.03	0.00	0.00	0.00	0.00
0.10	J-04	0.01	0.00	0.00	0.00	0.00	0.00	0.00
0.15	A-04	0.01	0.00	0.00	0.00	0.00	0.00	0.00
0.14	S-04	0.01	0.00	0.00	0.00	0.00	0.00	0.00
0.11	O-04	0.09	0.16	12.94	2.19	3.91	31.43	3.93
0.07	N-04	0.11	0.34	11.35	2.86	3.86	27.64	3.39
0.13	D-04	0.05	0.31	6.67	0.94	2.07	19.81	2.69
0.11	J-05	0.01	0.00	0.01	0.00	0.00	0.00	0.00
0.09	F-05	0.01	0.00	0.00	0.00	0.00	0.00	0.00
0.12	M-05	0.01	0.00	0.00	0.00	0.00	0.00	0.00
0.05	A-05	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.07	M-05	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.22	J-05	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-0.23	J-05	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.34	A-05	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.33	S-05	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.09	O-05	0.22	0.21	18.52	2.80	5.63	40.83	4.98
0.82	N-05	1.72	0.16	16.80	2.94	5.37	49.59	6.52
0.73	D-05	0.50	15.54	12.48	2.75	4.05	36.97	4.70
0.41	J-06	0.25	77.40	8.73	1.38	2.93	27.02	3.51
0.39	F-06	0.29	72.24	3.89	0.78	1.41	11.28	1.46
0.86	M-06	0.99	58.13	7.65	1.66	2.45	19.70	2.44
0.21	A-06	0.59	73.50	2.12	0.68	0.80	4.95	0.59
0.02	M-06	0.02	5.83	0.65	0.23	0.24	1.17	0.14
0.04	J-06	0.01	0.09	0.12	0.00	0.02	0.00	0.00
-0.02	J-06	0.01	0.01	0.01	0.00	0.00	0.00	0.00
-0.03	A-06	0.01	0.00	0.00	0.00	0.00	0.00	0.00
-0.02	S-06	0.01	2.08	5.32	2.23	2.08	10.88	1.21
1.60	O-06	1.57	0.10	16.71	4.15	5.30	33.48	3.69
9.49	N-06	9.02	12.70	9.44	2.28	3.06	20.96	2.37
2.48	D-06	3.39	20.56	1.30	0.22	0.41	3.58	0.45
0.47	J-07	0.90	20.80	0.16	0.04	0.04	0.27	0.04
1.02	F-07	1.01	17.49	1.88	0.52	0.70	4.74	0.58
0.27	M-07	0.30	20.68	0.77	0.21	0.28	1.70	0.21
0.27	A-07	0.03	3.96	6.43	2.10	2.32	13.93	1.61
0.07	M-07	0.13	5.37	5.82	2.40	2.28	13.10	1.51
-0.14	J-07	0.01	0.03	0.14	0.00	0.02	0.00	0.00
-0.23	J-07	0.01	0.01	0.02	0.00	0.00	0.00	0.00
-0.17	A-07	0.01	0.00	0.00	0.00	0.00	0.00	0.00
0.00	S-07	0.01	0.00	0.00	0.00	0.00	0.00	0.00
-0.10	O-07	0.01	0.01	0.08	0.00	0.01	0.00	0.00
0.00	N-07	0.01	0.00	0.00	0.00	0.00	0.00	0.00
0.09	D-07	0.01	0.00	0.00	0.00	0.00	0.00	0.00

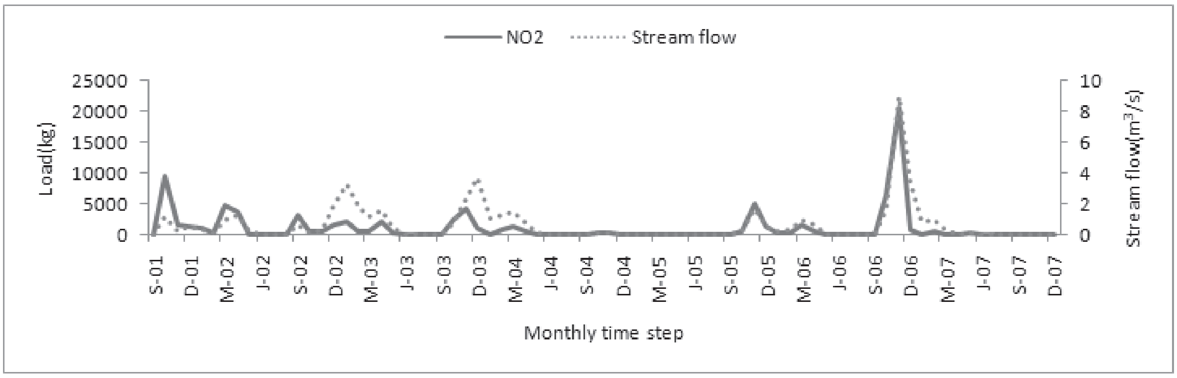
C-4: SWAT estimated nutrient loadings into the Roxo reservoir

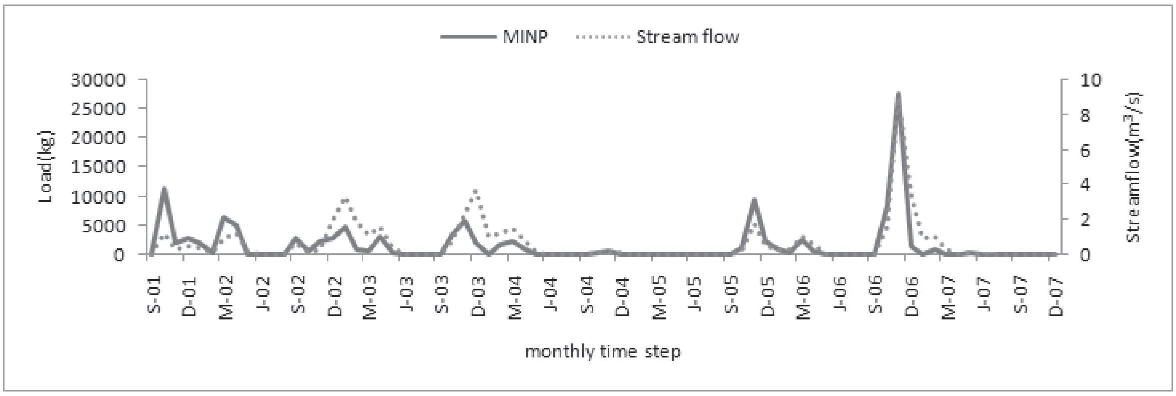









NO2
Stream flow
Load(kg)
Stream flow(m3/s)
25000
20000
15000
10000
5000
0
10
8
6
4
2
0
S-01
D-01
M-02
J-02
S-02
D-02
M-03
J-03
S-03
D-03
M-04
J-04
S-04
D-04
M-05
J-05
S-05
D-05
M-06
J-06
S-06
D-06
M-07
J-07
S-07
D-07
Monthly time step


MINP
Stream flow
Load(kg)
Streamflow(m3/s)
30000
25000
20000
15000
10000
5000
0
10
8
6
4
2
0
S-01
D-01
M-02
J-02
S-02
D-02
M-03
J-03
S-03
D-03
M-04
J-04
S-04
D-04
M-05
J-05
S-05
D-05
M-06
J-06
S-06
D-06
M-07
J-07
S-07
D-07
monthly time step