Stream flow and water quality modelling using the SWAT2005: A case study of the Roxo reservoir, Portugal

Demoz Kidane Negassi

March, 2010

Stream flow and water quality modelling using the SWAT2005: A case study of the Roxo reservoir, Portugal

By
Demoz Kidane Negassi

Thesis submitted to the University of Twente, Faculty of Geo-information Science and Earth Observation in partial fulfilment of the requirements for the degree of Master of Science in Geo-information Science and Earth Observation, Specialisation: (Environmental Hydrology and Water Management)

Thesis Assessment Board

Dr.ir.C.M.M. Mannaerts (Chairman)	WRS dept, ITC, Enschede
Dr.Ir.D.C.M.Augstijn (External examiner)	WEM dept, UT
Dr.Ir.Mhd S. Salama (First Supervisor)	WRS dept, ITC, Enschede
Ir.Gabriel Parodi (Second supervisor)	WRS dept, ITC, Enschede
M. Yevenes (Advisor)	WRS dept, ITC, Enschede

UNIVERSITY OF TWENTE, FACULTY OF GEO-INFORMATION SCIENCE AND EARTH OBSERVATION ENSCHEDE, THE NETHERLANDS

Disclaimer

Abstract

The European Water Framework Directive requires that all surface waters and groundwater must reach at least 'good' status by 2015. Thus, the directive requires the development of management strategies to restore rivers and lakes to "good" status within a specified timeframe. Thus this study was proposed to be an aid for the future decision making process concerning the improvement of water quality of Roxo reservoir; in order to achieve the goals set by the European water framework directive.

The overall objective of this study was to develop a reliable and well calibrated water flow and water quality for the Roxo Catchment Reservoir using soil and water assessment tool (SWAT) model. To achieve this purpose the following specific objectives were identified; in-situ measurements was carried out and added to available data to provide the modelling environment with calibration and validation data sets. Calibration, validation, error and sensitivity analysis of stream flow and water quality parameters was carried out.

Regarding the stream flow, performance of the model was statistical Nash-sucliffe prediction efficiency (ENS) value of 0.784 and 0.86, and the regression analysis (R^2) result 0.802 and 0.872 for calibration and validation period respectively. This confirms that the model was successfully simulating the inflow dynamics of the different streams into Roxo reservoir.

Chlorophyll a of Roxo reservoir over the 9 years (Sep. 2001-Oct.2009) simulated data was compared with observed data. The simulated chlorophyll a tends to show the trend of seasonal variation of the measured data. The regression line of simulated result was 0.17, (ENS) value of -1.4, RMSE result (101) and PBIAS (-9.22%) indicate the model tends to over estimating the simulated data. The result was not satisfactory in the calibration period as a result it was not validated. The most possible reason was the available water quality observation data; particularly chlorophyll a was incomplete (missing observed data) and inconsistence of the observed data. Monthly predicted and observed average total nitrogen (TN) of Roxo reservoir from Sep. 2001to Oct.2009 was compared. The performance of the model was statistical Nash-sucliffe prediction efficiency (ENS) value of -0.087 and -0.18, and the regression analysis (R^2) result 0.47 and 0.54 for calibration and validation period respectively, however the model show over estimating the simulated data; generally the result was satisfactory in the validation even better than calibration period. In similar way, the monthly predicted and observed average sediment of Roxo reservoir from Sep. 2001to Oct.2009 was compared. The performance of the model; the statistical Nash-sucliffe prediction efficiency (ENS) value of 0.45 and 0.04, regression analysis result (R^2) was 0.606 and 0.34 for calibration and validation period respectively. The validation period was not convincing as the calibration period, but it was satisfactory. The most possible reason was the available water quality observation data; was incomplete (missing observed data) and inconsistence of the observed data. Generally the SWAT model was successfully calibrated and validated for Roxo reservoir to estimate predicted monthly stream flow into the reservoir, sediment, chlorophyll a, and total nitrogen out of the reservoir from Sep.2001 to Oct 2009.

This study found that the SWAT model is a powerful tool used to make hydrological analysis of Roxo reservoir; particularly it works well with to quantify water flow dynamics. The model needs further improvement to simulate the water quality parameters in lakes and reservoirs to support for the decision making process

Acknowledgements

First and foremost I would like to express my sincere gratitude to the European Union for granting scholarship to pursue my study. I also need to thank all the Erasmus teams here in ITC, all the ITC staffs who participated in my visa application process; specially Dr.Mark Majid thank you very much for the effort you made; without your help it was impossible for me to participate in this programme. Furthermore I would like to thank the UNHCR office in Sudan, the Embassy of Netherlands in Sudan and IND office for taking my exceptional visa application process into consideration.

I would like to extend my sincere gratitude to Dr.Suhyb Salama and Dr.Chris Mannaerts for their supervision, critical and constructive comments. Also I would like to thank all the staffs of water resources department for transferring their scientific knowledge and skills which are very useful in my future professional career. I am especially grateful to Arno Lies shout for his thoughtful guidance and carrying from the beginning to the end.

I would like to thank my entire ARCSWAT user group members; SWAT developers Prof. Strinivasan, Nancy Sammmon of USDA deserve great appreciations for their help. I would like to thank also other SWAT developers and users whose names are not mentioned here.

I would like to express my appreciation to Eng. Elisabeal and Marea Jose (Agricultural University of Beja, Portugal) for permission to use their laboratory; also I would like to thank Eng Marta Fabiao, Jorge Maia and the entire staff of COTR, Beja, Portugal, for permission to use the weather data freely and for their willingness to give out all available data and information I needed.

I would also like to express my appreciation to people who are directly or indirectly have helped me with my study. My course mates Rishan Berhe, Amos Kabobah and Yin sun; my exceptional appreciation goes to Ali Ershadi, for his kindness and being nice to everyone what a wonderful personality!

I would like to express my humble appreciation to all my Eritrean friends Ermias Tsegay, Abraham Tesfay with his family, Mussie, Semehar, Eyerusalem, Yonas with his family, Ambassager and Zeray. I enjoyed all the times we spent together. I indebted in many ways to Zewdi Gebreab and Eyob Girmay for their kind help and encouragements, you are always in my heart.
I would like to thank my brother Minab Aregay and my sister Winta Aregay for their carrying and sweet love. Finally I would like to thank my lovely family Mebrat Abrham Abeba Abdela and all the Chak kingdom, God bless you all.

Table of contents

List of figures

List of tables

List of Appendices

1. Introduction

Water is a vital natural resource that sustains human populations and ecosystems. It can be fully characterised by three major components: hydrology, physico-chemistry, and biology (Chapman, 1996). All freshwater bodies are interconnected, from the atmosphere to the sea, via the hydrological cycle (Chapman, 1996). However the industrial and agricultural development has unbalanced this natural cycles. The hydrological problems related to artificial and natural changes in the quality of inland water bodies affect our life greatly; so it is important to know which nutrient elements affect the water body ecosystem.

1.1. Literature Review

Inland water bodies are important ecological and sociological zones. Many lakes and rivers are the main sources for drinking, agricultural and industrial usage (Collin and Quevauviller, 1998 , Faeth and Greenhalgh, 2002) According to (Chapman, 1996) water quality standard refers to the physical, chemical, or biological characteristics of water in relation to a specific use. Protection and maintenance of water quality is a primary objective for watershed resource managers. Increase of chlorophyll a, turbidity, total suspended solids (Chen, 2007)and nutrients in lakes are symptomatic of eutrophic conditions (Borah and Bera, 2004). Sediments also affect water quality and thus its suitability for drinking, irrigation and other activities. It serves as a carrier and storage agent for nitrogen, phosphors and organic compounds that can be indicators of pollution(Jayakrishnan et al., 2005). The traditional measurement of water quality requires in situ sampling, which is a costly and time-consuming process. Because of these limitations, it is impractical to cover the whole water body or obtain frequent repeat sampling at a site. This difficulty in achieving successive water quality sampling becomes a barrier to water quality monitoring and forecasting (Bukata, 2005). It would be advantageous to watershed managers to be able to detect, maintain and improve water quality conditions at multiple river and lake sites without being dependent on field measurements (Stefouli, 2007).Developing a model and application of remote sensing techniques has the potential to overcome these limitations by providing an alternative means of studying and monitoring water quality over a wide range of both temporal and spatial scales. Several studies have confirmed that modelling and remote sensing can meet the demand for the large sample sizes required for water quality studies conducted on the watershed scale. To achieve a good ecological and chemical status of the water environment the concentration of nitrogen and phosphorous should not be beyond acceptable range (Gitau, 2008). The amount of these chemicals can be determined using suitable model for water quantity and quality inventory of the water environment (Volk et al., 2008). The identification of the limiting nutrient plays a key role in the study of eutrophication processes, this allows focusing the management efforts on the most sensitive nutrient, to predict the algal group that could easily growth in the ecosystems (Xu, 2007).For better water quality assessment it is wise to choose an appropriate prediction techniques and methodologies such as low cost field measurements, continuous and automatic monitoring, use of biota and sediment for micro pollution monitoring, remote sensing, and geographic information systems (Brandmeyer, 2000, Chapman, 1996).

Stream flow and water quality modelling using the SWAT2005: A case study of the Roxo reservoir, Portugal

SWAT is a good model to develop time and cost efficient assessment for watershed/water resources management and decision making for sustainable domestic, agricultural, and industrial water supply as well as protection of the environment (Bärlund, 2007).An assessment made by the EU funded EUROHARP project in terms of applicability under different climatic, agricultural, geophysical and hydrological conditions in Europe classify SWAT as "suitable" or "very suitable" in almost all the conditions (Andersen et al., 2004).Because of this reason SWAT is one of the few contemporary methodologies currently used for quantifying diffuse pollution of nitrogen and phosphorus by European research institutes to inform policy makers at national and international levels SWAT has been widely validated across the United States and in other regions of the world for a variety of applications, including hydrologic, pollutant loss, and climate change studies (Zhang, 2005).Further more the model has good potential for application in hydrologic or water quality studies in countries around the world even watersheds with little monitoring data can be modelled (Saleh and Du, 2004, Jayakrishnan et al., 2005), it uses readily available inputs and computationally efficient simulation of very large basins and enables us to study long term impacts. In addition it has an easy to use interface for model set up which has been integrated into Arc GIS as extensions (Neitsch et al., 2005).To investigate the hydrodynamic and water quality of a reservoir it is important to know the critical physical, biological and chemical activities in the reservoir. A water reservoir is self-cleaning biological, chemical and physical processes that restore the initial properties and quality of water. Descriptions of self-cleaning processes of water bodies commonly use mathematical or physical models in which basic system variables are the concentration of dissolved oxygen and the biological consumption of oxygen (Zakirov and Frolova, 2004). A reservoir ecosystem represents interactions among living organisms, variable water conditions, and (Bärlund, 2007)channel properties. Water volume and channel shape are abiotic components of a reservoir ecosystem, and their changes influence the biotic components of the ecosystem. The change of water level changes the volume of the photosynthetic aeration zone and the area of shallow water where biological activity is highest, thereby influencing the processes of reservoir self-cleaning. The concentration of organic substances, in terms of BOD, and deficiency of oxygen are influenced by the shape of the reservoir channel and the water level (Zakirov and Frolova, 2004). Reservoirs can be considered as special lacustrine environments in which physical, chemical and biological features are strongly conditioned by surface-level fluctuations caused by periodic, usually seasonal, natural filling, and from almost perennial, anthropogenic dewatering (Boavida, 1999, Chapra, 1982, Chapra et al., 2008). Therefore, reservoirs are considered never to be in steady state since these water movements are often dynamic(Jayakrishnan et al., 2005). Water quality is a function of a variety of hydrodynamic and biogeochemical processes. Thus, nutrient dynamics modelling is limited if the hydrodynamics is not well known. For this reason, a model which incorporate both hydrodynamic and nutrient dynamic is recommended. Especially if the source of non point pollution is from a watershed; thus a model such as SWAT is helpful to predict catchments behaviour to flow and nutrient dynamics as a decision making tool and scenario analysis(Jayakrishnan et al., 2005). Management of nutrient loads into reservoirs requires knowledge of nutrient transport and delivery from the watershed stream system. 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. These nutrients are eventually delivered to downstream water bodies such as lakes and reservoirs (Migliaccio et al., 2007).

1.2. Problem statement

High nutrient loads from upstream watershed activities such as urban runoff, intensive agriculture and higher productivity, has resulted in a significant increase in fertilizer use, particularly organic nitrogen (Perka et al., 2008). Because of these lakes and reservoirs like Roxo reservoir are a concern; the Roxo reservoir is of high economic importance to the area as it provides water for irrigation and supplies for domestic use to Beja and Adjusted towns. Researches done by (Gurung, 2007, Chisha, 2005) reveal that the reservoir is affected by eutrophication, mainly caused by the extensive agricultural activities and waste water discharges in the catchment. According to their recommendation due to the complexity nature of the problem it needs further study. In addition the European Water Framework Directive requires that all surface waters and groundwater must reach at least 'good' status by 2015. Thus, the directive requires the development of management strategies to restore rivers and lakes to "good" status within a specified timeframe. Thus this study could be an aid for the future decision making process concerning the improvement of water quality of Roxo reservoir; in order to achieve the goals set by the European water framework directive.

1.3. Motivation of the research

Most of the previous researches were mainly focusing on- the streams of the Roxo catchment. Although the Roxo reservoir is considered to be the main source of domestic and irrigation water supply in Beja and Aljustral areas, it received minor attention towards the management of its water quality. In light of this problem it was proposed to conduct a research, mainly focusing on the Roxo reservoir. The objective of this research was to calibrate and validate the hydrodynamic-water quality model for the Roxo reservoir using, spatially semi distributed and high temporal resolution; SWAT model. This research was implemented using water flow and water quality model because it have proven to be very useful in predicting catchments behaviour to flow and nutrient dynamics as a decision making tool and scenario analysis.

1.4. Objective

The overall objective of this study was to develop a reliable and well calibrated water flow and water quality for the Roxo Catchment Reservoir using SWAT.
To achieve this purpose the following specific objectives were identified
Measurements: in-situ measurements was carried out and added to available data in the Roxo reservoir to provide the modelling environment with calibration and validation data sets

- Model set up: defining the boundary conditions of the model; simulating the inflow of the different streams into the reservoir
- Calibration: tuning the hydrodynamic and water quality model with respect to measured data
- Hydrodynamic and water quality model validation: comparing the results of the model to point measurements and quantifying the errors
- Error analysis of the of the model output

1.5. Research Questions

What are the main parameters which govern the water flow and water quality dynamics of the Roxo reservoir?
Is it possible to predict reasonably flow, sediment total nitrogen and chlorophyll a in Roxo reservoir?
How accurate the SWAT model can represent the water flow dynamics and water quality of the Roxo reservoir?
What are the spatial variability of (Nitrate) $NO3^{-1}$, (Phosphate) PO4-2, TSS (total suspended sediment), turbidity, SD (secchi disc depth), TN (total nitrogen), and TP (total phosphorus) in Roxo reservoir? These questions proposed to be answered based on the field visit assessment of the Roxo reservoir.

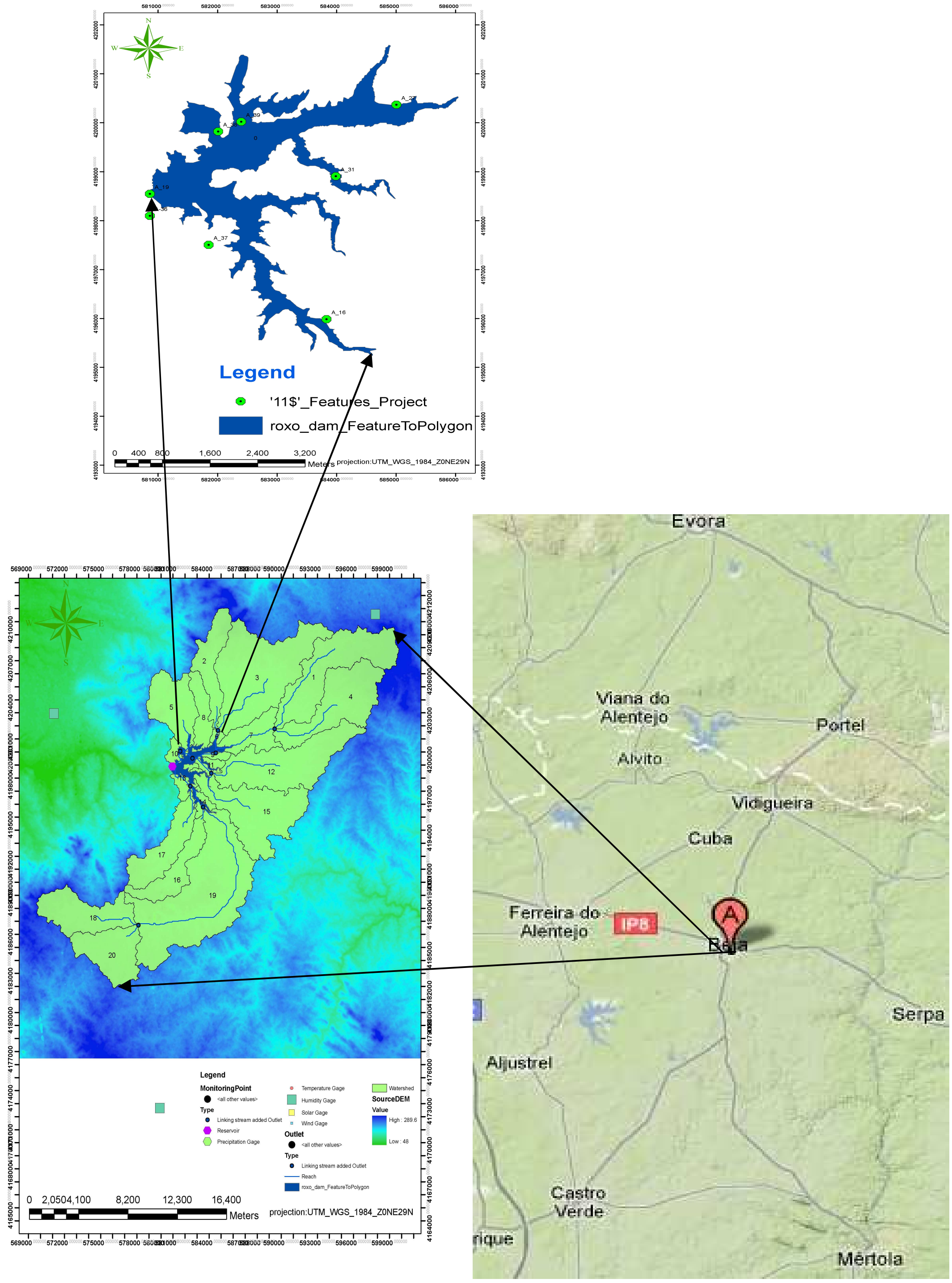
1.6. Hypotheses

SWAT can predict reasonably, the actual water flow and water quality dynamics of the Roxo reservoir and similar water bodies.

2. Methods and Material

2.1. Description of the study area

The Roxo reservoir catchment is located in the Beja District of Alentejo Province in southern Portugal. It has a population of about 165,000 with an area of 10,224km2. Beja municipality is the capital city of Beja district and there are about 35,000 population lives in 18 communes of an area of 1140 km2 (Vithanage, 2009).The Roxo watershed located 37o46’44.40’’N to 38o02’3939’’N in latitude and from 7o5.1’47.93’’W to 8o12’24.67’’W in longitude and has an area of 353km2; Roxo catchment mainly drained by the river “Ribere do Roxo” http://www.abroxo.pt/. The province is well known for its wheat production, it produces approximately 75% of the countries total production of wheat. Roxo reservoir is a man made and it covers a surface area of 13.8 km2 when it is full capacity. The reservoir provides water to down stream agricultural activities(Cau and Paniconi, 2007), water supply for drinking purpose to the Baja city and some industrial purposes as well. The Roxo catchment has a topography ranging from nearly flat (48 m above mean sea level) to gently slope (289 m above mean sea level), with an average elevation of 169.6m above mean sea level. Maximum temperature during the summer goes up to 40ºC and minimum temperature in the winter drops down to 5 ºC. Minimum and maximum temperatures occur during the month of December and July/August respectively. The average annual rainfall in the study area is estimated to be about 550 mm (Gökmen, 2006).According to the land use generated by SWAT the catchment is comprised of rain-fed (71.3%) agricultural land close grown (17.53%),residential –medium low density (0.84%), olives(1.92%),pasture(1.31%)and water(2.07%) irrigated. (4.94%) of the area, along the stream course, is covered by mixed forest largely covered by eucalyptus tree.



http://www.travel-in-portugal.com/Beja/

Figure 2-1: Geographical location of the study area

Figure 2-2: Roxo reservoir land covers (http://www.abroxo.pt/

Figure 2-3: Roxo reservoir dam-main source of historical water quality parameters

2.2. Research Methodology

2.2.1. Work plan

The study work plan was divided into three main phases and at each stage a number of tasks were conducted detailed description is provided in subsequent section the entire research phase and key activities are shown in Figure 2.6.

2.2.2. Pre field work

During this phase, the past research that had been done relevant to the research area Roxo catchment reservoir was reviewed. Effort was made to identify data sets essential for the modelling process and further analysis. In addition at this phase downloading and processing of remote sensing data was done. Research methodology was planned and field data collection was carried out to get the most important information required and to collect efficiently during the field work.

2.2.3. Field work

Field work was carried out from Sept.5th 2009 to Sept.20th 2009 in Beja, Portugal. The detail description of field data collection is provided in section 3.

2.2.4. Post field work

In this phase, data analysis and integration, preparation of a number of inputs data and building up the SWAT model, sensitivity analysis, model calibration, validation, result analysis and conclusion was done. The data integration involved were water sample analysis, preparation of data inputs, image processing, handling errors and integration of past data essential for the modelling work.

2.2.5. Field Data collection

The data collected from the field was used to fill the gap that was not available from previous work. Moreover the information gained was used for reasoning out some of the physical process in the catchments area during stetting/defining the boundary conditions of the model. The main purpose of the field visit was to acquaint with study area; to collect important information that would be integrated with the model; and to make over all assessment of the reservoir. The data collection process, results and discussion is presented in section 3.

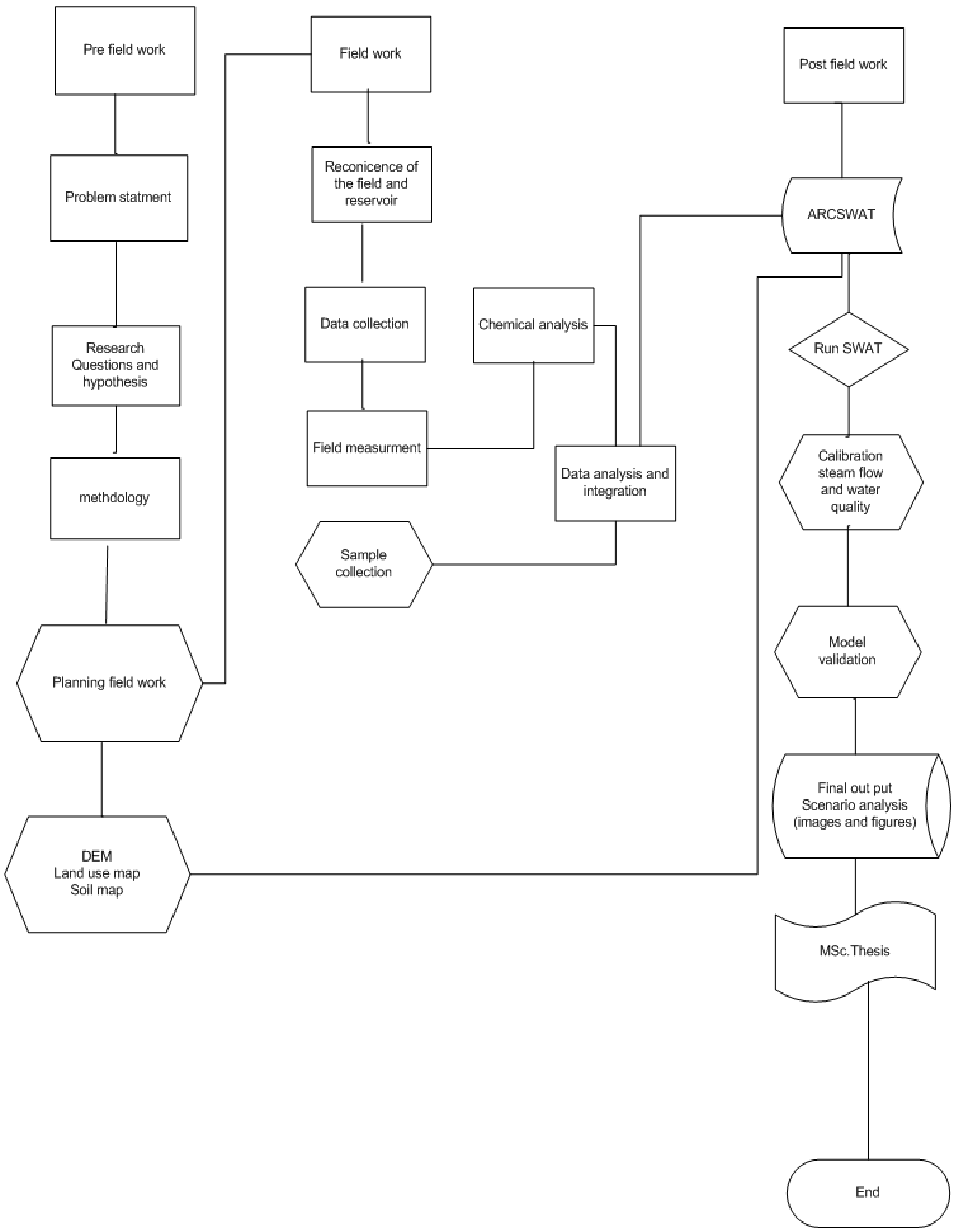


Figure 2-4: Schematic representation of the work plan of the research methodology

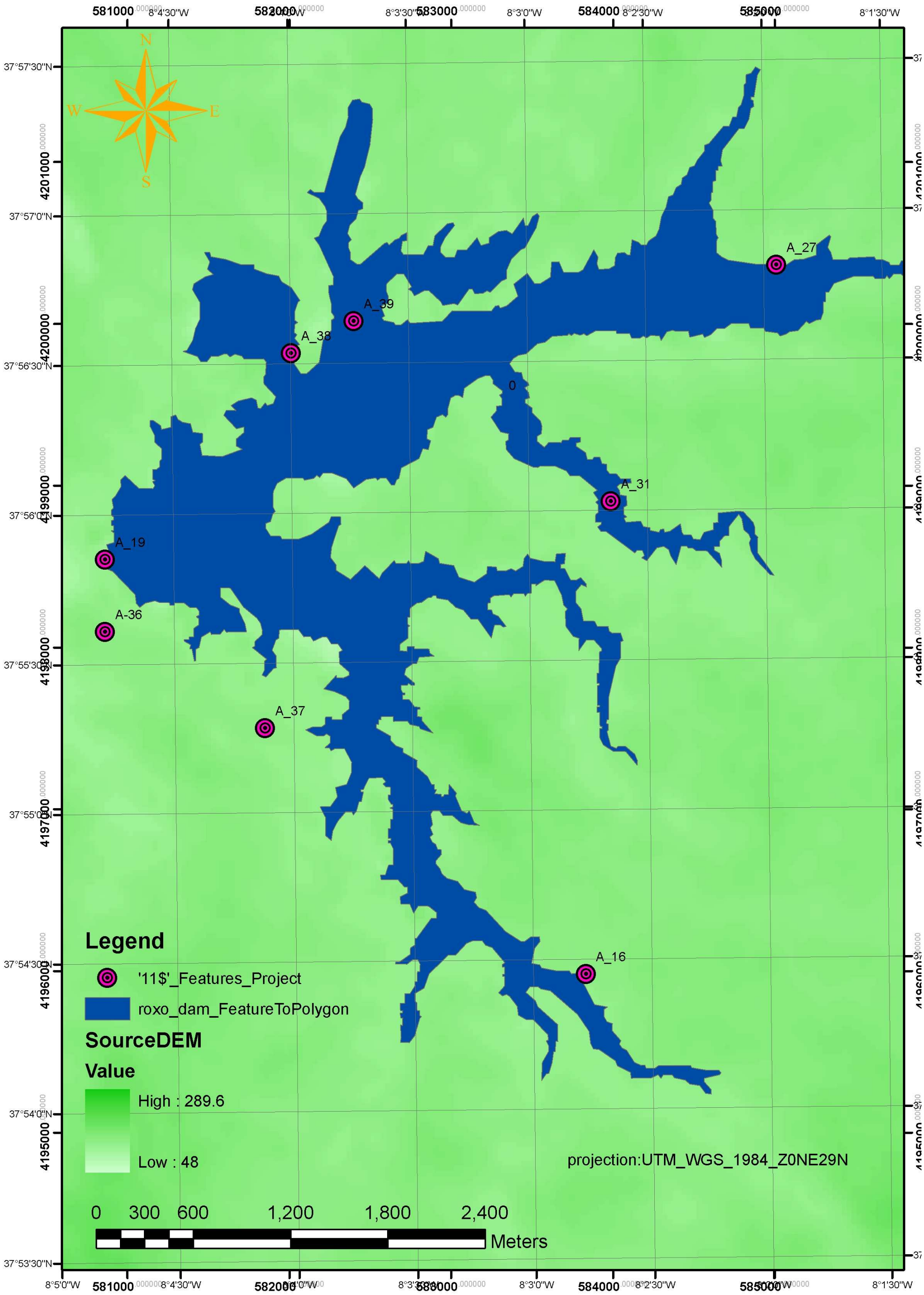


Figure 2-5: Selected points for field assessment of Roxo reservoir

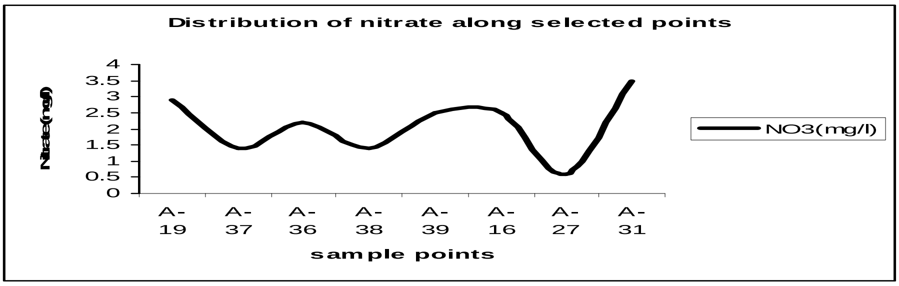
3. Field assessment of Roxo reservoir

3.1. Water quality data collection from Beja

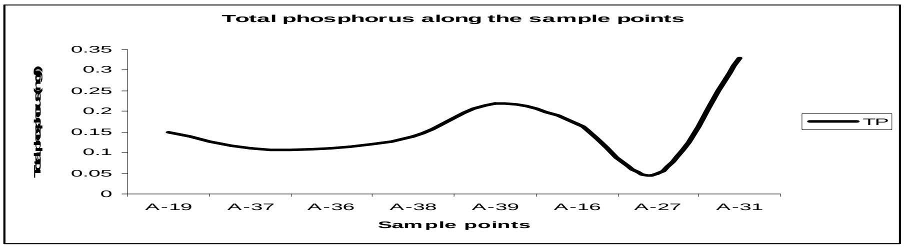
The sample collection was carried out 15th Sep. 2009 to 19th Sep.2009; based on the water quality standard and procedures defined by ITC (Dost, 2006) and (Australian Government) manual. Water quality data was one of the objectives of the study therefore; water samples were collected to supplement the historical water quality data for the modelling process. During the field work collection the following activities representative sample stations: [A_19, A_37, A_36, A_38, A_39, A_16, A_27, A_31] were selected see figure 2-3 for the exact location of these points. The selection criteria of these points were based on accessibility and representation of other parts of the reservoir in the surrounding vicinity. From each station water sample was collected for the test of hydro chemicals analysis: on site measurements of PH, alkalinity, electric conductivity, dissolved oxygen; chloride and temperature were carried out. For the test of total suspended sediment a litter of water was collected from each sample point and analyzed in the University of Agricultural and Environmental laboratory (Beja, Portugal); moreover Several Secchi disk depth measurement was done at each sample points of the reservoir and the average was recorded as representative value of that specific area. Furthermore samples were also taken for the test of turbidity; it was carried out in the University of Agricultural and Environmental (Beja) laboratory. The hydro-chemical sample was analysed in ITC laboratory. The SWAT model considers the whole reservoir as one system; as a result the flow and nutrients dynamics is quantified as an average so it was not possible to study the spatial variability of nutrients along the reservoir. Therefore it was attempted to check the spatial variability of nutrients based on the results obtained from the observation during the field visit.

3.2. Laboratory analysis

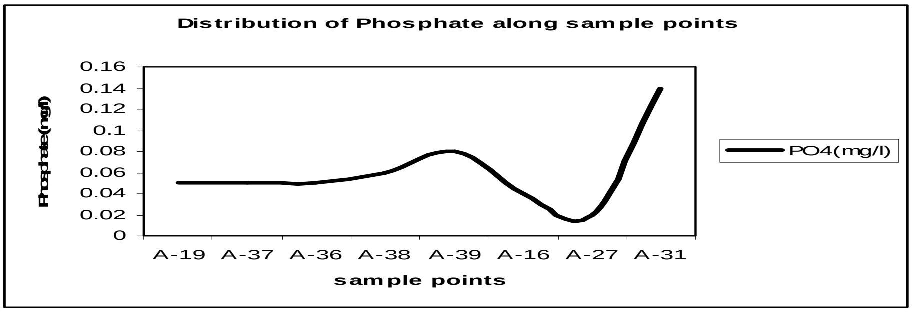
The anions-cat ions analysis of the collected water samples were carried out at the ITC laboratory. The cations (Al+3, Ca+2,Fe+2,K+1,Mg+2,Mn+2,Na+1), were tested with an instrument called ICP-AES. While the anions were tested with HACH DR/2001 spectrometer and a brief description of the anion analysis explained as follow:PO4-3 test N tube [0-5 mg/l PO4-3], program 535, phos3, SO4-2 test Sulphate [0-70 mg/l range], program 680, sulta Ver 4, NO3-1-N test: Nitrate, HR [0-30 mg/l NO3-1-N], program 355,Nitra Ver-5,NH3-N,test N tube [0-50 mg/l],program 343,Salicylate regent powder,Cynurate regent, results of field and laboratory results are depicted on appendix H. For Total suspended solids (TSS) measurement a litre of water sample was taken from each 8 sample points; filtered with What man Nylon membrane 0.45µm and the retained solid on the filter was dried in oven at 105ºC for two hours and finally measured with very accurate beam balance. The result is shown in appendix H. For turbidity measurement 20ml of sample was used and the laboratory test was done using nephlometry (lighting scattering by suspended particles).The light scattered by the sample was recorded on the nephlometry.The result is tabulated in appendix H. To check the spatial variability of nutrients along the selected sample points the following water quality parameters were considered: nitrate, total nitrogen, phosphate, total phosphorus, total suspended sediment, and the relationship between turbidity, secchi disc depth shown in figure 3-1 and figure 3-2 and discussed in section 3.3.



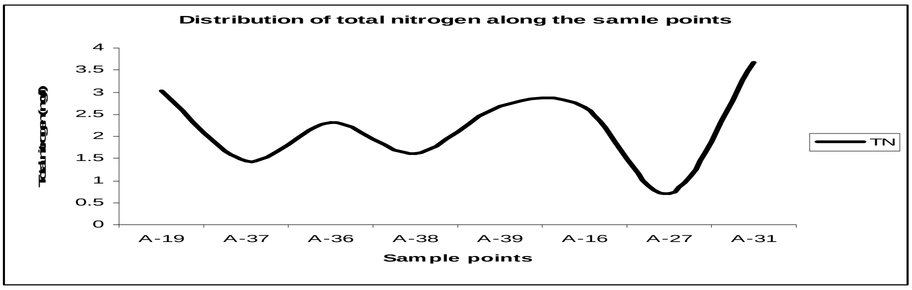
a. Distribution of nitrate ion along the sample points



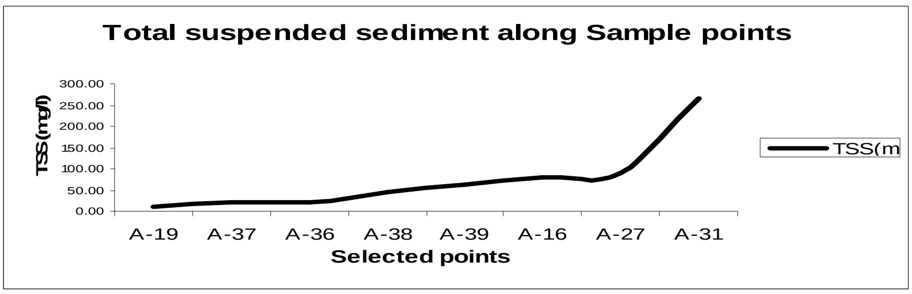
b. Distribution of total phosphorus along the sample points



c. Distribution of phosphate ion along the sample points

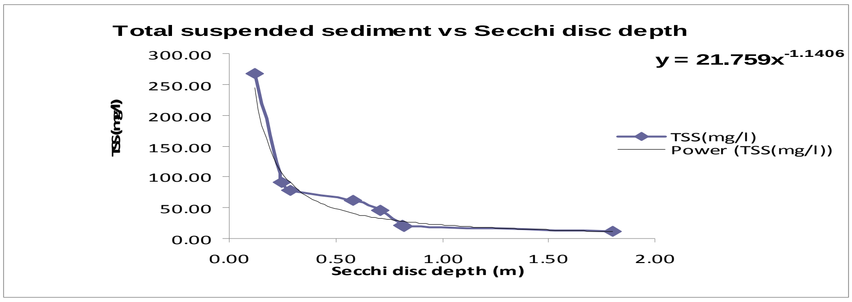


d. Distribution of total nitrogen along the sample points

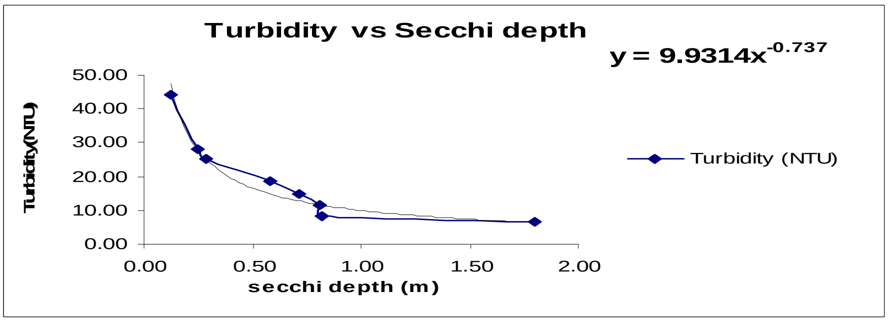


e. Distribution of total suspended sediment along the sample points

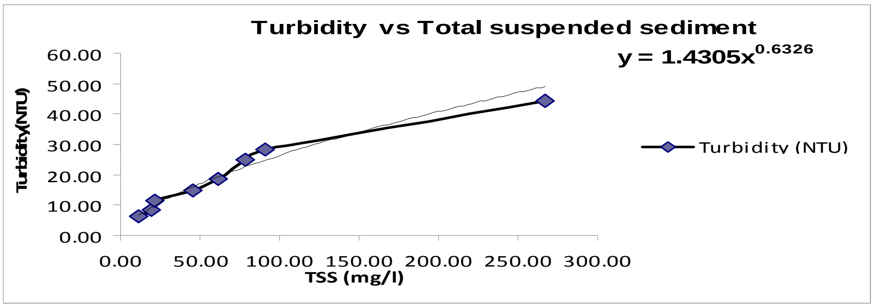
Figure 3-1: The variation of nitrate (a), total phosphorus (b), phosphate (c), total nitrogen (d), and total suspended sediment (e) along the selected sample points



f. Total suspended sediment against secchi disc depth



g. Turbidity against secchi depth



h. Turbidity versus total suspended sediment

Figure 3-2: The relationship between total suspended sediment and secchi disc depth (f), turbidity and secchi disc depth (g), and (h) turbidity and total suspended sediment

3.3. Discussion

The spatial variation of nitrate, total nitrogen, phosphate, total phosphorus, and total suspended sediment, Turbidity, secchi disc depth are shown in figure 3-1 and figure 3-2. As it shown in the figure 3-1 the variability of nutrients along the reservoir generally increases from point A_19 to A_31 except sample point 27.It was observed that Sample points A_31 showed high nutrients, total suspended sediment, and turbidity. Moreover the relationship between total suspended sediment, Turbidity and secchi disc depth were analysed and a regression equation was established; the result is shown in figure 3-2 and appendix H. The averaged value of TP (0.16mg/l), NO3 (2.1mg/l), DO (7.71) of Roxo reservoir was compared with standard value recommended by WFD according to this standard Roxo reservoir is in a good condition. Furthermore eeach sample had been checked for reliability and accuracy of the results. As it is shown in appendices (E, F, G and H), Piper and stiff graphical presentation of chemical analysis is presented. Detail sample summary report of points A_16 and A_19 and A_27, indices including electro neutrality anion-cation balance, TDS, Mg ,and others also shown in appendix E. Generally the result indicated that water quality check up indices were satisfactory. But it worth to mention that the concentration of chloride ion is higher in all sample stations this result clearly observed from Stiff graph of appendix G. It could be due to other undetermined chemical ions related to chloride compounds.

4. Overview of the SWAT mode

SWAT is the acronym for Soil and Water Assessment Tool, developed by the USDA Agricultural Research Service (Ahlgren et al., 2004). SWAT is developed to predict the impact of land management practices on water, sediment and agricultural chemical yields in large complex watersheds with varying soils, land use and management conditions over long Periods of time (Neitsch.S.L et al., 2005, Neitsch et al., 2005). It is a physically based model; rather than incorporating regression equations to describe the relationship between input and output variables. SWAT requires specific information about weather, soil properties, topography, vegetation and land management Practices in the watershed. The processes associated with water movement and nutrient Cycling is directly modelled by SWAT using this input data(Neitsch et al., 2005). SWAT primary objective is to predict the effect of management decisions on water, sediment, nutrient and pesticide yields with reasonable accuracy on large, ungauged river basins. The model simulates hydrology including surface runoff, return flow, percolation, evapotranspiration, transmission losses, pond &reservoir storage, crop growth & irrigation, groundwater flow, reach routing and nutrient nitrogen and phosphorus & pesticides loading. The model functions on a daily time step and can account for differences in soils, land use, crops, topography, weather, etc. Basins of several thousand square kilometres can be studied and the model uses measured data & point sources (Neitsch et al., 2005).

According to (Neitsch et al., 2005) the major SWAT modelling steps are:

1. Prepare Climate data for model input
2. Prepare hydrology and water quality data for calibration
3. Prepare GIS data base Soils, land use, DEM, Slope, etc
4. Set up model/Initial runs
5. Incorporate other processes hydrology storage, withdrawals, etc
6. Calibrate Hydrology
7. Calibrate Sediment
8. Calibrate Phosphorus
9. Calibrate Bacteria
10. Calibrate Nitrogen
11. Calibrate Pesticides
12. Run Scenarios

4.1. Hydrology of the SWAT model

To simulate hydrological processes, SWAT is using a water balance. The simulation of the water balance, as well as the pollutant balances can be separated into two major items. The first item is the land phase of the hydrologic cycle which controls the amount of water, sediment, nutrient and pesticide loadings to the main channel of each sub basin. The second item is the routing phase of the hydrologic cycle. This phase can be defined as the movement of the water, sediment, etc. through the channel network of the watershed to the outlet of the watershed (Neitsch et al., 2005).

4.2. Land phase of the hydrological cycle

The land phase of the hydrological cycle is based upon the water balance (Neitsch et al., 2005) Processes simulated include precipitation, infiltration, surface runoff, evapotranspiration, lateral flow and percolation. SWAT divides groundwater into two aquifer systems, a shallow unconfined aquifer which contributes to the return flow and a deep and confined aquifer that, besides pumping is disconnected from the system (Neitsch et al., 2005).

$$\left[SW_t = SW_o + \sum_{i}^{t} (R_i - Q_{sur,i} - E_{a,i} - W_{seep,i} - Q_{gw,i}) \right] \quad \text{Equation 1}$$

SW_t =the soil water content at time t (mmH2O)

SW_O = the initial water content on day i (mm H2O)

t = time (days)

R_i = the amount of precipitation on day i (mm)

$Q_{surf,i}$ = the amount of surface runoff on day i (mm)

$E_{a,i}$ =the amount of evapotranspiration on day i (mm)

$W_{seep,i}$ =the amount of percolation on day i (mm)

$Q_{gw,i}$ =the amount of base flow on day i (mm)

4.3. Routing phase of the hydrological cycle

Once SWAT determines the loadings of water, sediments, nutrients and pesticides to the main channel, the loadings are routed through the stream network of the watershed (Neitsch et al., 2005). As water flows downstream, a part may be lost due to evaporation and transmission through the bed of the channel. Another potential loss of water is through utilization for agricultural. Flow may be supplemented by rainfall directly on the channel and addition of water from point source discharges. Flow is routed through the channel using the variable storage routing method or the Muskingum method (Neitsch et al., 2005). In the variable storage routing method, storage routing is based on the continuity equation for a given reach segment see Equation 2

$$V_{in} - V_{out} = \Delta V_{stored} \quad \text{Equation 2}$$

V_{in} =the volume of inflow during the time step (m^3 H2O)

V_{out} =the volume of outflow during the time step (m^3 H2O)

ΔV_{stored} =the change in volume of storage during the time step (m^3 H2O)

With a storage coefficient, dependent on the length of the time step and travel time, the outgoing volume at the end of the time step can be calculated with the average incoming volume during the time step and the storage at the beginning of the time step (Neitsch et al., 2005). The Muskingum method is a hydrologic routing method that is based upon a variable discharge-storage relationship. This method models the storage volume of flooding in a river channel by a combination of wedge and prism storage. When a flood wave advances into a reach segment, inflow exceeds outflow, producing a wedge of storage. During the recession, outflow exceeds inflow in the reach segment, resulting in a negative wedge. In addition to wedge storage, there is a prism of storage that is formed by a volume of constant cross-section along the length of the prismatic channel. The volume of the prim storage can be expressed as K*qout. Where K is the ratio of storage to discharge and the dimension of time and qout is discharge. In a similar manner, the volume of wedge storage can be expressed as K*X*(qin – qout). Where X is a weighting factor that controls the relative importance of inflow and outflow determining the storage in the reach, qout is the discharge rate and qin is the inflow rate (Neitsch et al., 2005).

4.4. Water quality modeling with SWAT

As in the part about the hydrology, the water quality module of SWAT can be separated into two major items. The catchment or land phase model calculates the mass flows as they travel along the land phase to the receiving water body. A pollutant, originating from the land phases are generally called non-point or diffuse sources. The in-stream water quality model is responsible for the in-stream transformations and the determination of the water quality status of the stream as well as for the integration of all contributors of the catchment or land phase model to the river and the contribution of the point sources (Neitsch et al., 2005).

4.4.1. Land phase water quality modelling

The catchment or land phase model simulates the runoff of water and entrained pollutants from the land area to the receiving water body. Rainfall-runoff processes are the main Processes of the land phase water quality model. Carbonaceous Biochemical Oxygen Demand (CBOD) Carbonaceous biochemical oxygen demand (CBOD) defines the amount of oxygen required to decompose the organic matter transported in surface runoff. Thus, oxygen demand for oxidation of ammonia does not contribute to CBOD. The SWAT loading function for CBOD is based on the relationship given by Mueller (Marsili and Giusti, 2007).

$$CBOD_{surq} = \frac{2.7 orgC_{surq}}{Q_{surf} * Area_{HRU}} \qquad \text{Equation 3}$$

$$orgC_{surq} = 10 orgC_{surf} * sed * E_{csed} \qquad \text{Equation 4}$$

$$E_{csed} = 0.78 \left(conc_{sed,surq} \right)^{-0.2486} \qquad \text{Equation 5}$$

$$conc_{sed,surq} = \left[\frac{sed}{10 Area_{HRU} * Q_{usrf}} \right] \qquad \text{Equation 6}$$

$CBOD_{surq}$ =the concentration of CBOD in the surface runoff (mg O2/L)

$orgC_{surq}$ =the organic carbon in the surface runoff (kg Org-C)

Q_{surf} =the surface runoff (mm H2O)

$AreaHRU$ =the area of the HRU (km^2)

$orgC_{surf}$ =the percentage organic carbon in the top 10 mm of the soil (%)

sed =the sediment loading from the HRU (metric tons)

$EC.sed$ =carbon enrichment ratio, the ratio of the concentration of organic carbon transported with the sediment to the concentration in the soil surface layer

$conc_{sed,surq}$ =the concentration of sediment in the surface

Now we will explain the water quality parameters as they are modelled in

4.4.2. Dissolved oxygen (DO)

To determine the dissolved oxygen concentration of the surface runoff (see EQ6),the oxygen uptake by the oxygen demanding substances in runoff is subtracted from the saturated oxygen concentration (Marsili and Giusti, 2007, Neitsch et al., 2005).

Rainfall is assumed to be saturated with oxygen.

$$DO_{surf} = DO_{sat} - K1 * CBOD_{surq} * \frac{t_{ov}}{24}$$ Equation 7

DO_{surf} =the dissolved oxygen concentration in the surface runoff (mg O2/L)

DO_{sat} =the saturation concentration of DO at local temperature and pressure, calculated using the APHA (Neitsch et al., 2005) equation (mg O2/ L)

K_1 =the CBOD deoxygenating rate (default value of 1.047 day-1)

$CBOD_{surq}$ =the concentration of CBOD in the surface runoff (mg O2/L)

t_{ov} =time of concentration for overland flow (h)

In SWAT no ammonia nitrogen originates from overland flow. Ammonia binds tightly to soil particles and does not leach into groundwater unless it is first oxidized to nitrate which is highly soluble and does not bind to the soil.

4.4.3. Nutrients

The transport of nutrients in the watershed depends on the transformations of the compounds undergo in the soil environment. SWAT models the nutrient cycles for Nitrogen and phosphorus. The transformations and movement of nitrogen and phosphorus within a HRU are simulated based on their natural cycles. In large sub-basins with a retention time larger than one day, only a portion of the surface runoff and lateral flow will reach the main channel on the day it is generated. SWAT incorporates a storage function to lag a portion of the surface runoff, lateral flow and the nutrients they transport (Neitsch et al., 2005).

4.4.3.1. Nitrogen

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. Nitrogen may be added to the soil by fertilizer, manure or residue application, fixation by bacteria and rain. Nitrogen is removed from the soil by plant uptake, leaching, volatilization, denitrification and erosion (Neitsch et al., 2005). SWAT monitors 5 different pools of nitrogen in the soil. Two pools are inorganic forms of nitrogen: NH4 and NO3.The other 3 pools are organic nitrogen forms. Fresh organic nitrogen is associated with crop residue and microbial biomass while the active and stable organic N pools are associated with the soil humus. The organic nitrogen associated with the soil humus is partitioned into two pools to account for the variation in availability of humic substances to mineralization (Neitsch et al., 2005). Plant use of nitrogen is estimated using the supply and demand approach where the daily plant nitrogen demands are calculated as the difference between the actual concentration of the element in the plant and the optimal concentration. In addition to plant use, nitrate and organic N may be removed from the soil via the water fluxes. Amounts of nitrate 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 loading function, estimating daily organic N runoff loss based on the concentration of organic N in the top soil layer, the sediment yield and the enrichment ratio. The enrichment ratio is the concentration of organic N in the sediment divided by that in the soil (Griensven, 2007).

4.4.3.2. Phosphorus

The three major forms of phosphorus in mineral soils are organic phosphorus associated with humus, insoluble forms of mineral phosphorus and plant-available phosphorus in soil solution. In SWAT, phosphorus can be added to the soil by fertilizer, manure or residue application. Phosphorus which is present in the soil through sorption processes is removed from the soil by plant uptake and erosion. Unlike nitrogen which is highly mobile, phosphorus solubility is limited in most environments. SWAT monitors 6 different pools of phosphorus in the soil. Three pools are inorganic forms of phosphorus while the other three pools are organic forms of phosphorus. Fresh organic P is associated with crop residue and microbial biomass while the active and stable organic P pools are associated with the soil humus. The organic phosphorus associated with humus is partitioned into two pools to account for the variation in availability of humic substances to mineralization. Soil inorganic P is divided into solution, active and stable pools. The solution pool is in rapid equilibrium with the active pool. The active pool is in slow equilibrium with the stable pool (Neitsch et al., 2005).Plant use of phosphorus is estimated using the supply and demand approach where the daily plant phosphorus demands are calculated as the difference between the actual concentration of the element in the plant and the optimal concentration. In addition to plant use, soluble phosphorus and organic phosphorus may be removed from the soil via the water fluxes. Because phosphorus is not very soluble, the loss of phosphorus dissolved in surface water is based on the concept of partitioning phosphorus into a solution and a sediment phase. The amount of soluble phosphorus removed in runoff is predicted using concentrations in the top 10 mm of the soil, the runoff volume and the partitioning factor. Sediment transport of phosphorus is simulated with a loading function similar to organic N transport (Abaspour and SRinivas, 2005, Griensven, 2007).In-stream water quality modelling water quality algorithms of the SWAT model incorporate constituent interactions and relationships used in the QUAL2E model (Neitsch et al., 2005).The QUAL2E model includes the major interactions of the nutrient cycles, algal production, benthic and carbonaceous oxygen demand, atmospheric reaeration and their effect on the dissolved oxygen balance. In addition, the model includes a heat balance for the computation of temperature and mass balances for conservative minerals; coli form bacteria and non-conservative constituents. Chlorophyll a is modelled as the indicator of algae biomass in QUAL2E.The nitrogen cycle is composed of four compartments: organic nitrogen, ammonia nitrogen, nitrite nitrogen and nitrate nitrogen. The phosphorus cycle is simpler, having only two compartments. Carbonaceous biochemical oxygen demand is modelled as a first order degradation process in QUAL2E, which also takes into account removal by settling. The major source of dissolved oxygen, in addition to that supplied from algal photosynthesis, is atmospheric reaeration (Neitsch et al., 2005, Chapra et al., 2008).

4.5. WATER ROUTING IN THE RESERVOIR

The water balance for reservoirs includes inflow, outflow, rainfall on the surface, evaporation, seepage from the reservoir bottom and diversions.

4.5.1. Reservoir outflow

The model offers three options for estimating outflow from the reservoir. The first choice allows the user to provide input measured outflow. The second option, designed from small, uncontrolled reservoirs, requires the users to specify a water release rate. When the reservoir volume exceeds the principle storage, the extra water is released at the specified rate. Volume exceeding the emergency spillway is released within one day. The third option, designed for larger, managed reservoirs, the user has to specify monthly target volume of the reservoir. In this project the third option was applied.

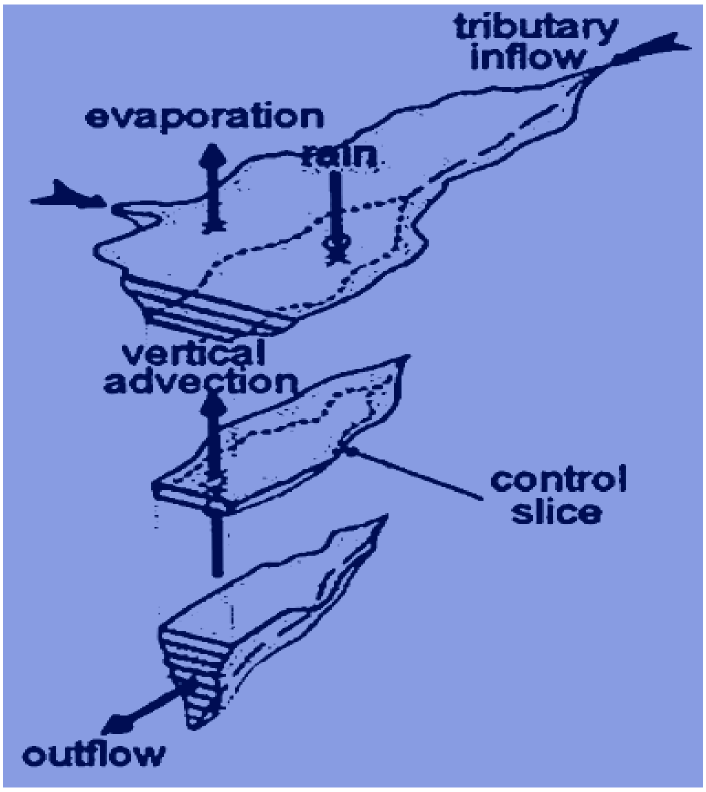


Figure 4-1: Schematic model structure showing horizontal layers and the major internal and external forcing functions used in the model, such as inflow, outflow, evaporation (USACE, 1977)

The most important equations concerning the water balance and water qualities of the reservoir are summarized below. More detailed information on the reservoir water balance and water quality algorithms of the SWAT model can be found in (Neitsch et al., 2005).

4.5.2. The water balance for a reservoir

Equation 8

$$S_A = \beta_{sa} * V^{\exp sa}$$

Where SA is the surface area of the water body (ha), β_{sa} is a coefficient V is the volume of water in the reservoir (m3 H2O) and $\exp sa$ This two known points are surface area and volume information provided for the principal and emergency spillways.

$$\exp sa = \frac{\log_{10}(S_{aem}) - \log_{10}(S_{apr})}{\log_{10}(V_{aem}) - \log_{10}(V_{pr})}$$

$$\beta_{sa} = S_{aem} \left(\left(\frac{S_{aem}}{V_{em}} \right) \right)^{\exp sa}$$

Where S_{aem} is the surface are of the reservoir when filled to the emergency spillway (ha), S_{apr}r is surface area of the reservoir when filled to the principal spillway (ha), V_{em} is the volume of water held in the reservoir when filled to the emergency level of the spillway (m3 H2O), and V_{pr} is the volume of water held in the reservoir when filled to the principal spillway (m3 H2O).

$$V_{pcp} = 10 * R_{day} * SA$$

Where V_{prcp} is the volume of water added to the reservoir by precipitation during the day (m3 H2O). R_{day} is the amount of precipitation falling on a given day (mm H2O), and S_A is the surface area of the reservoir (ha).

$$V_{evap} = 10 \eta E_O S_A$$

Where V_{seep} the volume of water is lost from the reservoir by seepage (m3 H2O), k_{sat} is the effective saturated hydraulic conductivity of the reservoir bottom (mm/hr), and S_A is the surface area of the water body (ha).

$V_{flownout}$ =86400* q_{out}

Where $V_{flownout}$ t is the volume of water flowing out of the reservoir during the day (m3H2O), and q_{out} is the outflow rate (m3/s).

In this project $V_{flownout}$ measured monthly outflow of target release (IRESCO=2) was chosen as the method to calculate reservoir.

4.6. Sedimentation

Sedimentation is a matter of concern to watershed and natural resource managers. Two of the main reasons reservoirs are built are water supply and flood control. Erosion upstream of a reservoir deposits sediment in the bottom of the reservoir which lowers the reservoirs water holding capacity and as a result the sedimentation process in the reservoir affects the living condition of the beneficiaries.

4.6.1. Sediment routing in the reservoir

Sediment inflow may originate from transport through the upstream reaches or from surface runoff within the sub-basin. The concentration of sediment in the reservoir is estimated using a continuity equation based on volume and concentration of inflow, outflow, and water retained in the reservoir. Settling of sediment in the reservoir is governed by an equilibrium sediment concentration and the median sediment particle size. The amount of sediment in the reservoir outflow is the product of the volume of water flowing out of the reservoir and the suspended sediment concentration in the reservoir at the time of release (Neitsch et al., 2005). SWAT incorporates a mass balance model to simulate the transport of sediment into and out of a reservoir. When calculating sediment movement through the reservoir, SWAT assumes the system is completely mixed. In a completely mixed system, as sediment enters the reservoir it is instantaneously distributed throughout the volume (Neitsch et al., 2005).

4.6.1.1. Mass balance of sediment

The mass balance equation for sediment in a reservoir is:

$$sed_{wb} = sed_{wb,i} + sed_{flowin} - sed_{stl} - sed_{flowout} \qquad \text{Equation 9}$$

Where sed_{wb} is the amount of sediment in the reservoir at the end of the day (metric tons), $sed_{wb,i}$ is the amount of sediment in the reservoir at the beginning of the day (metric tons), sed_{flowin} is the amount of sediment added to the reservoir with inflow (metric tons), sed_{stl} is the amount of sediment removed from the reservoir by settling (metric tons), $sed_{flowout}$ is the amount of sediment transported out of the reservoir with outflow (metric tons).

4.6.1.2. Settling of sediment in the reservoir

The amount of suspended solid settling that occurs in the reservoir on a given day is calculated as a function of concentration. The initial suspended solid concentration is:

$$conc_{sed,i} = \frac{(sed_{wb,i} + sed_{flowin})}{(V_{stored} + V_{flowin})}$$ Equation 10

Where $conc_{sed,i}$ is the initial concentration of suspended solids in the water (ton/m3), $sed_{wb,i}$ is the amount of sediment at the beginning of the day in the reservoir (metric ton), sed_{flowin} is the amount of sediment added to the reservoir with inflow (metric tons) ,V_{stored} is the volume of water stored in the reservoir or channel at the beginning of the day (m3H2O),and V_{flowin} is the amount of volume of water entering into the reservoir on a given day (m3H2O).

Settling only occurs when the sediment concentration in the reservoir exceeds the equilibrium sediment concentration specified by the user; $conc_{sed,eq}$.The concentration of sediment in the reservoir at the end of the day is calculated:

$$conc_{sed,f} = (conc_{sed,i} - conc_{sed,eq}) \exp(k_s * t * d50) + conc_{sed,eq}$$ Equation 11

if $conc_{sed,f} > conc_{sed,eq}$

$conc_{sed,f}$ if $conc_{sed,i} \leq conc_{sed,eq}$ Equation 12

Where k_s is the decay constant (1/day),t is the length of the time step (1 day) and $d50$ is the median particle size of the inflow sediment (µm).Assuming99% of the 1µm size particles settle out of solution within 25 days, k_s is equal to 0.184.

The median particle size of the inflow sediment in the reservoir is calculated:

$$d_{50} = \exp\left(\alpha . \frac{mc}{100} + \Omega \frac{msilt}{100} + \Theta \frac{ms}{100}\right)$$ Equation 13

Where m_c is the % of clay in the surface soil layer in the sub-basin, $msilt$ silt is the % of silt in the surface soil layer in the sub-basin m_s is the % of sand in the surface of soil layer in the sub-basin. α, Ω, Θ are constants for clay, silt and sand soil layer in the sub-basin respectively.

Because reservoirs are located on the main channel network and receive sediment from the entire area of the upstream, defaulting the sand, silt, and clay fractions to those of a single sub-basin or HRU in the upstream area is not appropriate. Instead the user is allowed to set the median particle size diameter to a representative value for reservoirs. The amount of sediment settling out of solution on a given day is calculated:

$$sed_{stl} = (conc_{sed,i} - conc_{sed,f}) * V$$ Equation 14

Where sed_{stl} is the amount of sediment removed from the water by settling (metric tons), and V is the volume of water in the reservoir (m3H2O)

Sediment outflow

The amount of sediment transported out of the reservoir on a given day is calculated as a function of the final concentration. The initial suspended solid concentration:

$$sed\ flowout = concsed, f \cdot$$ Equation 15

Where:

$V\ flowout$ is the volume of outflow from the reservoir (m^3H_2O)

4.6.1.3. Nutrients in reservoirs

SWAT incorporates a simple empirical model to predict the trophic status of lakes or water bodies. For studies that require detailed modelling of lake water quality, SWAT has been linked to water quality model Qual2E (Neitsch et al., 2005). When calculating nutrient transformations in a lake or reservoirs, SWAT assumes the system is completely mixed system, as nutrients enter the reservoir they are distributed instantaneously throughout the volume of the reservoir. The assumption of completely mixed system ignores lake stratification and intensification of phytoplankton in the upper layer of the reservoir.

The initial amount of nitrogen and phosphorus in the reservoir on a given day is calculated by summing the mass of nutrient entering the reservoir on the day with the mass of nutrient already present in the reservoir.

$$M\text{int}ial = M stored + M\ flowin$$ Equation 16

Where $M\text{int}ial$ is the initial mass of nutrient in the reservoir for the given day (kg), $M stored$ is the mass of nutrient in the water body at the end of previous day (kg), and $M\ flowin$ is the mass of nutrient added to the reservoir on the given day (kg).

The initial volume of water in the reservoir of water in the reservoir is calculated:

$$Vinitial = Vstored + V\ flowin$$ Equation 17

Where $Vinitial$ is the initial volume of water in the reservoir for a given day (m3H2O), $Vstored$ is the volume of water in the reservoir at the end of the previous day (m3H2O), and $V\ flowin$ is the volume of water entering the water body on the given day (m3H2O). The initial concentration simulated in the reservoir is limited to the removal of nutrients by settling. Transformations such as NO3 $\Leftrightarrow$ NO2 $\Leftrightarrow$ NH4 between nutrient pools are ignored. Settling losses in the reservoir can be expressed as a flux of mass across the surface area of sediment-water interface (Malmaeus, 2004, Chapra, 1982).

The mass of nutrient lost via settling is calculated:

$$M_{settling} = V \cdot C \cdot A_s \cdot dt \quad \text{Equation 18}$$

Where $M_{settling}$ is the mass of nutrient lost via settling on a day (kg) ,V is the apparent settling velocity (m/day), A_s is the area of the sediment –water interface (m2), C is the initial concentration of nutrient in the water (kg/m3 H2O), and dt is the length of time step (1 day).The settling velocity is named "apparent" because it represents the net effect of the different process that deliver nutrients to the reservoir's sediments. The reservoir is assumed to have a uniform depth of water and the area of the sediment-water is equivalent to the surface area of the reservoir. The apparent settling velocity is most commonly reported in (m/year) the SWAT model also require V in (m/year) as an input. For natural lakes, measured phosphorus settling velocities most frequently fall in the range of 5 to 20 m/year, but values less than 1 m/year to over 200m/year have been reported (Malmaeus, 2004, Chapra, 1982). (Rydin and Welch, 1999) noted that the range in apparent settling velocity values for man-made reservoirs tend to be significantly greater than for natural lakes. Several studies indicate there is significant variation of$V$. (Panuska and Robertson, 1999) reported phosphorus apparent settling velocities ranging from -1 to 125 m/year with an average value of 12.7 m/year. A negative settling rate indicates that the reservoir sediments are a source of N or P; while a positive settling rate indicates that the reservoir sediments are a sink (sediments are accumulated and stored for an indefinite period) for N or P. A number of inflow and the reservoir properties affect the apparent settling velocity; factors of particular importance include the form of phosphorus in the inflow (dissolved or particulate) and the settling velocity of the particulate fraction. In the lake, the mean depth, potential for sediment resuspension and phosphorus release from the sediment will affect the apparent velocity (Panuska and Robertson, 1999). Lakes with high internal phosphorus release tend to posse's lower phosphorus retention and lower phosphorus apparent settling velocities than lakes with low internal phosphorus release (Panuska and Robertson, 1999, Hejzlar et al., 2006). Recommended apparent settling velocity values for phosphorus (Panuska and Robertson, 1999).

The SWAT model allows the users to define two settling rates for each nutrient and the time of the year during which each settling rate is used. A variation in settling rates is allowed so that the impact of temperature and other seasonal factors may be accounted for in the modelling of nutrient settling. To use only one settling rate for the entire year, both variables for the nutrient may be required to set to the same value. Setting all variables to zero will cause the model to ignore settling of nutrients in the reservoir. After nutrient losses in the reservoir are determined, the final concentration of nutrients in the reservoir is calculated by dividing the final mass of nutrients by initial volume of water. The concentration of nutrients in outflow from the reservoir is equivalent to the final concentration of nutrients in the reservoir on that day.

4.6.1.4. Total balance

Assuming that the volume of the reservoir remains constant over time, the inflow, settling and outflow can be combined into the following mass balance equation for a well-mixed lake.

$$V \quad = W(t) - Q.c - v.c.\ A_s \qquad \text{Equation 19}$$

Where V is the volume of the system ($m^3 H_2O$),c is the concentration of nutrients in the system (kg/m^3 H_2O), $\frac{\partial c}{\partial t}$ change of concentration with respect to time, here ∂t is the length of the time step(1 day), $W(t)$ is the amount of nutrient entering the reservoir during the day (kg/day),Q is the rate of water exiting the reservoir ($m^3 H_2O$/day), v is the apparent settling velocity (m/day),and A_s is the area of the sediment-water interface (m^2).

4.7. Water temperature in a reservoir

Reservoirs respond much more slowly to thermal loading than rivers and streams because of their large volume. Although surface waters may respond quickly to meteorological conditions, the bulk of the reservoir volume changes much more slowly days, weeks, or months. Thus, reservoir temperature model can be applied over daily, weekly, or longer times steps and have quite different data requirements than rivers. Water temperature is required to model reservoir biological and water quality process. SWAT uses an equation developed by (Mohseni and Stefan, 1999) to calculate average daily water temperature for a well mixed reservoir.

$$T_{water} = 5.0 + 0.75\overline{T}_{av} \qquad \text{Equation 20}$$

T_{water} : is the water temperature for the day (0C), and

$\overline{T}_{av}$: is the average air temperature on the day (ºC)

Due to thermal inertia of the water, the response of water temperature to a change in air temperature is dampened and delayed. When water and air temperature for stream or a river is, the peaks in the water temperature usually lag 3-7 hours behind the peaks in air temperature. As the depth of the reservoir increases, the lag time can increase beyond this typical interval (Neitsch et al., 2005). For very large rivers or reservoirs, the lag time extend up to a week. The above equation assumes that the lag time between air and water temperature is less than 1 day. In addition to air temperature, water temperature is affected by solar radiation, relative humidity, wind speed, water depth, ground water inflow, artificial heat inputs, and thermal conductivity of the sediments and the presence of other water storage structures along the reservoir (Neitsch et al., 2005). SWAT assumes that the impact of these other variables on water temperature is not significant.

4.8. Reservoir pesticides

The reservoir/lake pesticide balance model is also taken from (Reckhow and Chapra, 1999, Håkanson and Bryhn, 2008) and assume a well mixed conditions. The system is portioned into a well mixed surface water layer underlain by a well mixed sediment layer. The pesticide is partitioned into dissolved and particulate phases both in the water and sediment layers. The major processes simulated by the model are loading, outflow, transformation, volatization, settling, diffusion, resuspension and burial.

4.9. Pathogens in the reservoir

SWAT calculates loading of pathogens and indicator bacteria for pathogens from land areas and watershed. However in the reservoir bacteria die-off is the only process modelled (Chapra et al., 2008). Advection transport of heat in the direction of flow, e.g., water flow, wind driven currents, tidal currents heat exchange across the air-water interface: provides for fluxes of heat at the water surface buoyancy induced convection: horizontal density and/or vertical gradients induce buoyant convection. Dispersion depth heat flux at the air- and bed- water interface is distributed through the depth of the water column. The top-most layer in a thermally stratified lake (Epilimnion), occurring above the deeper hypolimnion (Chapra et al., 2008) has higher PH & dissolved oxygen, turbulently mixed as a result of wind exposure and free to exchange dissolved (O2&Co2) with the atmosphere.

4.10. The limiting nutrient in the reservoir

For water quality model SWAT incorporates ,the most widely used model for river/reservoir quality modelling called the QUAL2E (Neitsch et al., 2005, Chapra et al., 2008). In the reservoir the model assumes: complete mixing ignores lake stratification and intensification of phytoplankton in the epilimmon, P is limiting nutrient this valid when non point source dominates. Total P is indicator of trophic status of the reservoir, implies the relationship b/n total P and biomass and the P mass balance equation includes the concentration in the lake, inflow, outflow, & overall loss rate (Ernst and Owens, 2009, Håkanson and Bryhn, 2008, Reckhow and Chapra, 1999, Chapra et al., 2008).

4.11. Eutrophication

Under favourable conditions of light and temperature, excess amounts of nutrients in water can increase the growth of algae and other plants. The result of this growth is an increase in the rate of eutrophication, which is a natural ecological process of change from a nutrient –poor to nutrient-rich environment. Eutrophication can be defined as the process by which a water body becomes enriched in dissolved nutrients that simulate the growth of aquatic plant life, usually resulting in the depletion of dissolved oxygen (Onderka, 2007). Nutrient enrichment of moving water and lakes is a result of soil weathering and erosion process. Excessive plant growth caused by accelerated eutrophication can lead to stagnation of the water. The stagnation process is caused by an increase in a biological oxygen demand created by decaying plant remains. The result of the BOD is a tendency towards anaerobic conditions and the inability of the water body to support fish and other aerobic organisms. Nitrogen, carbon and phosphorus are essential to the growth of aquatic life. Due to the difficulty of controlling the exchange of nitrogen and carbon between the atmosphere and water and fixation of atmospheric nitrogen by some blue- green algae, attempts to mitigate eutrophication have focused on phosphorus inputs. In fresh-water systems, phosphorus is often the limiting element. Therefore by controlling the amount of phosphorus loading, accelerated rate of eutrophication can be reduced (Chapra, 1982). In systems where phosphorus is the primary, controlling limiting nutrient of water body eutroiphication, the amount of phosphorus present in the water body can be used to estimate the amount of eutrophication present in the water body.

4.11.1. Chlorophyll a and phosphorus correlation

Phosphorus and chlorophyll a correlations: A number of empirically derived equations have been developed to calculate chlorophyll a level as a function of total phosphorus concentration. SWAT uses an equation developed by (Seo and Canale, 1996) to calculate the chlorophyll a concentration in the reservoir /lake.

$$Chla = 0.551 \; P^{0.76}$$ Equation 21

Where Chlorophyll a concentration ($\frac{\mu g}{L}$) and P is the total phosphorus concentration ($\frac{\mu g}{L}$)

The equation has been modified to include a user defined coefficient:

$$Chla = d50 \; 0.551 \; P^{0.76}$$ Equation 22

The user defined coefficient, $chla_{co}$ is included to allow the user to adjust the predicted Chlorophyll a concentration for limitations of nutrients other than phosphorus. For most water bodies the original equation is satisfactory.

4.11.2. Chlorophyll a and secchi-disk depth correlation

Secchi-disc depth is a measure of the trophic status of water; it quantifies the clarity of the water. It can be calculated from chlorophyll a using the equation (Malmaeus, 2004, Seo and Canale, 1996, Chapra, 1982).

$$SD = 6.35 * Chla^{-0.473}$$ Equation 23

Where SD is the secchi-disc depth (m) and Chlorophyll a concentration ($\frac{\mu g}{L}$) for incorporation in SWAT the above equation can be modified to define the empirical value of the given water body.

$$SD = SDCO * 6.35 * Chla^{-0.473}$$ Equation 24

SD_{CO} = Empirical coefficient defined by the user. But for most water bodies the original equation is adequate. Some, general correlations between secchi disk depth and public perception of water quality have been made the following table shows relationships between secchi disk depth and public perception of water quality.

5. The preprocessing phase of the model

5.1. Model input

The SWAT interface requires weather data input and three spatial dataset; a digital elevation model land use and soil layers. Data on flow and water chemical data were used for calibration purpose. Thus the model setup involved the implementation of: Watershed Configuration; HRU Analysis; Weather Data Definition and Selection of management practices.

5.1.1. Watershed configuration and sub-watershed discretization

Watershed configurations define the spatial relationship of objects within the watershed. SWAT uses the sub watershed discretization method to divide a watershed (Neitsch et al., 2004). 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. In this study the Watershed Delineation tool was used in SWAT model setup to discretize the sub-watersheds using Arc-SWAT interface. 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 (Mishra, 2001).The watershed delineation interface consists of DEM setup; stream definition; outlet and inlet definition; watershed outlets selection and definition; and calculation of sub-basin parameters. The procedures are: DEM importation; definition of area of interest; 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 defining the position of reservoir.

5.1.2. DEM setup

A 30 X 30 m resolution DEM was downloaded from ASTER, with a geographic coordinate system WGS84 datum then it was converted to ESRI grid format as required by the delineation tool. Then the image was re-projected into UTM – Zone 29 N – WGS 1984. The DEM was resampled to 15m with a finer resolution which was finally downloaded into DEM set up interface; at this stage the interface reminds for a quick check on the projection setup, were the user can check on all DEM properties which include units a 3-D cell size, area and projection reference. The DEM was processed and downloaded to the SWAT interface. The DEM, Sub-basins, Stream definition, monitoring points and outlets of Roxo catchment are shown together in figure 5-1.

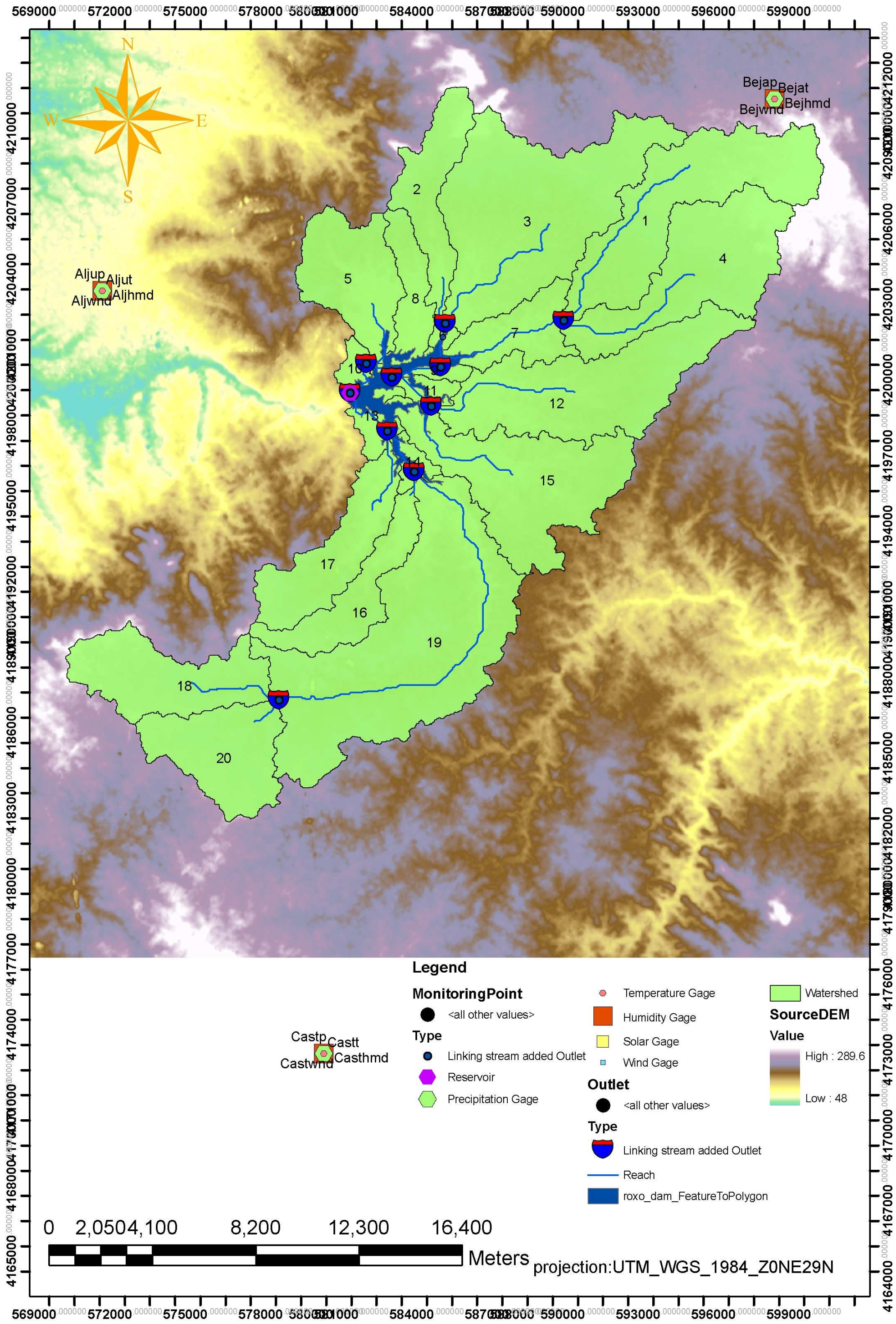


Figure 5-1 Sub-basins, DEM, Stream definition of Roxo catchment

5.1.3. Stream definition

For stream definition the interface provides a DEM- based or predefined streams and watersheds options. In this study the stream was defined using a DEM- based option, it allows to define flow direction and accumulation. The watershed delineation model identifies streams and drainage divides from DEM using the eight direction pour point algorithm (Srinivas.B, 1988). It follows the procedure presented by (Olivera, 1999) 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 defined 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 Arc-SWAT watershed delineation interface as used here allows a definition of threshold area of in the stream definition sections. In this project SWAT suggested a range of area 290-58067 ha and the area recommended by the SWAT model was1161.33ha and this gave rise to 20 numbers of sub-basins and outlets this is adequate enough to show variability in the study area. The steam network created 34 outlets during the first instance and finally 20 outlets were created. Watershed delineation map of Roxo catchment is shown in appendix A.

5.1.4. Definition of additional elements

These elements are Outlet and Inlet Definition; Watershed Outlets 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. 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 sub-basin 13, this sub-basin was the main interest of this study and is also used to study the whole basin as nutrient and stream flow data were available only in this sub-basin. Thus Calibration was carried out in this sub basin. In this project the whole basin area delineated by ARCSWAT was 352.82km2, this compares very well with previous research carried out in this study area. According to (Prscilla, 2009, Mekonnen, 2005) the Roxo catchment area ranges from 349 - 353km2. After completion of the delineation, a topographic report and several GIS layers were created: Basin, Watershed, Reach, Longest Path, Outlet, monitoring point and reservoirs. Basin stores the polygon that represents the whole study area; Watershed stores the sub-basin polygons; Reach stores the segments of the channel network; Longest Path stores the longest flow path within each sub-basin; Outlet stores the sub-basin outlet points; Monitoring point stores inlet points to the basin. The topographic report describes the elevation distribution within the watershed and within each sub watershed unit. The layers added to the map contain the parameters of the watershed characterization.

5.1.5. 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., 2005) HRU analysis menu in ArcSWAT2005 was used to characterize, land use, soil, and slope of the Roxo reservoir watershed. The ArcSWAT2005 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 and the corresponding sub watersheds. All datasets used were in ESRI grid and projected in UTM – Zone 29 N – WGS 1984 datum.

5.1.6. 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.

5.1.6.1. 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 downloaded from CORNIE Land cover database owned by the European Topic Centre on Terrestrial Environment Agency(EEA, 2000). 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, 2008). 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, some missing classes from the CORNIE assigned based on observed ground data during field visit. ESRI Arc-GIS was used to prepare and reclassify the land use maps into7 classes: agricultural closely grown crops, mixed forest, pasture, rain fed agricultural area, olive, low and medium density urban resident area, and water bodies. The land use classes' rain fed agricultural area, and olive was not included in the SWAT data base as a result they were assigned with 4 letter codes as required by SWAT model. Prior to using the data for SWAT modelling, the basin boundary created from the 15 m resampled DEM during watershed configuration was used to clip CORINE map of Portugal. The SWAT document recommends the use of the basin boundary to ensure reasonable overlay during HRU analysis. In this study 100% of overlap was achieved during overlay process of land cover and soil map. Fig 5-2: shows the reclassified land cover/use data used for SWAT simulations. Portion of land use, soil, and slope data used for the model are shown in appendix J.

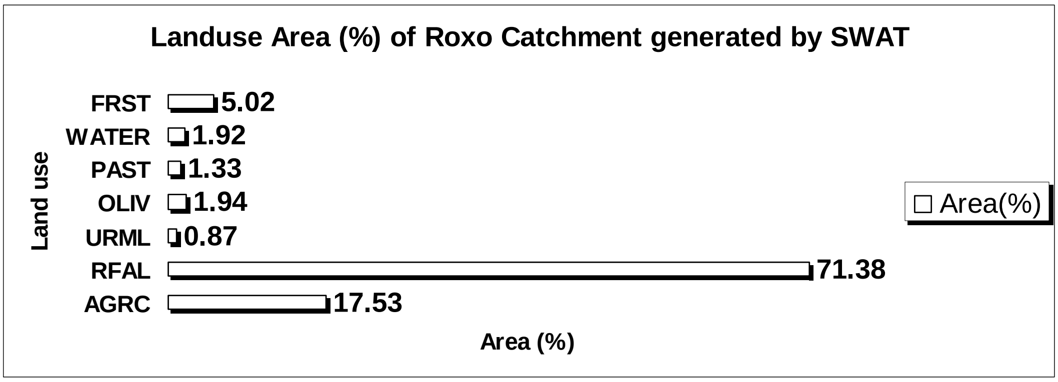


Figure 5-2: reclassified land cover/use data used for SWAT simulations

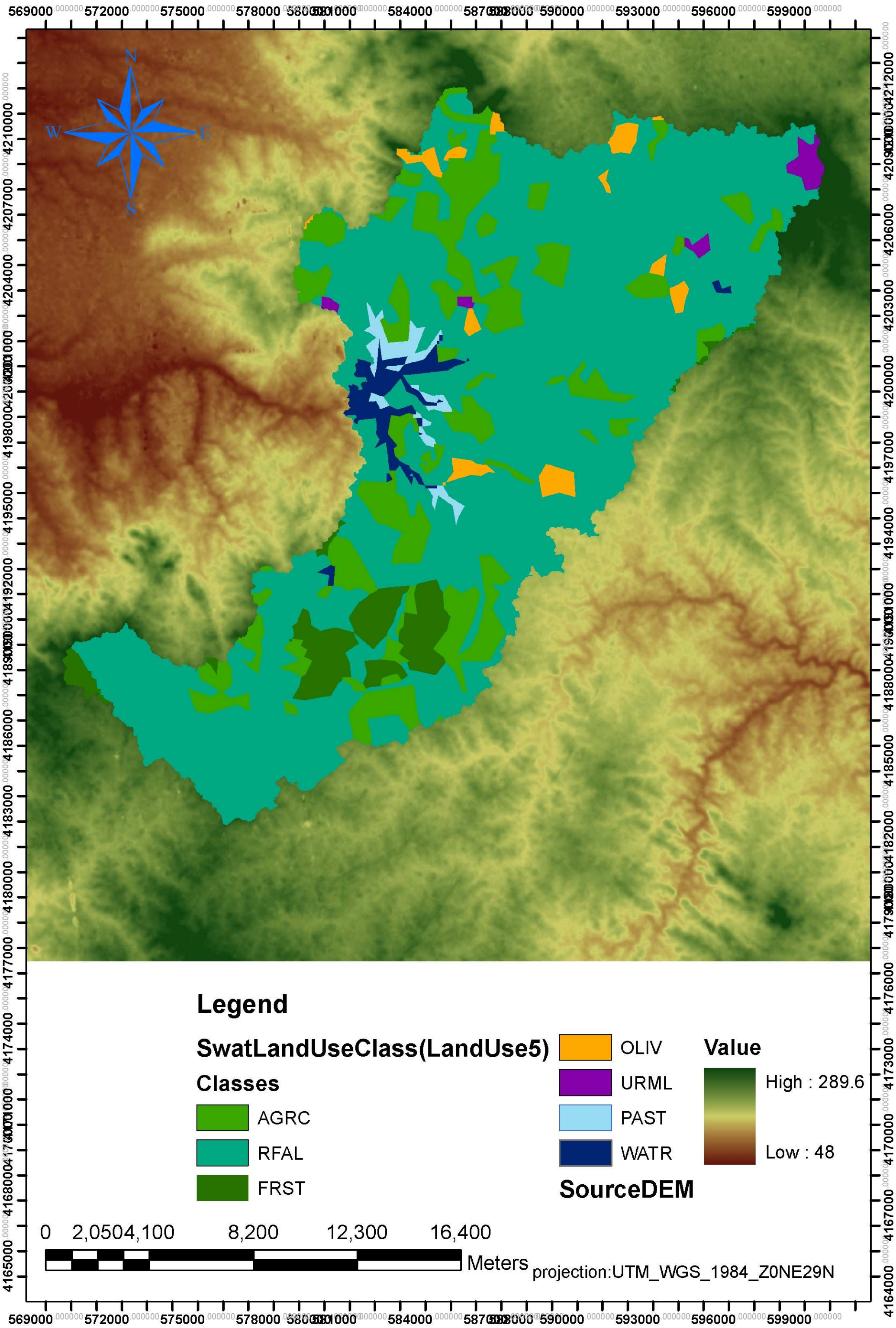


Figure 5-3 Land cover of Roxo catchment

5.1.6.2. 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 % of 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 % of soil weight and the initial concentrations of chemicals in the soil. These data were obtained from previous ITC soil analysis research in the study area by (Gökmen, 2006, Prscilla, 2009) and from the Portuguese soil database. COTR provided digital soil map of 1:50,000 with complete tiles during the field campaign from 05/09/09 to 20/10/09 in Roxo reservoir watershed. Soil names were derived from the soil maps with some modification; soil hydrologic group were derived from United States Soil Conservation Service; soil depth was derived from Soil Portugal report. Based on the laboratory analysis of (Gamises, 2009, Gökmen, 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 based on FAO 56 (Richard et al., 2000, Prscilla, 2009). Although there was no data on soil layer, it is advisable to use more than a single layer (Neitsch et al., 2005) because if the upper layer water is not available for the plant the model compensate from the lower layer. Therefore in this research two soil layers were assumed for SWAT modelling. The soil map was reclassified into twelve (12) classes by merging soils of similar physical properties in one group. A new user soil database was created and parameterized in the SWAT soil database. Soil characteristics of the catchment is explained in appendix I; also portion of soil parameters used in the model are displayed in appendix K.

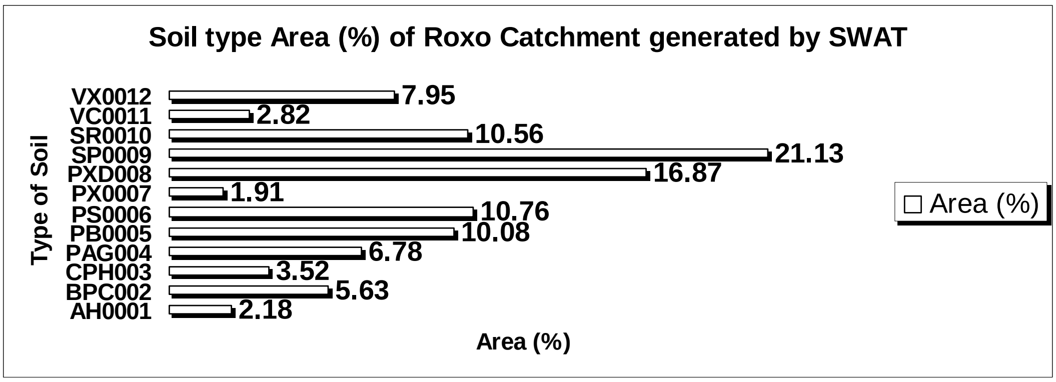


Figure 5-4: reclassified soil data used for SWAT simulations

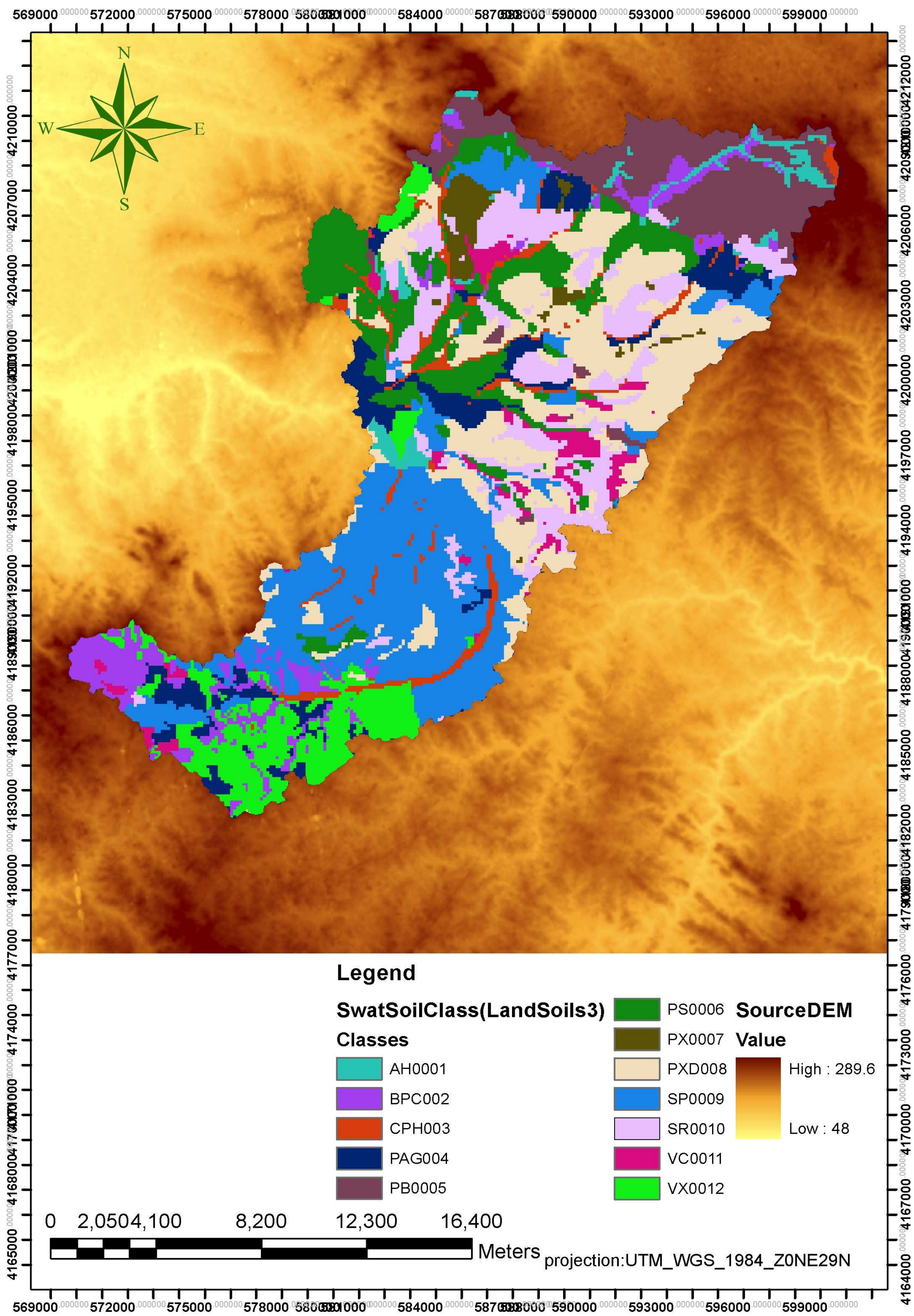


Figure 5-5: Soil map of Roxo catchment used for SWAT model

5.1.6.3. Slope definition

The slope was calculated automatically based on the DEM provided. The Arc-GIS-SWAT calculates terrain slopes per HRU and run off curve numbers developed by the division of HRU. In Arc-SWAT, 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 slopes are found to be impractical while 3 or fewer slope classes are sufficient for most cases (Setegn et al., 2009).Therefore based on the suggestion above and the topographic conditions of the Roxo reservoir watershed, 2 class for slope descritization was applied.

5.1.6.4. 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 C. The report provides detailed description of the distribution of the land use, soil, and slope classes in the watershed and the 20 sub-watershed delineated in the study area. 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 better physical description of the water balance of the study area (Setegn et al., 2009). 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 modelling of the sub-watershed while using single land use and main soil unit of each sub-watershed was employed.

5.2. Weather data definition

5.2.1. Meteorological data

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. 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 gauge data from three (3) ground stations in the vicinity area of Roxo catchment; this data was accessed from COTR http://www.cotr.pt/sagranet/sagranet were utilized to create daily precipitation, min/max temperatures, dew point temperature, wind velocity and solar radiation statistics minimum, maximum, average and standard deviation for Beja , Aljustrel and Castro Verde weather stations for the period 2001 - 2009. Similarly daily precipitation data for the same period were derived from SNIRH http://snirh.pt for

Castro Verde weather station. The spatial distribution of these weather stations is shown in Figure 5-1 and the monthly weather parameters were derived from these series of observed daily data. Weather generation Arc-GIS/SWAT includes a point feature class of weather stations in a static geodatabase. User stations was established for observed time series of Beja, Aljustrel and Castro Verde weather stations for the observed time series data, the weather generator capability of the SWAT model was used to assign a station to each sub-watershed. The weather generator data was first defined by creating a customize weather station in the static geodatabase because the weather information was not registered in the SWAT weather geodatabase. Therefore the personal geodatabase was customized for the three gauge stations and nine (9) years of simulations; with their respective elevation, geographical coordinates and all monthly weather parameters was defined. The method used to generate the monthly parameters with mathematical equations used to derive values as specified the SWAT input/output file documentation (Neitsch et al., 2004). The program was designed to calculate the average daily dew point temperature per month using daily air temperature and humidity data. Weather generator data were entered into the weather stations before starting Arc-SWAT project. Weather gage location tables were prepared to link the weather stations as well as daily precipitation and temperature gage location table. 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; it is recommended to fill -99.0 for all missing values to facilitate the generation of time series. SWAT uses a Markov chain concept (Cau and Paniconi, 2007) statistically generate values and assigns them to a specific sub-watershed in which they belongs.

5.3. Management practices

Arc/GIS-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. 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 literatures (Neitsch et al., 2005) were used to parameterize specific crop type in the land cover/plant growth database. In this study, sunflower and maize were used to characterize Closely Grown Agricultural Crops /AGRC, while winter wheat was characterized by Rain Fed Agricultural Area /RFAL. Other plant types were found not to be fertilized. Information on fertilizer date was obtained during fieldwork from the COTR, Beja. Finally, after preparing all the required input data, updating databases and parameterization, Arc-GIS-SWAT was ready to run.

5.3.1. Simulating the reservoir

The parameters of the reservoir, in the database were edited; first the reservoir characters tics, year of the reservoir become operational, year of simulation which includes reservoir principal and emergency level of surface area and volume, initial volume and sediment concentration in the reservoir, normal sediment concentration, hydraulic conductivity of the reservoir bottom, information on reservoir management: maximum and minimum of monthly outflow data, beginning and ending month of flooding season, monthly water consumption, average and emergency of daily/monthly spillway release are the main ones. The other important part of the reservoir edited in the database was lake water quality data it includes: initial concentration of nitrates, phosphates, nitrite, organic nitrogen and phosphorus, chlorophyll production coefficient median particle of the sediment are the few ones. It was so difficult to get all the data required by the model, thus literature was used to fill the information which were not obtained from ITC archives http://www.cotr.pt/sagranet/sagranet and http://snirh.pt.

5.4. Processing of SWAT output files

After running the SWAT model, five output files in text format are created: basins.sbs- basins; basins.rch; basins.wtr; and basins.rsv. Since the main interest o this study was the reservoir, the output.rsv file was used for analysis which is located in sub-basin 13. 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.The observed data for stream flow and nutrient, of the model outputs (output.rsv) were compared with the observed data. After successful simulation of the model; to achieve a better fit, the result was calibrated and validated. The process of calibration and validation explained in the following section six.

6. Model calibration and Validation

After all the SWAT input data were set and ready to run the model successfully , five(5) main output files were generated: basins.sbs- basins; basins.rch; basins.wtr; and output.rsv. To achieve a better fit, the model needs to be conditioned by optimising its internal parameters. As such model calibration and validation was performed based on the output.rsv; because the main purpose of the study was mainly focusing on the reservoir which is found in sub-basin 13. Model calibration is a process to adjust the model parameters so that the simulated results represent observed data while the validation is testing of the calibrated model results with independent data sets without any further modification (Neitsch et al., 2005) at different spatial and temporal scales; it is recommended that first to calibrate water flow then sediment and nutrients respectively. After the initial configuration of SWAT, model calibration and validation were performed on sub-basin 13, the reservoir output (output.rsv) first stream flow, and then nutrient concentration and sediment was calibrated respectively on monthly time step. The period Sep.2001-May 2005 was used for calibration and June 2005-Oct 2009 was used for validation of the model. Calibration can be performed manually or can be automated. The success of manual calibration depends on the knowledge, experience and patience of the modeller. Automated calibration is conducted by computer programs which make multiple model simulations using different parameter values in the different simulations. The best solutions for the parameters are found by evaluating the simulations according to a mathematical function, called the objective function, which is a mathematical expression of the model error (Griensven, 2007)In this study, a rough manual calibration is performed, followed by an automated calibration by use of the parasol method (Griensven, 2007). Stream flow and nutrients were calibrated on monthly time step then the performance of the model was evaluated.

6.1. Model performance statistical criteria

Simulated and observed time series of stream flow, and nutrients were compared, for calibration and validation periods. A number of statistical tests can be considered in model performance evaluation. The four numerical model performance measures used are coefficient of determination (R^2 coefficient), Nash-Sutcliffe simulation efficiency ENS (McCuen et al., 2006, Daren Harmel and Smith, 2007) , root mean square error (RMSE) and percentage bias(PBIAS). All of these tests are generally known and widely used in hydrological model performance evaluation. The coefficient of determination R^2 coefficient and Nash-Sutcliffe simulation efficiency - ENS measure how well the trends in the measured data are reproduced by the simulation results over a specific time period and for a specific data set. The coefficient of determination R^2 for time steps is calculated as Equation 25.

$$R^2 = \left(\frac{\sum_{i=1}^{n} \left((sim_i - sim_{ave})(mea_i - mea_{ave}) \right)}{\sqrt{\sum_{i=1}^{n} (sim_i - sim_{ave})^2} \sqrt{\sum_{i=1}^{n} (mea_i - mea_{ave})^2}} \right)^2 \quad \text{Equation 25}$$

$$ENS = 1 - \left(\frac{\sum_{i=1}^{n} (meai - simi)^2}{\sum_{i=1}^{n} (simi - simave)^2} \right)$$ Equation 26

Where

= the efficiency of the model

mea_i = measured values

$simave$ = simulated [predicted] values

mea_{ave} = average measured values.

R^2 =correlation coefficient

n = total number of observed or simulated data

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n} \left(\theta^t sim - \theta^t mea \right)^2}{n}}$$ Equation 27

$\theta meas^t$ =total measured

θsim^t = total simulated values

$$PBIAS = \left(\frac{\sum_{i=1}^{n} \left(\theta^t mea - \theta^t sim \right)}{\sum_{i=1}^{n} \left(\theta^t mea \right)} \right) .100\%$$ Equation 28

It describes the portion of total variance in the measured data that can be explained by the model. The range is from 0.0 (poor model) to 1.0 (perfect model). A value of 0 for R^2 means that none of the variance in the measured data is replicated by the model and value 1 means that all of the variance in the measured data is replicated by the model predictions. The fact that only the spread of data is quantified is a major drawback if R^2 is considered alone. A model which systematically over- or under predicts all the time will still result in good values close to 1.0 even if all predictions were wrong. The Nash-Sutcliffe simulation efficiency index (ENS) for n time steps is calculated as Equation 27.It is widely used to evaluate the performance of hydrological models (Daren Harmel and Smith, 2007). It measures how well the simulated results predict the measured data relative to simply predicting the quantity of interest by using the average of the measured data over the period of comparison. Values for ENS range from negative infinity (poor model) to1.0 (perfect model). A value of 0.0 means, that the model predictions are just as accurate as using the measured data average. A value greater than 0.0 means, that the model is a better predictor of the measured data than the measured data average. The ENS index is an improvement over R^2 for model evaluation purposes because it is sensitive to differences in the measured and model-estimated means and variance. A major disadvantage of Nash-Sutcliffe is the fact that the differences between the measured and simulated values are calculated as squared values and this places emphasis on peak flows. As a result the impacts of larger values in a time series are strongly overestimated whereas lower values are neglected. Values should be above zero to indicate minimally acceptable performance. Root mean square error (RMSE) is determined by calculating the standard deviation of the points from their true position, summing up the measurements, and then taking the square root of the sum. RMSE is used to measure the difference between flow values simulated by a model and actual measured flow values. Smaller values indicate a better model performance. The range is between 0 and infinity. Percentage bias (PBIAS %) measures the average tendency of the simulated flows to be larger or smaller than their observed counter parts. The optimal value is 0, and positive values indicate a model bias toward underestimation and vice versa.

6.2. Sensitivity analysis

A second measure of model performance or reliability is sensitivity analysis. Sensitivity analysis is a method to determine the response of a state variable to variations in parameters, initial conditions or boundary conditions. It can help for further understanding or defining the model behaviour. Many variables may influence model output; however, usually a model is most sensitive to only a few variables or parameters. Sensitivity analysis can identify parameters that have the greatest impact on model predictions, and resources can be directed towards defining and refining these parameters. When carrying out sensitivity analysis, typically one model parameter or input data type is varied at a time, usually by a fixed percentage or through an accepted range of values while all other values remain unchanged (Griensven, 2007). As such sensitivity analysis was performed to identify the critical model parameters. The top five parameters which were more sensitivity of the model were analyzed; curve number moisture condition 2 (CN2), parameter for calculating maximum amount of sediment (SPOCN), runoff curve number (CNOP) and exponent parameter for channel sediment routing(SPEXP) were found to be the most sensitive parameters for flow, sediment, total nitrogen and total phosphorus respectively. The detail analysis is displayed in table.

Further more, part of the SWAT project which indicates the progress of sensitivity analysis is shown in appendix B.

Table 6-1: List of parameters and their ranking that produced the five main important sensitivity of the model

	Rank				
parameters	1	2	3	4	5
Flow	CN2.mgt	BLAI	ESCO.hru	Rchrg_Dp.gw	Alpha_Bf.gw
Sediment	SPOCN.bsn	Ch_N2	CN2.mgt	Alpha_Bf	SPEXP
Total nitrogen	CNOP.mgt	SPEXP.bsn	Cn2.mgt	ESCO.hru	FERT_LY1.mgt
Total phosphorus	SPEXP.bsn	EVRCH.bsn	EPCO.hru	USLE_P.mgt	FERT_LY1.mgt

6.3. Model results

After having very convincing results of stream flow calibration; nutrient calibrations was made (Chlorophyll a, sediment, and total nitrogen).During the calibration phase water quality time series predicted output to available water quality (Chlorophyll a, sediment, and total nitrogen) was obtained from EMAS-Beja,Portugal municipal water supply and sanitation site http://www.emas-beja.pt/. The observed data recorded was taken from a point measurement (A_19) at the dam of the reservoir see figure 2-6.This observed data was incomplete and not continuous. Although temporal variation exists effort was made to fill this gap with the field observation data. To reproduce the observed data the simulated water quality parameter was calibrated based on the recommended range by (Srinivasan and Griensven, 2007) Calibration of sediment in SWAT sources of sediment are both from HRU's and from channel degradation and deposition. SWAT parameters commonly used during model sediment calibration: USLE crop management factor (USLE_P), USLE slope length (SLSUBBSN), Slope of HRU-s (SLOPE), Crop practice factor (RSDCO), Bio-mixing efficiency (BIOMIX) and initial sediment in the reservoir were adjusted the simulation was satisfactory during calibration period but the validation result was not convincing. Calibration of average total nitrogen (ORGN_OUT, NO3_OUT, NH4_OUT, NO2_OUT) transported by surface runoff from sub-catchments into the reservoir during simulation period was high as it is shown in figure 6-7.It is observed that this scenario is mainly associated with organic nitrogen in surface flow which indicate that the amount of nitrogen contribution to the reservoir is high. For calibration of nitrogen compounds initial concentration of the nutrient in soils SOL_NO3 in soil chemistry, fertilizer application rates and fertilizer application fraction to surface layer as (FRT_LY1) in land management set to 0.2 as recommended by (Srinivasan and Griensven, 2007) adjustment of crop residue coefficient (RSDCO) and bio-mixing efficiency (BIOMIX) and nitrogen percolation coefficient (NPERCO) adjustment of initial concentration of nitrogen compounds was done the calibration result was satisfactory finally the result was validated. In SWAT chlorophyll a production is limited on the total phosphorus and total nitrogen compounds as such the calibration of chlorophyll depends on the calibration of total phosphorus and total nitrogen. Chlorophyll a is estimated based on the equation 22 which assumes that limiting nutrient for production of Chlorophyll a is total phosphorous with a constant for adjustment of other limiting nutrient such as total nitrogen. The simulation was not satisfactory during calibration period thus the result was not validated. Calibration and validation results were evaluated by comparing time series model prediction output to point observed data. In flow and nutrient dynamics graphical and statistical comparison is very useful (Griensven, 2007) for judging the results of model calibration as it provides a good visual control over time series plots of measured against model predicted values.

6.3.1. Calibration

Calibration and Validation

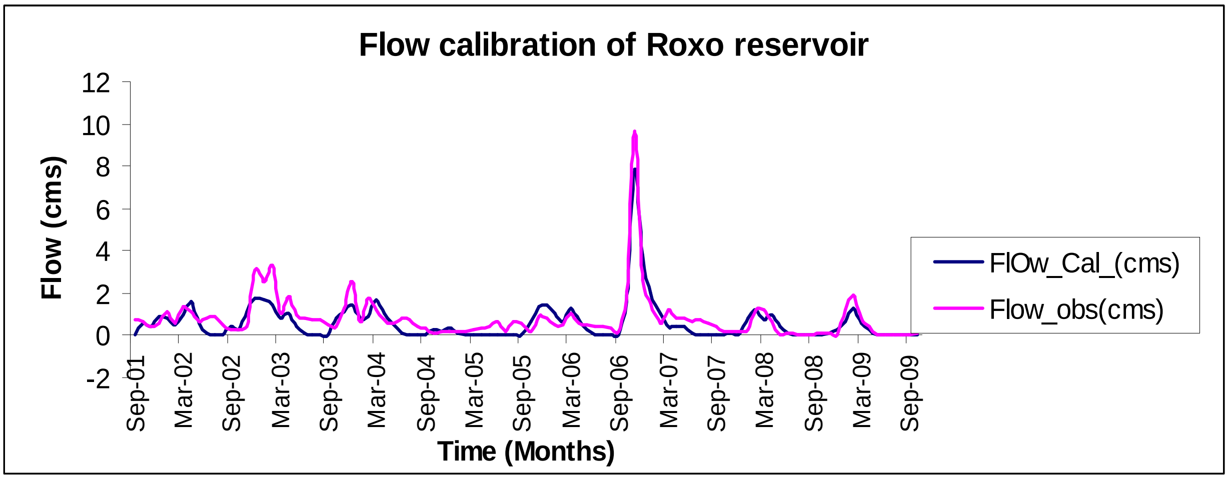
Calibration and validation is required due to the fact that each reservoir has unique attributes that should be sufficiently represented with field data to allow satisfactory calibration and validation. Further, the SWAT model should be tested at multiple locations and over sufficiently representative time periods.The calibration of SWAT2005 was performed for water flow, sediment and chlorophyll a at Roxo reservoir (Sub-basin 13). The period Sep.2001-May 2005 was used for calibration, and the period June 2005-Oct 2009 was used for validation. The analysis of the results was based on comparison of model simulated of monthly average with monthly measured averaged.

Table 6-2: Data used for calibration and validation

Parameter	SWAT output	Calibration data	Validation
Flow(m3s-1)	Flow(m3/s)	Sep.2001-May2005	June2005-Oct.2009
Chlorophyll a (µg/l)	Chlorophyll a(kg)	Sep.2001- May2005	June2005-Oct.2009
TSS (mg/l)	Sediment(tons)	Sep.2001- May 005	June2005-Oct.2009
TN(mg/l)	Total nitrogen(kg)	Sep.2001- May 005	June2005-Oct.2009

6.3.2. Water flow calibration

Since nutrients dynamics are influenced by water flow dynamics parameters controlling water balance was calibrated first. In Roxo reservoir there is no measured gauge flow data, but the daily flow was calculated based on the available historical volume -elevation relationship of the reservoir (Vithanage, 2009, Mekonnen, 2005).This daily calculated flow data was averaged to monthly daily average for the period of Sep.2001 –Oct 2009 and the results compared with the model simulated of the same period. The monthly calibrated results of Sep.2001-Oct 2009 and the observed flow of the same duration are shown graphically in figure. The detailed monthly observed and the correspondingly SWAT simulated data are shown in appendix L.



Stream flow and water quality modelling using the SWAT2005: A case study of the Roxo reservoir, Portugal

Figure 6-1: observed monthly average flow against model calibrated at Roxo reservoir

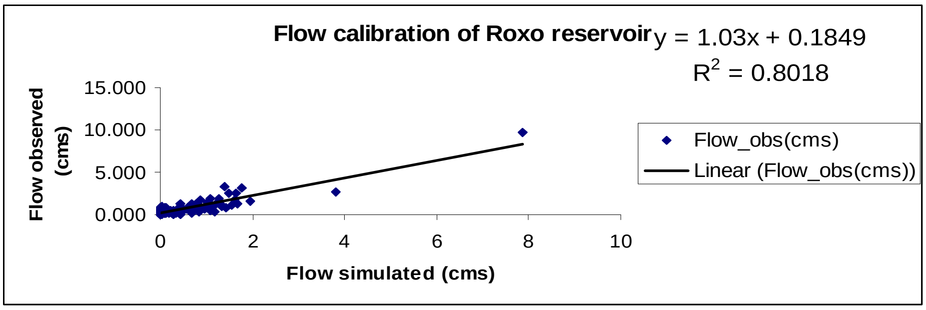


Figure 6-2: regression line of observed monthly average flow against model calibrated at Roxo reservoir

Figure 6-1 shows the time series comparison of model predicted and observed monthly flow of Roxo reservoir over the 9 years (Sep. 2001-Oct.2009) calibration period. The performance of the model is very satisfactory; it follows closely the pattern of the observed monthly flow. The match between observed and simulated flow values was both in magnitude and temporal variation but the model underestimate a little bit compared to Observed data. The performance of the model was further confirmed by the high statistical Nash-sucliffe prediction efficiency (ENS) value of 0.784, showing in good agreement between observed and model simulated values. The regression analysis result (0.802) also shows how the two variables have strong correlation between observed and simulated flow. Furthermore RMSE result (.55) and PBIAS (26.4%) also confirms the strong similarities between the observed and simulated data. The detailed monthly observed and the correspondingly SWAT simulated flow data are shown in appendix L.

Table 6-3 : result summary of calibrated flow

Calibration	ENS	R^2	PBIAS	RMSE
Sep.2001-May 2005	0.76	0.802	26.4	0.55

6.3.3. Calibration of Sediment

Sediment was considered for calibration based on the availability of observed data. The measured sediment data was available as concentration (Csed) in (g/ml), while the SWAT simulated sediment load (tons), therefore either measured concentration should be converted into load or the SWAT simulated results converted into concentration. In this study the measured sediment data was converted into sediment load. Sediment concentration (Csed) was converted into sediment load by multiplying estimated flow out of the reservoir: (Sedload) = [Concentratation [mg/l]]*10-3kg/m3*l/mg*flow_out [m3/s]*86400s*# of days in a given month. Sediment concentration (Csed) is sediment which is transported with water out of the reservoir (Neitsch et al., 2005). The predicted results were compared with the observed data on a monthly basis for the period of Sep.2001-Oct 2009.The result showed satisfactory agreement between simulated and observed data.

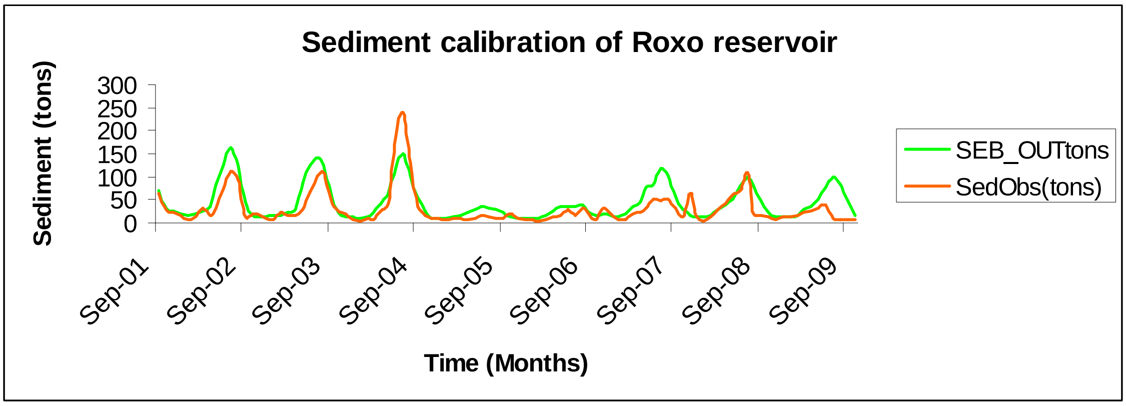


Figure 6-3: observed monthly average sediment load against model calibrated of Roxo reservoir

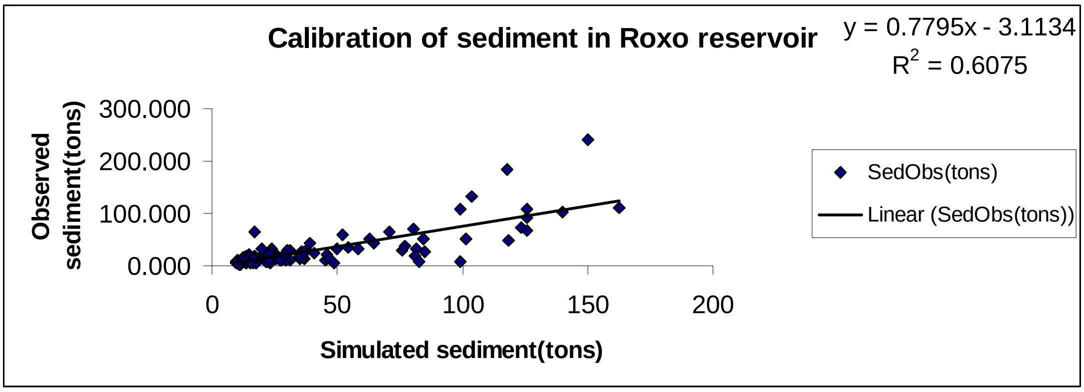


Figure 6-4: regression line of observed monthly average sediment load against model calibrated at Roxo reservoir

Figure 6-3 shows the time series comparison of model predicted and observed monthly sediment of Roxo reservoir over the 9 years (Sep. 2001-Oct.2009) calibration period. The performance of the model is satisfactory; it follows closely the pattern of the observed monthly sediment load but generally the model overestimate the sediment except between June 2004 and August 2004 when the sediment load was reached unusually larger than similar seasons. The performance of the model was also satisfactory the statistical Nash-sucliffe prediction efficiency (ENS) value of 0.45, indicate that there is agreement between observed and model simulated values. The regression analysis result was (0.606) indicate good correlation between observed and simulated sediment load. Furthermore RMSE result was 28 and PBIAS (-41%) also confirms that the model biased towards overestimation. The detailed monthly observed and the correspondingly SWAT simulated sediment data are displayed in appendix M.

Table 6-4: Result summary of calibrated sediment

calibration	E_{NS}	R^2	RMSE	PBIAS

Sep.2001-May 2005	0.45	0.606	28	-41

6.3.4. Calibration of Chlorophyll a

Chlorophyll a was calibrated based on the availability of observed data. The measured chlorophyll a data was available as concentration in (µg/ml), while the SWAT simulated chlorophyll a, therefore either measured concentration should be converted into load or the SWAT simulated results converted into concentration. In this study the measured chlorophyll a data was converted into chlorophyll a. Chlorophyll a concentration was converted into chlorophyll a load by multiplying estimated flow out of the reservoir: Chlorophyll a =[Concentratation [µg/l]]*10-6kg/m3*l/mg*flow_out [m3/s]*86400s*# of days in a given month. Chlorophyll a is the chlorophyll a which is transported with water out of the reservoir (Neitsch et al., 2005). The predicted results were compared with the observed data on a monthly basis for the period of Sep.2001-Oct 2009.The result showed poor agreement between the observed and measured data.

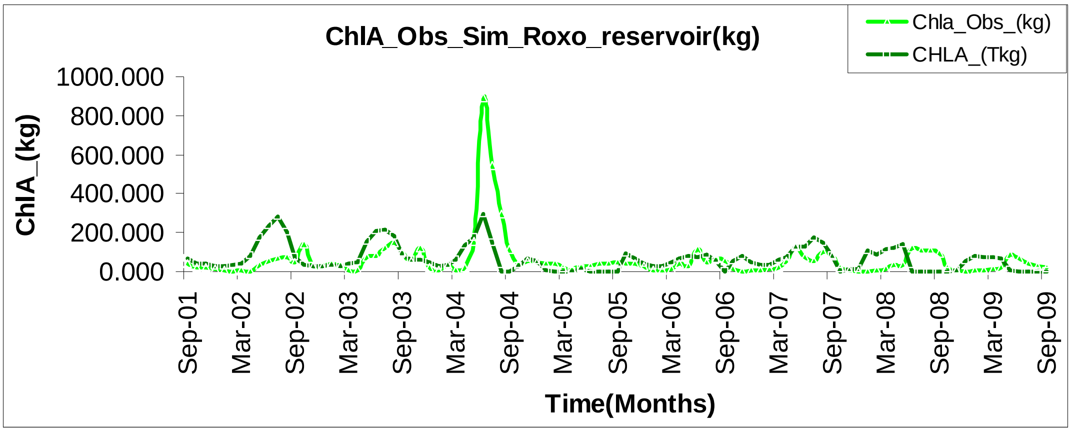


Figure 6-5: observed monthly average chlorophyll a against model calibrated

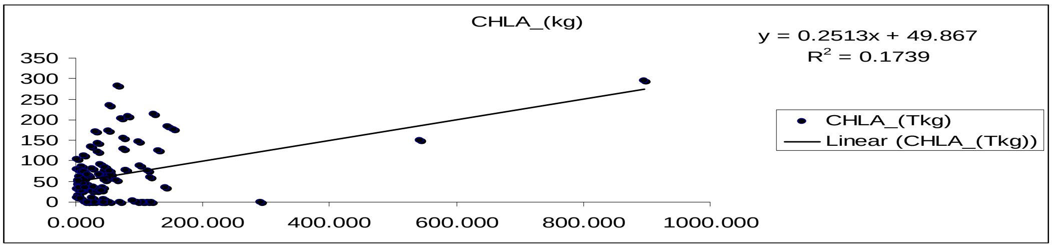


Figure 6-6: regression line of observed monthly average chlorophyll a against model calibrated

Table 6-5: Result summary of calibrated chlorophyll a

calibration	E_{NS}	R^2	PBIAS	RMSE
Sep.2001-May 2005	-1.4	0.17	-9.22	101.2

Figure 6-5 shows the time series comparison of model predicted and observed monthly chlorophyll a of Roxo reservoir over the 9 years (Sep. 2001-Oct.2009) calibration period. The performance of the model was poor; although the most influential process in simulation of chlorophyll a; mineral and organic phosphorus was calibrated, it was not possible to simulate good results. The most possible reason was the available water quality observation data; particularly chlorophyll a was incomplete (missing observed data) and inconsistence of the observed data. However poor match between observed and simulated values; the simulated chlorophyll a tends to show the seasonal variation of the measured data. The poor simulated could be observed from ENS (-1.4) and the regression line (Figure 6-6) result 0.17 and RMSE result (101) and PBIAS (-9.22%) indicate the model tends to over estimating the simulated data. Effort was made to improve the result by removing the outliers but it was not possible to get much improvement.

6.3.5. Calibration of total nitrogen

Total nitrogen was also calibrated based on the availability of observed data. All the measured organic and inorganic nitrogen was summed up and converted in to load of nitrogen because the nitrogen observed data was available as concentration in (mg/ml), while the SWAT simulated nitrogen compounds in load (kg), therefore either measured concentration should be converted into load or the SWAT simulated results converted into concentration as it was applied in sediment and chlorophyll a the measured total nitrogen data was converted into load (kg). Nitrogen concentration was converted into nitrogen load by multiplying concentration of nitrogen by flow out of the reservoir:
Total nitrogen = [Concentratation [mg/l]]*10-3kg/m3*l/mg*flow_out [m3/s]*86400s*# of days in a given month. The total nitrogen load is the total nitrogen which is transported with water out of the reservoir (Neitsch et al., 2005).first the simulated nitrogen compounds summed up compared with the observed data on a monthly basis for the period of Sep.2001-Oct 2009.The result showed not convincing agreement between the observed and measured data. The detailed monthly observed and the correspondingly SWAT simulated total nitrogen data are shown in appendix L.

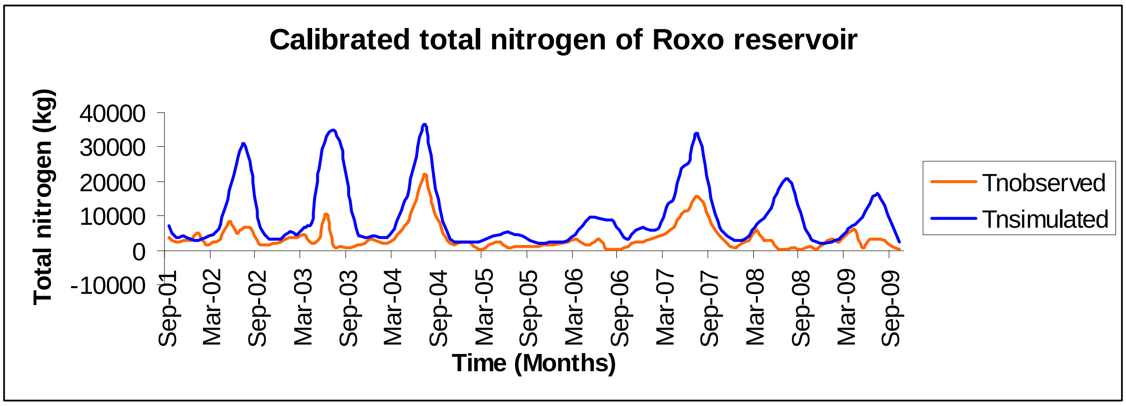


Figure 6-7: Observed monthly average total nitrogen against model predicted

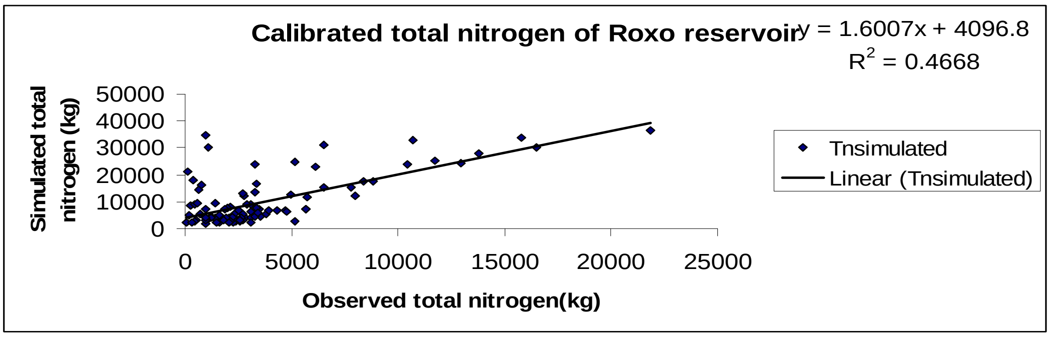


Figure 6-8: Regression line of observed monthly average total nitrogen against model simulated

Figure 6-7 shows the time series comparison of model predicted and observed monthly total nitrogen of Roxo reservoir over the 9 years Sep. 2001-Oct.2009 calibration period. The performance of the model was not strong but satisfactory; the most possible reason was the available water quality observation data was incomplete and inconsistence of the observed data. The simulated total nitrogen tends to show similar pattern with observed data and also could show the seasonal variation with the measured data. The performance of the model was statistical Nash-sucliffe prediction efficiency ($\mathbf{E_{NS}}$) value -0.087 with regression line result 0.47 and RMSE result (9005) and PBIAS (-174%) indicate the model tends to over estimating the simulated data.

6.3.6. Validation

6.3.6.1. Validation of water flow

Model validation was performed for Roxo reservoir based on observed data derived from historical daily volume –area relationship of the reservoir. In the validation step a comparisons of simulated values was made with an independent dataset which was not used in the calibration process. As such the period June 2005 –Oct.2009 was used for validation of flow of Roxo reservoir. The time series of validation result for the monthly flow in Roxo reservoir is shown graphically in (figure6-9) while the regression line is shown in the figure 6-10.

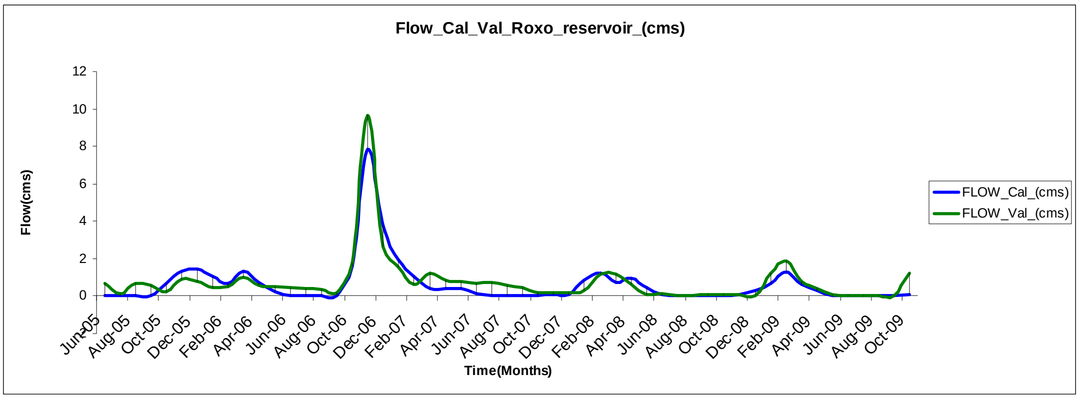


Figure 6-9: simulated versus measured monthly water flow for model validation

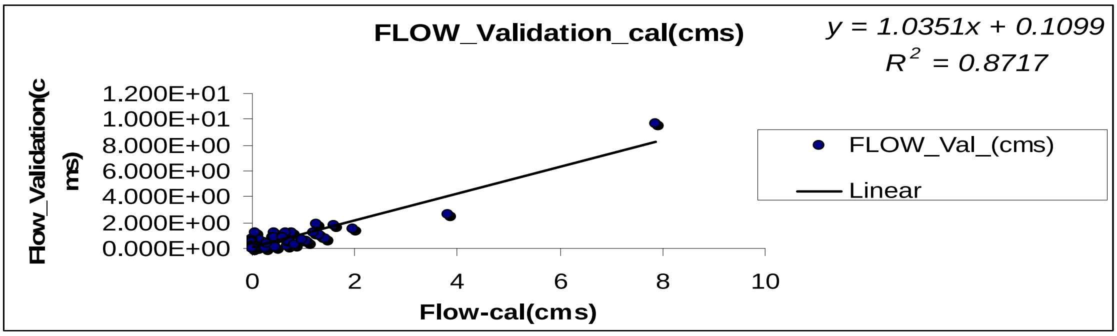


Figure 6-10: regression line of observed monthly average water flow against simulated for model validation

Figure 6-7 shows the time series comparison of model predicted and validated monthly flow of Roxo reservoir within the time frame of June 2005-Oct.2009 validation period. The performance of the model is very satisfactory; it follows closely the pattern of the observed monthly flow. The match between observed and simulated flow values was both in magnitude and temporal variation but the model underestimate a little bit compared to Observed data. The performance of the model was further confirmed by the high statistical Nash-sucliffe prediction efficiency (ENS) value of 0.86, showing in very good agreement between observed and model simulated values. The regression analysis (figure 8) result (0.872) also shows very strong correlation between observed and simulated flow. Furthermore RMSE result (.5) and PBIAS (17.47%) also confirms the strong similarities between the observed and simulated data in the validation process. This could indicate that the model is successfully simulating the inflow dynamics of the different streams into Roxo reservoir.

Table 6-6: Result summary validation of flow

validation	E_{NS}	R^2	PBIAS	RMSE
June2005-Oct 2009	0.86	0.872	17.47	0.5

6.3.6.2. Validation of sediment

The predicted results were compared with the observed data on a monthly basis for the period of June 2005-Oct 2009.The validation result showed poor agreement between the observed and simulated data. Figure 6-11 shows the time series comparison of model predicted and observed monthly sediment load of Roxo reservoir for the validation period of June 2005-Oct 2009.

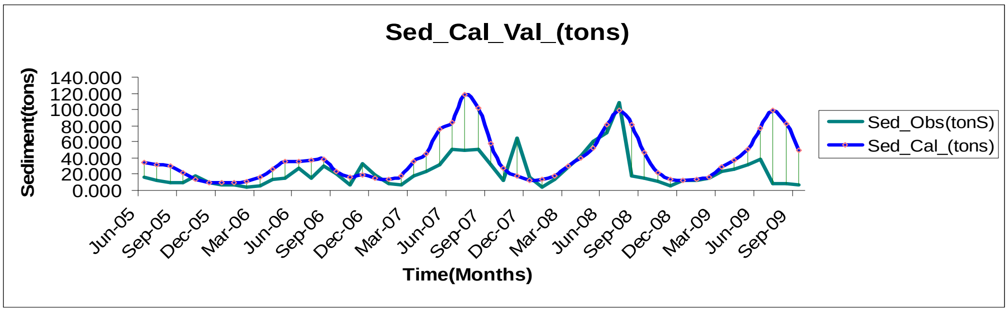


Figure 6-11: Simulated versus measured monthly sediment load for model validation

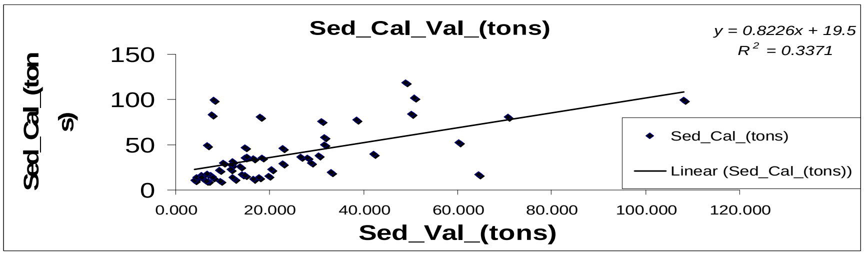


Figure 6-12: regression line of Simulated versus measured monthly sediment load for validation

The predicted results were compared with the observed data on a monthly basis for the period of June 2005-Oct 2009.The validation result showed poor agreement between the observed and simulated data. Figure 6-9 shows the time series comparison of model predicted and observed monthly sediment load of Roxo reservoir for the validation period of June 2005-Oct 2009. The performance of the model is poor is for the validation period. The most possible reason for less performance of the model was the available sediment concentration was inconsistence. Generally the model over estimate the sediment load in the validation period. However the time series of figure 6-11 tends to show the seasonal variation of the measured data. The performance of the model was observed by the statistical Nash-sucliffe prediction efficiency (ENS) value of 0.04.Promising validated result was observed. From (Figure 6-12) the regression line result 0.34 and RMSE result (28.02) and PBIAS (66.7%) indicate that the model tends to over estimating the simulated result.

Table 6-7: Result summary validation of sediment

validation	E_{NS}	R^2	PBIAS	RMSE
June2005-Oct 2009	0.04	0.34	66.7	28.02

6.3.6.3. Validation of total nitrogen (TN)

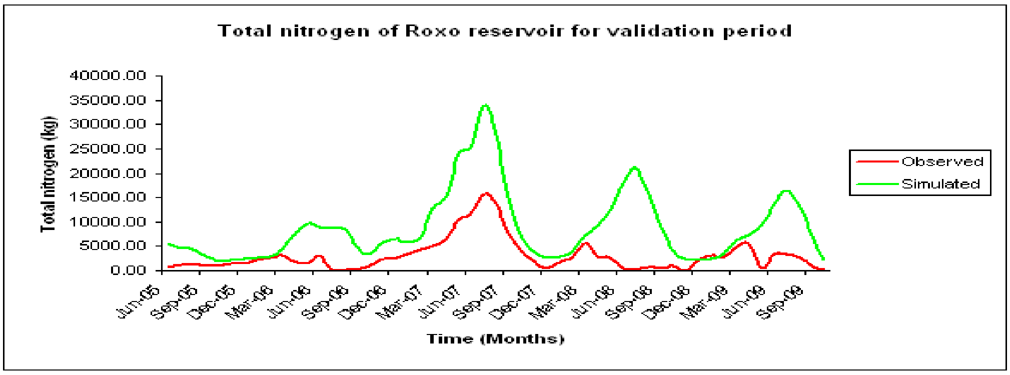


Figure 6-13: Simulated versus measured monthly TN load for model validation

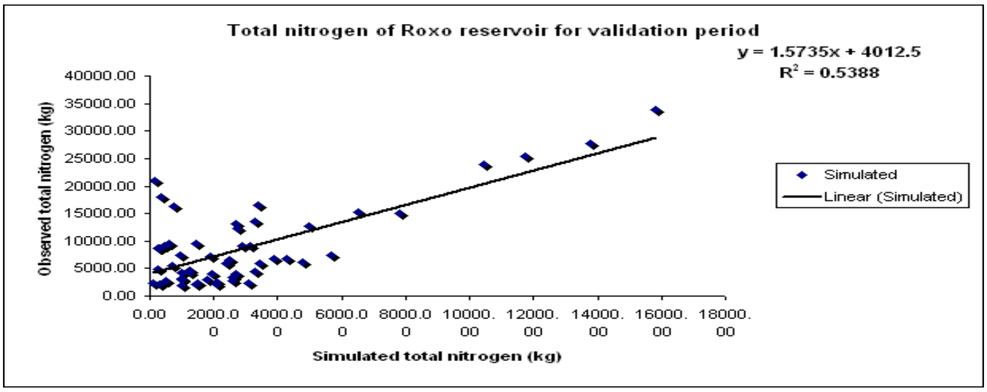


Figure 6-14: Regression line of **Simulated versus measured monthly TN for model validation**

Figure 6-13 shows the time series comparison of model predicted and observed monthly total nitrogen of Roxo reservoir over the 9 years of validation period (Sep. 2001-Oct.2009). The performance of the model was satisfactory even better than calibration period. Moreover the simulated total nitrogen tends to show similar pattern with observed data and also could show the seasonal variation with the measured data. The strength of the validated result could be observed from figure 6-14 the regression line result **0**.54, (ENS) value of -0.18 , RMSE result (7792) and PBIAS (-188%) indicate the model over estimating the simulated data. Generally the model simulation of total nitrogen was satisfactory in the validation period.

7. Discussion,limitation,conclusion and recommendations

7.1. Discussion

After having very convincing results of stream flow calibration; nutrient calibrations was made (Chlorophyll a, sediment, and total nitrogen).During the calibration phase water quality time series predicted output to available water quality (Chlorophyll a, sediment, and total nitrogen) which was obtained from EMAS-Beja municipal water supply and sanitation site http://www.emas-beja.pt/.

The observed data recorded was taken from a point measurement (A_19) at the dam of the reservoir shown in figure 2-6.This observed data was incomplete and not continuous. Although temporal variation exists effort was made to fill this gap with the field observation data. To reproduce the observed data the simulated water quality parameter was calibrated based on the recommended range by (Srinivasan and Griensven, 2007) Calibration of sediment in SWAT sources of sediment are both from HRU's and from channel degradation and deposition. Parameters used during model sediment calibration: USLE crop management factor (USLE_P), USLE slope length (SLSUBBSN), Slope of HRU-s (SLOPE), Crop practice factor (RSDCO), Bio-mixing efficiency (BIOMIX) and initial sediment in the reservoir were adjusted the simulation was satisfactory during calibration period but the validation result was not convincing. The average total nitrogen (ORGN_OUT, NO3_OUT, NH4_OUT, NO2_OUT) transported by surface runoff from sub-catchments into the reservoir during simulation period was high as it is shown in figure 6-7.

According to the results obtained (not shown) it was observed that this was mainly associated with organic nitrogen in surface flow which indicates that the amount of nitrogen contribution to the reservoir is high. For calibration of nitrogen compounds initial concentration of the nutrient in soils SOL_NO3 in soil chemistry, fertilizer application rates and fertilizer application fraction to surface layer as (FRT_LY1) in land management set to 0.2 as recommended by (Srinivasan and Griensven, 2007) adjustment of crop residue coefficient (RSDCO) and bio-mixing efficiency (BIOMIX) and nitrogen percolation coefficient (NPERCO) adjustment of initial concentration of nitrogen compounds was done. In SWAT chlorophyll a production is limited on the total phosphorus and total nitrogen compounds as such the calibration of chlorophyll depends on the calibration of phosphorus, total nitrogen and sediment. In SWAT Chlorophyll a is estimated based on the equation 22; which assumes that limiting nutrient for production of Chlorophyll a is mainly total phosphorous with a constant for adjustment of other limiting nutrient such as total nitrogen in this study 0.85 was used for the coefficient adjustment. The simulation was not satisfactory during calibration period thus the result was not validated.Calibration and validation results were evaluated by comparing time series model prediction output to point observed data. In flow and nutrient dynamics graphical and statistical comparison is very useful for judging the results of model calibration as it provides a good visual control over time series plots of measured against model predicted values.

7.2. Limitation

As there were only small amounts of data available for estimation of nutrient concentrations, the results for the calibration period were encouraging. Generally, simulated total nitrogen, sediment and chlorophyll a tend to follow the observed data but validation result was not convincing as the stream flow. This is mainly due to the fact that some short-term sampling exercises were performed which resulted in monitoring of short-term high concentrations and because flow from discharges were simulated as constant daily loadings. That means that periods of time when discharge concentration or load of nutrients or sediment in outflow were high or low are not modelled. The cumulative distribution results for the validation period for total nitrogen, sediment and chlorophyll a show more high values than measured data, due to the reasons described for total nitrogen, sediment and chlorophyll a calibration and validation period. As a semi distributed catchment scale model, SWAT consider for spatio-temporal variability of climatic representation at sub-basin level. It provides a dynamic complex process at a reasonable resolution. It is very good model for distributed modelling. But due to the lumping concept, the model limits the accurate representation of flow and nutrient dynamics. Other important issues that should be mentioned; SWAT applied simple empirical equations to represent complex hydrological and geochemical process. It considers the whole reservoir as one system so it was not possible to study the spatial variability of nutrient dynamics along the reservoir. SWAT assumes complete mixing of nutrients but it doesn't represent the actual phenomena of the reservoir. The other limitation of the model; it does not consider the transformation of NO3 ⇔ NO2 ⇔ NH4 between nutrients and the initial concentration simulated in the reservoir was limited to the removal of nutrients by settling. SWAT calculates loading of pathogens and indicator bacteria for pathogens from land areas and watershed. But in the reservoir bacteria die-off is the only process modelled (Chapra, 2003).Hence for the time being; SWAT is not well developed for modelling of bacteria in the reservoir. The research done by (Migliaccio et al., 2007) indicated that currently, many of the parameters affecting the fate and transport of nutrients' such as TP or NO3-N are held constant as a function of time in the SWAT model, which limits the ability of SWAT to simulate temporal changes that occur with many in stream processes. There is a need to assess improvement in the model performance when these parameters are made dynamic to accurately reflect seasonal variations. The SWAT model developers have also indicated that all aspects of stream routing need further testing and refinement. The incomplete and inconsistence of observed nutrients in the reservoir add for the complication of the problem and affected the simulated results (Tolson and Shoemaker, 2007) emphasized the importance of continuous collection of monitoring data for adequate calibration and validation of the SWAT model ; although generally, the result of the calibrated and validated results of nutrients satisfactory it would had been achieved better results. There was also a measure of uncertainty in the flow data, because it was indirectly estimated based on the historical volume and elevation stage of the reservoir. Missing climatic data records also contributed for the limitation of the prediction ability of the model; Because of all these errors and the incomplete data record of the Roxo reservoir nutrients resulted in inaccuracies in the monthly average and other statistically inferred data.

7.3. Conclusion

The stream flow and nutrient dynamics of Roxo reservoir was modelled using Arc-SWAT 9.3.1. The performance of the model was statistical Nash-sucliffe prediction efficiency (ENS) value of 0.784 and 0.86, and the regression analysis (R2) result 0.802 and 0.872 for calibration and validation period respectively. This confirms that the model was successfully simulating the inflow dynamics of the different streams into Roxo reservoir.For calibration and validation of observed data; all the nutrients were taken from a point measurement (A_19) at the dam of the reservoir shown in figure 2-6.

Chlorophyll a of Roxo reservoir over the 9 years (Sep. 2001-Oct.2009) simulated data was compared with observed data. As it is depicted on figure 6-5; the simulated chlorophyll a tends to show the trend of seasonal variation of the measured data. As it was shown in figure 6-6 the regression line of simulated result was 0.17, (ENS) value of 0.97 , RMSE result (101) and PBIAS (-9.22%) indicate the model tends to over estimating the simulated data. The result was not satisfactory in the calibration period as a result it was not validated. The most possible reason was the available water quality observation data; particularly chlorophyll a was incomplete (missing observed data) and inconsistence of the observed data. Monthly predicted and observed average total nitrogen (TN) of Roxo reservoir from Sep. 2001to Oct.2009 was compared. The performance of the model was statistical Nash-sucliffe prediction efficiency (ENS) value of -0.087 and -0.18, and the regression analysis (R2) result 0.47 and

0.54 for calibration and validation period respectively, however the model show over estimating the simulated data; generally the result was satisfactory in the validation even better than calibration period. In similar way, the monthly predicted and observed average sediment of Roxo reservoir from Sep. 2001to Oct.2009 was compared. The performance of the model; the statistical Nash-sucliffe prediction efficiency (ENS) value of 0.45 and 0.04, regression analysis result (R2) was 0.606 and 0.34 for calibration and validation period respectively. The validation period was not convincing as the calibration period, but it was satisfactory. The most possible reason was the available water quality observation data; was incomplete (missing observed data) and inconsistence of the observed data. Generally the SWAT model was successfully calibrated and validated for Roxo reservoir to estimate predicted monthly stream flow into the reservoir, sediment, chlorophyll a, and total nitrogen out of the reservoir from Sep.2001 to Oct 2009.

7.4. Recommendation

The European Water Framework Directive requires that all surface waters and groundwater must reach at least 'good' status by 2015. Thus, the directive requires the development of management strategies to restore rivers and lakes to "good" status within a specified timeframe. As this study was proposed as an aid for the future decision making process concerning the improvement of water quality of Roxo reservoir. As such Roxo reservoir was evaluated comparing the results obtained from the model and the standard recommended by WFD. According to the model result obtained the average total nitrogen (TN), total suspended sediment (TSS), (mg/l) of Roxo reservoir is 3.34 and 14.73 (mg/l) respectively. When these values were compared with the WFD standard the result indicated that Roxo reservoir is in good condition with respect to sediment and total nitrogen. Moreover the reservoir was evaluated based on the secchi disc depth. According to the result obtained from the model the average secchi disc depth of Roxo reservoir was 0.85m based on the public perception of water quality index (Neitsch et al., 2005) Roxo reservoir is classified as poor, water body not suitable for recreation and other uses. Moreover the average Chlorophyll a of the reservoir was 74.9µg/l, according to (Chapman, 1996) chlorophyll a concentration used as an indication of eutrophication of a water body. If the average value of chlorophyll a is greater than 25µg/l,it is considered as hypertrophic. Thus Roxo reservoir is highly affected by eutrophication. This result agree with the previous research done by (Gurung, 2007, Chisha, 2005) related to the eutrophicatoin of the Roxo reservoir. Generally the result indicated that the main source of nutrient for eutruphication of the lake is the excess total phosphorus generated from the Roxo catchment; thus the proper and efficient use of organic phosphorus fertilizers is recommended.

Reference:

ABASPOUR, K. & SRINIVAS, R. 2005. Book of abstract 3rd International SWAT Conference.

AHLGREN, J., TRANVIK, L., GOGOLL, A., WALDEBACK, M., MARKIDES, K. & RYDIN, E. 2004. Sediment Depth Attenuation of Biogenic Phosphorus Compounds Measured by 31P NMR. Environmental Science & Technology, 39, 867-872.

ANDERSEN, H., ANTHONY, S., ARHEIMER, B., GROENENDIJK, P., BEHREND, H. & TERRA, M. 2004. Model parameterisation, calibration and performance assessment methods in the EUROHARP project. Oslo: Norwegian Institute for Water Research (NIVA), Norway.

BÄRLUND 2007. Assessing SWAT model performance in the evaluation of management actions for the implementation of the Water Framework Directive in a Finnish catchment. Environmental Modelling & Software, 22, 719-724.

BOAVIDA 1999. Seasonal water level fluctuations:implications for reservoir limnology and management.

BORAH, D. & BERA, M. 2004. Watershed- scale hydrologic and non point source pollution models. 47(3): 789−803.

BRANDMEYER 2000. Coupling methodologies for environmental models. Environmental Modelling and Software, 15, 479-488.

BUKATA, R. P. 2005. Satellite monitoring of inland and coastal water quality

CAETANO, M. 2008. Accuracy assessnment of the high resolution built-up map for continental Portugal.

CAU, P. & PANICONI, C. 2007. Assessment of alternative land management practices using hydrological simulation and a decision support tool: Arborea agricultural region, Sardinia

CHAPMAN, D. 1996. Water Quality Assessments: A guide to the use of biota, sediments and water in environmental monitoring. In: CHAPMAN, D. (ed.) 2nd ed. London and New York: E & FN SPON.

CHAPRA, S. 1982. A budget model accounting for the positional availability of phosphorus in lakes. Water Research, 16, 205-209.

CHAPRA, S., PELLETIER, G. & TAO, H. 2008. A modeling framework for simulating river and stream water quality. Documentation and Users Manual. Civil and Environmental Engineering Dept., Tufts University, Medford, MA. Washington DC.

CHAPRA, S. C. 2003. Engineering Water Quality Models and TMDLs. Journal of Water Resources Planning and Management, 129, 247-256.

CHEN, C. 2007. Remotely sensed assessment of water quality levels in the Pearl River Estuary, China.

CHISHA. 2005. Assessment of nutrient pollution contribution of the Outerio catchment of the Roxo lake in Poortugal usingthe GWLF model. INTERNATIONAL INSTITUTE FOR GEO-INFORMATION SCIENCE AND EARTH OBSERVATION.

COLLIN, F. & QUEVAUVILLER, P. 1998 Monitoring of water quality
Amsterdam,The Netherlands.

DAREN HARMEL, R. & SMITH, P. K. 2007. Consideration of measurement uncertainty in the evaluation of goodness-of-fit in hydrologic and water quality modeling. Journal of Hydrology, 337, 326-336.

EEA 2000. Cornie land cover database

ERNST, M. R. & OWENS, J. 2009. Development and application of a WASP model on a large Texas reservoir to assess eutrophication control. Lake and Reservoir Management, 25, 136 - 148.

FAETH, P. & GREENHALGH, S. 2002. Policy synergies between nutrient over-enrichment and climate change. Estuaries and Coasts, 25, 869-877.

GAMISES, F. 2009. The study of spatial and temporal aspects of denitrification processes in Roxo Catchment,Portugal. MSc Master of science, Twente.

GITAU, M. 2008. Use of the SWAT model to quantify water quality effects of agricultural BMPs at the farm scale level. Transactions of the Asabe, 51, 1925-1936.

GÖKMEN, 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. MSc., INTERNATIONAL INSTITUTE FOR GEO-INFORMATION SCIENCE AND EARTH OBSERVATION.

GRIENSVEN, A. 2007. Sensitivity, auto-calibration , uncertainty and model evaluation in SWAT2005. 48.

GURUNG. 2007. modelling of eutophication in Roxo reservoir,a system based approach. INTERNATIONAL INSTITUTE FOR GEO-INFORMATION SCIENCE AND EARTH OBSERVATION.

HÅKANSON, L. & BRYHN, A. 2008. A Dynamic Mass-balance Model for Phosphorus in Lakes with a Focus on Criteria for Applicability and Boundary Conditions. Water, Air, & Soil Pollution, 187, 119-147.

HEJZLAR, J., ŠÁMALOVÁ, K., BOERS, P. & KRONVANG, B. 2006. Modelling Phosphorus Retention in Lakes and Reservoirs. Water, Air, & Soil Pollution: Focus, 6, 487-494.

JAYAKRISHNAN, R., SANTHI, S. & ARNOLD, J. 2005. Advances in the application of the SWAT model for water resources management. 749–762

MALMAEUS, J. M. 2004. Variation in the Settling Velocity of Suspended Particulate Matter in Shallow Lakes, with Special Implications for Mass Balance Modelling. International Review of Hydrobiology, 89, 426-438.

MARSILI, S. & GIUSTI, E. 2007. Water quality modelling for small river basins. 13.

MCCUEN, R. H., KNIGHT, Z. & CUTTER, A. G. 2006. Evaluation of the Nash--Sutcliffe Efficiency Index. Journal of Hydrologic Engineering, 11, 597-602.

MEKONNEN, S. C. 2005. Assessment of catchment water balance usin GIS and remote sensing;Roxo,Portugal.

MIGLIACCIO, K. W., CHAUBEY, I. & HAGGARD, B. E. 2007. Evaluation of landscape and instream modeling to predict watershed nutrient yields. Environ. Model. Softw., 22, 987-999.

MISHRA, V. 2001. Automatic delineation of watersheds for hydrological applications.

MOHSENI, O. & STEFAN, H. G. 1999. Stream temperature/air temperature relationship: a physical interpretation. Journal of Hydrology, 218, 128-141.

NEITSCH, S., ARNOLD, J. & KINIRY, J. 2005. Soil and Water Assessment Tool Theoretical Documentation and User's Manual.

NEITSCH, S., ARNOLD, J., KINIRY, J., SRINIVASAN, R. & WILLIAMS, J. 2004. soil and water assessment tool input/output file documentation version 2005. 19.

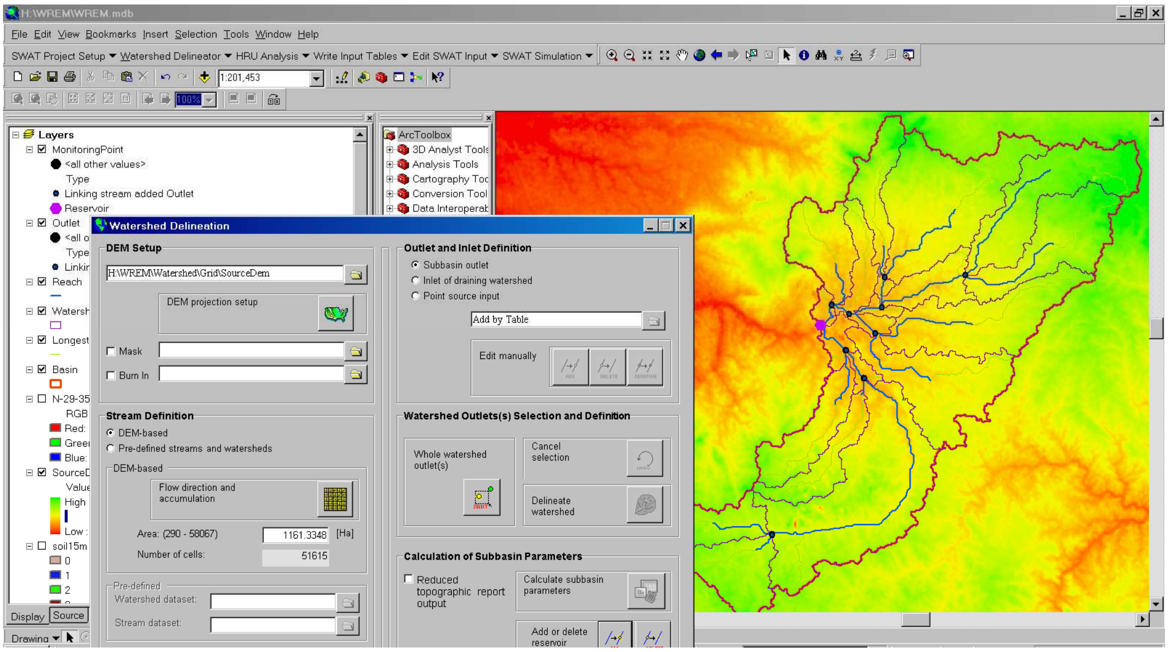
NEITSCH.S.L, ARNOLD, J. G., KINIRY.J.R & WILLIAMS.J.R 2005. Soil and Water Assessment Tool Theoretical Documentation and User's Manual.

OLIVERA, F. 1999. GIS Tools for HMS Modeling Support.

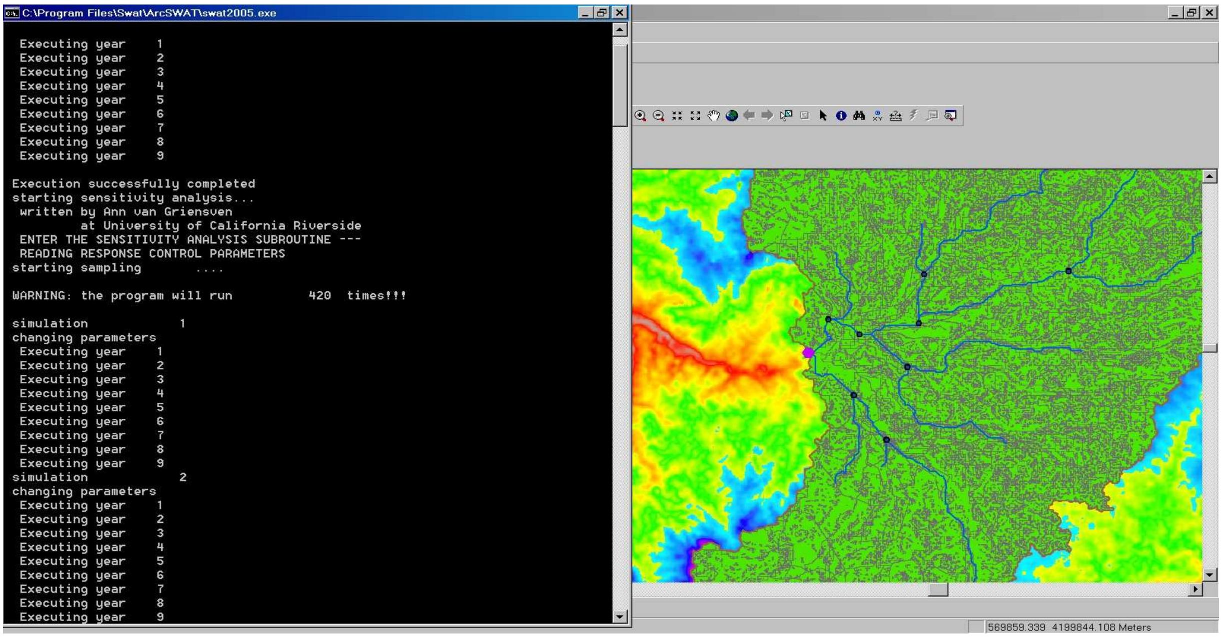
ONDERKA, M. 2007. Correlations between several environmental factors affecting the bloom events of cyanobacteria in Liptovska Mara reservoir (Slovakia)--A simple regression model. Ecological Modelling, 209, 412-416.

PANUSKA, J. C. & ROBERTSON, D. M. 1999. Estimating Phosphorus Concentrations Following Alum Treatment Using Apparent Settling Velocity. Lake and Reservoir Management, 15, 28 - 38.

PERKA, M. V. D., BLAKEBMARC, W. H., EISMAC, M. & DR. PHILIP, N. O. 2008. Decision support tools for sediment management. Sustainable Management of Sediment Resources. Elsevier.
PRSCILLA, I. 2009. Integration of satellite data in the SWAT watershed water quality model:a case study of Roxo reservoir watershed,Portugal. MSc., Twente.
RECKHOW, K. H. & CHAPRA, S. C. 1999. Modeling excessive nutrient loading in the environment. Environmental Pollution, 100, 197-207.
RICHARD, A., PEREIRA, S., RAES, D. & MARTIN, S. 2000. FAO Irrigation and drainage guidlines for computing crop water requirements
RYDIN, E. & WELCH, E. B. 1999. Dosing Alum to Wisconsin Lake Sediments Based on <i>in vitro</i> Formation of Aluminum Bound Phosphate. Lake and Reservoir Management, 15, 324 - 331.
SALEH, A. & DU, B. 2004. evaluation of swat and hspf within basins program for the upper north bosque river watershed in central texas
Vol. 47(4): 1039−1049, 12.
SEO, D.-I. & CANALE, R. P. 1996. Performance, reliability and uncertainty of total phosphorus models for lakes--I. Deterministic analyses. Water Research, 30, 83-94.
SETEGN, S. G., SRINIVASAN, R., MELESSE, A. M. & DARGAHI, B. 2009. SWAT model application and prediction uncertainty analysis in the Lake Tana Basin, Ethiopia. Hydrological Processes, 9999, n/a.
SRINIVAS.B 1988. High Resolution DTM Process to generate accurate River Network for Efficient Water Resource Management.
SRINIVASAN, R. & GRIENSVEN, A. 2007. SWAT calibration techniques. calibration and validation techniques of flow and nutrients.
STEFOULI, M. 2007. Study of Prespa and Vegoritis lakes using multi sensor sensing data.
TOLSON, B. A. & SHOEMAKER, C. A. 2007. Cannonsville Reservoir Watershed SWAT2000 model development, calibration and validation. Journal of Hydrology, 337, 68-86.
VITHANAGE. 2009. Analysis of nutrient dynamics in Roxo catchment using remote sensensing data and numerical modelling. MSc.
VOLK, M., LIERSCH, S. & SCHMIDT, G. 2008. Towards the implementation of the EuropeanWater Framework Directive?Lessons learned from water quality simulations in an agricultural watershed. 580-589.
XU 2007. The hydrological calibration and validation of a complexly-linked watershed-reservoir model for the Occoquan watershed, Virginia. Journal of Hydrology, 345, 167-183.
ZAKIROV, A. & FROLOVA, L. 2004. Model of influence of reservoir shape on processes of self-cleaning.
ZHANG 2005. Modelling of point and non-point nutrient loadings from a watershed. Environmental Modelling & Software, 20, 561-574.



Appendix A: Watershed delineation of Roxo catchment



Appendix B: Sensitivity analysis of the SWAT model

Appendix C: Roxo catchment summary of sub-basins, HRUs and elevation report generated by SWAT model

SWAT model simulation Date: 11/19/2009 12:00:00 AM Time: 00:00:00
MULTIPLE HRUs Land Use/Soil/Slope OPTION THRESHOLDS: 1 / 10/7(%)
Number of HRUs: 322
Number of Sub-basins: 20
Watershed: 35280.1350

Elevation report for the watershed
Min. Elevation: 76
Max. Elevation: 289
Mean. Elevation: 169.638203773441
Std. Deviation: 27.0243851892308

Appendix D: Detail sample summary reports of points A_19 and A_27

Sample Date	9/9/2009	
Station	A-16	
Location		
Geology		
Watertype	Na-Cl-HCO3	
Temperature (°C)	30.20	
pH	9.54	
Conductivity	454.00	uS/cm

Sum of Anions	15.24	meq/L
Sum of Cations	6.03	meq/L
Balance	43.27	%

Total dissolved solids	778.21	mg/L
Total hardness	178.11	mg/l CaCO3
Alkalinity	215.13	mg/l CaCO3

Major ion composition	mg/l	mmol/l	meq/l
Na	56.04	2.44	2.44
K	1.24	0.032	0.032
Ca	34.35	0.86	1.71
Mg	22.42	0.92	1.84
Cl	352.00	9.93	9.93
SO4	47.00	0.49	0.98
NO3	2.50	0.03	0.03
HCO3	262.30	4.30	4.30

Ratios			Comparison to Seawater	
	mg/l	mmol/l	mg/l	mmol/l
Ca/Mg	1.53	0.93	0.319	0.194
Ca/SO4	0.73	1.75	0.152	0.364
Na/Cl	0.16	0.25	0.556	0.858
Cl/Br			287	648

Sample Summary Report : A-19

Sample Date	9/10/2009
Station	A-19
Location	
Geology	
Watertype	Na-Mg-Ca-Cl-HCO3
Temperature (°C)	27.50
pH	9.61

Conductivity	1392.00	uS/cm		
Sum of Anions	13.99	meq/L		
Sum of Cations	10.24	meq/L		
Balance	15.47	%		
Total dissolved solids	785.46	mg/L		
Total hardness	301.99	mg/l CaCO3		
Alkalinity	150.34	mg/l CaCO3		
Major ion composition	mg/l	mmol/l	meq/l	
Na	95.20	4.14	4.14	
K	2.30	0.059	0.059	
Ca	58.92	1.47	2.94	
Mg	37.60	1.55	3.09	
Cl	340.00	9.59	9.59	
SO4	65.00	0.68	1.35	
NO3	2.90	0.04	0.04	
HCO3	183.30	3.00	3.00	
Ratios			Comparison to Seawater	
	mg/l	mmol/l	mg/l	mmol/l
Ca/Mg	1.57	0.95	0.319	0.194
Ca/SO4	0.91	2.17	0.152	0.364
Na/Cl	0.28	0.43	0.556	0.858
Cl/Br			287	648

Sample Summary Report: A-27

Sample ID	MSc_demoz	
Sample Date	9/10/2009	
Station	A-27	
Location		
Geology		
Watertype	Na-Mg-Ca-Cl-HCO3	
Temperature (°C)	28.30	
pH	9.81	
Conductivity	452.00	uS/cm
Sum of Anions	16.55	meq/L
Sum of Cations	16.20	meq/L
Balance	1.06	%
Total dissolved solids	1020.38	mg/L
Total hardness	464.17	mg/l CaCO3
Alkalinity	215.13	mg/l CaCO3

Major ion composition	mg/l	mmol/l	meq/l
Na	157.84	6.87	6.87
K	2.16	0.055	0.055
Ca	80.00	2.00	3.99
Mg	64.20	2.64	5.28
Cl	380.00	10.72	10.72
SO4	73.00	0.76	1.52
NO3	0.60	0.01	0.01
HCO3	262.30	4.30	4.30

Ratios			Comparison to Seawater	
	mg/l	mmol/l	mg/l	mmol/l
Ca/Mg	1.25	0.76	0.319	0.194
Ca/SO4	1.10	2.63	0.152	0.364
Na/Cl	0.42	0.64	0.556	0.858
Cl/Br			287	648

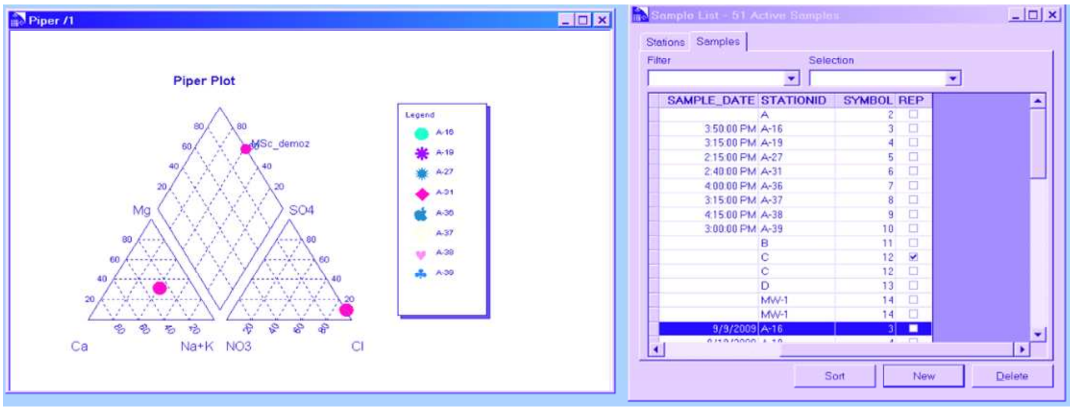
Appendix E: Balance check for anion-cation, conductivity, and total dissolved solid and others of sample A_19 and A_27

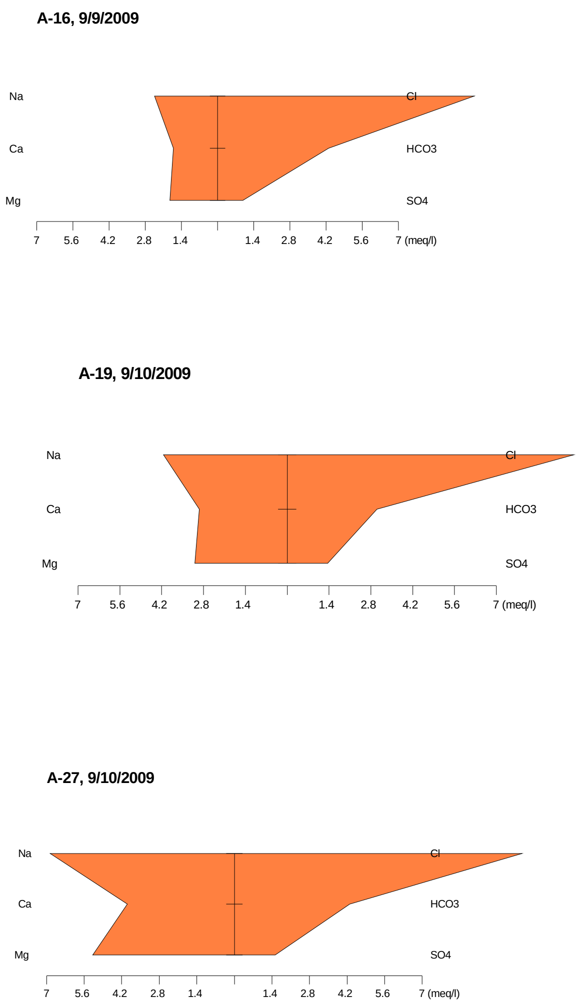
Sample Designation: A_19			
Check	Attention Value	Analysis Value	Result
Balance (C-A)/(C+A)*100	<5%	-0.33	Pass
TDS: (Entered - calculated)/Entered*100	<5%	24.36	Fail
TDS: (Entered - TDS180 calculated)/Entered*100	<5%	0.03	Pass
TDS Entered/Conductivity	55< ## <75%	108	Fail
Conductivity/sum MEQ Cations	90< ## <110%	5164	Fail
K+/(Na+ + K+)	<20%	13	Pass
Mg++/(Ca++ + Mg++)	<40%	37	Pass
Ca++/(Ca++ + SO4-)	>50%	83	Pass
Na+/(Na+ + Cl-)	>50%	89	Pass

Sample Designation: A_27			
Check	Attention Value	Analysis Value	Geschulpt
Balance (C-A)/(C+A)*100	<5%	-0.33	Pass
TDS: (Entered - calculated)/Entered*100	<5%	24.36	Fail
TDS: (Entered - TDS180 calculated)/Entered*100	<5%	0.03	Pass
TDS Entered/Conductivity	55< ## <75%	108	Fail
Conductivity/sum MEQ Cations	90< ## <110%	5164	Fail
K+/(Na+ + K+)	<20%	13	Pass
Mg++/(Ca++ + Mg++)	<40%	37	Pass

Ca++/(Ca++ + SO4-)	>50%	83	Pass
Na+/(Na+ + Cl-)	>50%	89	Pass

Appendix F: Piper test for the selected sample points





Appendix G: Stiff graph of A_16, A_19 and A_27 sample points

Appendix H: Water quality parameters measured on site and laboratory during field visit of Roxo reservoir

points	X-Cor	Y-Cor	Ele(m)	SDepth(m)	TSS(mg/l)	Turbidity (NTU)
A-19	580863	4198543	217	1.8	11.7	6.5
A-37	581852	4197501	133	0.82	19.4	8.24
A-36	580863	4198094	138	0.81	21.2	11.5
A-38	582012	4199819	149	0.71	45.3	14.8
A-39	582399	4200017	106	0.58	61.2	18.4
A-16	583835	4195981	136	0.29	77.9	25.1
A-27	585011	4200365	252	0.25	91	28.3
A-31	583990	4198903	215	0.12	267	44.2

Cl(mg/l)	EC(µs/cm)	HCO3- (mg/l)	Ca(mg/l)	Mg(mg/l)	Na(mg/l)	Si(mg/l)	Al(mg/l)	Fe(mg/l)
340	1392	183	58.92	37.575	95.145	0.085	0.06	0.01
330	1417	213.5	85.875	60.865	148.375	0.11	0.08	0.03
350	1398	244	44.09	27.935	68.945	0.075	0.06	0.03
350	1416	219.6	25.325	18.035	46.955	0.055	0.06	0.02
368	1437	207.4	36.45	25.61	64.92	0.075	0.08	0.07
352	454	262.3	34.345	22.42	56.035	0.085	0.08	0.06
380	452	262.3	79.885	64.115	157.84	0.11	0.075	0.02
360	1469	170.8	54.035	43.18	107.045	0.085	0.3	0.39

P2O5(mg/l)	PO4(mg/l)	P(mg/l)	SO4(mg/l)	NO3- N(mg/l)	NO3(mg/l)	NH4(mg/l)
0.05	0.05	0.05	65	0.7	2.9	0.05
0.01	0.05	0.05	52	0.3	1.4	0.02
0.01	0.05	0.05	69	0.5	2.2	0.04
0.02	0.06	0.06	68	0.3	1.4	0.07
0.06	0.08	0.08	42	0.6	2.5	0.07
0.09	0.04	0.04	47	0.6	2.5	0.06
0.01	0.02	0.02	73	0.3	0.6	0.04
0.05	0.14	0.14	48	0.8	3.5	0.06

NH3- N(mg/l)	NH3(mg/l)	TN(mg/l)	TKN(mg/l)	TP(mg/l)	PH(mg/l)	DO(mg/l)
0.04	0.05	3.04	0.14	0.15	9.61	7.26

0.01	0.01	1.44	0.04	0.11	9.62	7.27
0.03	0.04	2.31	0.11	0.11	9.63	7.5
0.06	0.07	1.6	0.2	0.14	9.65	7.4
0.05	0.06	2.68	0.18	0.22	9.62	7.47
0.05	0.06	2.67	0.17	0.17	9.54	6.69
0.03	0.03	0.7	0.1	0.05	9.81	8.47
0.05	0.06	3.67	0.17	0.33	9.89	9.58

Appendix I: Soil characterstics of Roxo catchment used for the model

Soil code	SWAT soil	Soil texture	Soil character
AH	AH0001	Clay loam	Alluvial soils
BPC	BPC002	Clay	Vertisols – calcareous black, strongly decarbonated
CPH	CPH003	Clay	Vertisols – calcareous black, strongly decarbonated
PAG	PAG004	Silty loam	Brown Mediterranean Soils from Non-calcareous rocks - hydromorphic
PB	PB0005	Clay loam	Hydromorphic soils(without alluvial horizon –unsaturated
PS	PS0006	Loam	Hydromorphic soils with alluvial horizon – planosols
PX	PX0007	Clay loam	Brown Mediterranean Soils from Non-calcareous rocks
PXD	PXD008	Loam	Brown Mediterranean Soils from Non-calcareous rocks –normal
SP	SP0009	Silty clay	Hydromorphic soils hydromorphic organic soils
SR	SR0010	Loam	Red-yellow Mediterranean soils from non-calcareous rocks
VC	VC0011	Clay loam	Red calcareous soils red calcareous soils of semi-arid climate/ normal
VX	VX0012	Clay loam	Red-yellow Mediterranean soils from non-calcareous rocks/ normal

Soil character: Cardoso, 1965, Os Solos De Portugal

Appendix J: Portion of land use, soil, slope and their corresponding area used in the model

SUBBASIN	LU_CODE	SOIL_NUM	SOIL_CODE	MEAN_SLOPE	AREA	UNCOMB
13	RFAL	8	PXD008	1.013873577	4.8375	RFAL_PXD008
13	RFAL	6	PS0006	4.972372532	22.095	RFAL_PS0006
13	RFAL	12	VX0012	4.942148685	0.405	RFAL_VX0012
13	RFAL	12	VX0012	1.008610129	0.405	RFAL_VX0012
13	WATR	8	PXD008	5.491978168	25.425	RFAL_PXD008
13	RFAL	12	VX0012	6.969592094	22.1625	WATR_VX0012
13	AGRC	1	AH0001	1.179831982	9.8775	RFAL_AH0001
13	RFAL	12	VX0012	7.819442749	27.135	AGRC_VX0012
13	WATR	1	AH0001	4.880764008	63.0225	RFAL_AH0001
13	WATR	12	VX0012	1.15438652	2.43	WATR_VX0012
13	RFAL	1	AH0001	1.340895176	1.215	WATR_AH0001
13	WATR	10	SR0010	4.739098072	0.045	RFAL_SR0010
13	WATR	10	SR0010	12.92580032	8.37	WATR_SR0010
13	WATR	4	PAG004	1.224241495	6.7725	WATR_PAG004
13	WATR	6	PS0006	8.125256538	30.915	WATR_PS0006
13	RFAL	3	CPH003	13.28442478	6.2325	WATR_CPH003
13	RFAL	4	PAG004	5.110088348	25.335	RFAL_PAG004

13	RFAL	4	PAG004	0.992006004	3.9825	RFAL_PAG004
13	AGRC	6	PS0006	1.393891454	3.0375	RFAL_PS0006
13	WATR	12	VX0012	1.094366431	1.8	AGRC_VX0012
13	PAST	4	PAG004	12.44815826	132.66	WATR_PAG004
13	PAST	4	PAG004	5.348863602	0.4275	PAST_PAG004
13	WATR	4	PAG004	1.901025176	0.0225	PAST_PAG004
13	PAST	1	AH0001	4.145147324	5.49	WATR_AH0001
13	WATR	6	PS0006	4.905490398	19.6875	PAST_PS0006
13	PAST	6	PS0006	1.227729321	2.0475	WATR_PS0006
13	WATR	6	PS0006	0.862804472	2.5875	PAST_PS0006
13	RFAL	10	SR0010	1.592292786	0.135	WATR_SR0010
14	WATR	12	VX0012	9.274608612	0.27	RFAL_VX0012
14	RFAL	12	VX0012	1.32362926	0.9225	WATR_VX0012
14	RFAL	8	PXD008	0.984864712	4.6575	RFAL_PXD008
14	RFAL	10	SR0010	1.180489421	4.2075	RFAL_SR0010
14	AGRC	1	AH0001	5.52120924	32.04	RFAL_AH0001
14	AGRC	10	SR0010	0.614079893	0.9	AGRC_SR0010
14	AGRC	1	AH0001	7.043404102	27.6525	AGRC_AH0001
14	AGRC	11	VC0011	0.955189049	2.0925	AGRC_VC0011
14	AGRC	11	VC0011	4.84266901	9.6975	AGRC_VC0011
14	AGRC	1	AH0001	1.396869183	1.665	AGRC_AH0001
14	RFAL	12	VX0012	7.480499744	10.395	AGRC_VX0012
14	RFAL	9	SP0009	5.383751392	37.125	RFAL_SP0009
14	RFAL	10	SR0010	4.690425873	14.895	RFAL_SR0010
14	RFAL	11	VC0011	3.61474967	3.15	RFAL_VC0011
14	AGRC	9	SP0009	1.099145889	5.04	RFAL_SP0009
14	WATR	10	SR0010	5.252162933	2.25	AGRC_SR0010
14	AGRC	1	AH0001	7.428303242	9.1125	WATR_AH0001
14	WATR	12	VX0012	1.266312957	0.945	AGRC_VX0012
14	WATR	1	AH0001	1.135195971	1.755	WATR_AH0001

Appendix K: Part of soil parameters used in the model

SOIL	HYDGRP	SOL_ZMX	ANION_EXCL	SOL_CRK	TEXTURE	SOL_Z1	SOL_BD1
VX0012	B	165	0.5	0.5	CLAY_LOAM	101.6	1.87
AH0001	D	200	0.5	0.5	CLAY_LOAM	101.6	0.9
AH0001	D	200	0.5	0.5	CLAY_LOAM	101.6	0.9
PAG004	B	100	0.5	0.5	SIL_LOAM	80	1.69
PAG004	B	100	0.5	0.5	SIL_LOAM	80	1.69

PS0006	B	250	0.5	0.5	LOAM	101.6	1.66
PS0006	B	250	0.5	0.5	LOAM	101.6	1.66
PXD008	A	150	0.5	0.5	LOAM	101.6	1.59
PXD008	A	150	0.5	0.5	LOAM	101.6	1.59
PS0006	B	250	0.5	0.5	LOAM	101.6	1.66
PS0006	B	250	0.5	0.5	LOAM	101.6	1.66
PAG004	B	100	0.5	0.5	SIL_LOAM	80	1.69
PS0006	B	250	0.5	0.5	LOAM	101.6	1.66
VX0012	B	165	0.5	0.5	CLAY_LOAM	101.6	1.87
VX0012	B	165	0.5	0.5	CLAY_LOAM	101.6	1.87

SOL_AWC1	SOL_K1	SOL_CBN1	CLAY1	SILT1	SAND1	ROCK1	SOL_ALB1	USLE_K1
0.13	7.44	1.1	35.5	31.9	32.7	17.5	0.01	0.333
0.12	1.02	0.9	44.8	21.6	33.7	16.6	0.01	0.324
0.12	1.02	0.9	44.8	21.6	33.7	16.6	0.01	0.324
0.12	5.88	0.8	25.3	34.8	39.95	26.1	0.01	0.321
0.12	5.88	0.8	25.3	34.8	39.95	26.1	0.01	0.321
0.13	5.52	1.3	27	36	37	15.5	0.01	0.33
0.13	5.52	1.3	27	36	37	15.5	0.01	0.33
0.13	11.8	1.7	29	32.4	38.6	23.3	0.01	0.331
0.13	11.8	1.7	29	32.4	38.6	23.3	0.01	0.331
0.13	5.52	1.3	27	36	37	15.5	0.01	0.33
0.13	5.52	1.3	27	36	37	15.5	0.01	0.33
0.12	5.88	0.8	25.3	34.8	39.95	26.1	0.01	0.321
0.13	5.52	1.3	27	36	37	15.5	0.01	0.33
0.13	7.44	1.1	35.5	31.9	32.7	17.5	0.01	0.333
0.13	7.44	1.1	35.5	31.9	32.7	17.5	0.01	0.333

Appendix L: Observed and simulated flow data

Date	Flow cal(cms)	Flow observed(cms)
Sep-01	0.01405	0.700
Oct-01	0.559	0.643
Nov-01	0.4391	0.455
Dec-01	0.8627	0.552
Jan-02	0.8161	1.148
Feb-02	0.4845	0.549
Mar-02	1.008	1.359
Apr-02	1.563	1.096

May-02	0.6085	0.645
Jun-02	0.1349	0.829
Jul-02	0.02275	0.912
Aug-02	0.000007522	0.483
Sep-02	0.4512	0.294
Oct-02	0.3026	0.305
Nov-02	1.164	0.387
Dec-02	1.778	3.050
Jan-03	1.65	2.512
Feb-03	1.403	3.351
Mar-03	0.8316	1.070
Apr-03	1.08	1.807
May-03	0.4432	0.946
Jun-03	0.102	0.786
Jul-03	0.01219	0.764
Aug-03	0	0.730
Sep-03	0.06625	0.512
Oct-03	0.8532	0.427
Nov-03	1.096	1.300
Dec-03	1.473	2.539
Jan-04	0.8353	0.660
Feb-04	0.8734	1.745
Mar-04	1.668	1.191
Apr-04	1.077	0.758
May-04	0.5803	0.603
Jun-04	0.107	0.778
Jul-04	0.01282	0.769
Aug-04	0.001432	0.440
Sep-04	0	0.358
Oct-04	0.2579	0.120
Nov-04	0.1866	0.169
Dec-04	0.335	0.215
Jan-05	0.1148	0.186
Feb-05	0.02628	0.209
Mar-05	0.01155	0.292
Apr-05	0	0.314
May-05	0.05562	0.394
Jun-05	0.001428	0.662
Jul-05	0	0.151
Aug-05	0	0.666
Sep-05	0	0.564
Oct-05	0.688	0.219
Nov-05	1.328	0.896
Dec-05	1.427	0.787
Jan-06	1.069	0.479
Feb-06	0.6982	0.493

Mar-06	1.318	1.025
Apr-06	0.7236	0.577
May-06	0.2294	0.508
Jun-06	0.04603	0.440
Jul-06	0.0007857	0.400
Aug-06	0.0001209	0.351
Sep-06	0.0009652	0.212
Oct-06	1.6	1.751
Nov-06	7.86	9.660
Dec-06	3.814	2.630
Jan-07	1.958	1.540
Feb-07	1.054	0.603
Mar-07	0.4251	1.230
Apr-07	0.3938	0.850
May-07	0.4243	0.810
Jun-07	0.132	0.680
Jul-07	0.009337	0.737
Aug-07	0.001115	0.588
Sep-07	0.004125	0.447
Oct-07	0.01109	0.187
Nov-07	0.09079	0.184
Dec-07	0.08508	0.201
Jan-08	0.8324	0.302
Feb-08	1.204	1.192
Mar-08	0.7597	1.192
Apr-08	0.9582	0.635
May-08	0.4465	0.063
Jun-08	0.09959	0.140
Jul-08	0.01181	0.030
Aug-08	0	0.010
Sep-08	0.01178	0.070
Oct-08	0.02002	0.080
Nov-08	0.08285	0.090
Dec-08	0.2702	0.031
Jan-09	0.6658	1.200
Feb-09	1.258	1.900
Mar-09	0.6018	0.800
Apr-09	0.2758	0.400
May-09	0.02578	0.060
Jun-09	0.001563	0.010
Jul-09	0	0.020
Aug-09	0	0.010
Sep-09	0.00007626	0.010
Oct-09	0.06843	0.100

Appendix M: Observed and simulated sediment load

date	Sediment_Cal_ (tons)	Sediment_Obs (tonS)
Sep-01	71.01	63.525
Oct-01	31.22	29.652
Nov-01	25.76	21.962
Dec-01	19.2	15.097
Jan-02	15.14	7.021
Feb-02	18.81	12.217
Mar-02	23.94	32.264
Apr-02	36.56	14.638
May-02	81.48	31.273
Jun-02	123.6	72.558
Jul-02	162.8	110.727
Aug-02	125.6	92.070
Sep-02	45.39	11.745
Oct-02	17.21	19.379
Nov-02	13.23	15.170
Dec-02	12.39	9.797
Jan-03	17.32	6.164
Feb-03	14.87	22.118
Mar-03	23.26	15.005
Apr-03	27.64	16.460
May-03	85.21	27.279
Jun-03	126	66.503
Jul-03	139.8	102.004
Aug-03	125.6	108.810
Sep-03	62.69	51.811
Oct-03	23.37	25.808
Nov-03	14.26	18.880
Dec-03	13.24	7.572
Jan-04	11.11	3.259
Feb-04	13.1	10.851
Mar-04	23.43	6.192
Apr-04	40.81	24.315
May-04	64.48	42.009
Jun-04	118.1	184.599
Jul-04	150	239.899
Aug-04	103.5	131.142
Sep-04	54.53	34.572
Oct-04	26.02	17.134
Nov-04	10.37	9.715
Dec-04	11.13	10.391

Jan-05	10.47	7.908
Feb-05	11.99	8.277
Mar-05	16.91	10.566
Apr-05	22.29	7.861
May-05	28.02	9.491
Jun-05	34.84	16.587
Jul-05	31.28	12.102
Aug-05	29.55	10.047
Sep-05	21.62	9.233
Oct-05	13.61	17.731
Nov-05	9.999	9.498
Dec-05	9.373	6.879
Jan-06	9.597	6.471
Feb-06	10.7	4.023
Mar-06	16.46	5.456
Apr-06	25.49	13.670
May-06	35.39	14.660
Jun-06	35.75	28.048
Jul-06	36.54	15.116
Aug-06	37.96	30.399
Sep-06	22.74	20.380
Oct-06	15.97	7.386
Nov-06	19.65	33.105
Dec-06	15.39	19.766
Jan-07	13.92	7.844
Feb-07	17.69	6.577
Mar-07	35.16	18.273
Apr-07	45.73	22.794
May-07	75.79	30.912
Jun-07	84.14	50.146
Jul-07	118.4	48.922
Aug-07	101.4	50.682
Sep-07	58.14	31.654
Oct-07	27.23	11.929
Nov-07	17.19	64.463
Dec-07	12.34	16.590
Jan-08	13.62	4.462
Feb-08	17.28	14.178
Mar-08	30.24	28.786
Apr-08	39.15	42.004
May-08	52.16	60.194
Jun-08	80.44	70.710
Jul-08	99.3	108.141
Aug-08	81.04	17.828

Sep-08	47.06	14.620
Oct-08	22.49	11.623
Nov-08	13.7	5.337
Dec-08	12.42	12.414
Jan-09	13.54	12.048
Feb-09	16.34	14.733
Mar-09	28.97	22.769
Apr-09	36.66	26.642
May-09	50.14	31.602
Jun-09	77.21	38.491
Jul-09	99.09	8.048
Aug-09	82.67	7.717
Sep-09	48.91	6.739

Appendix N: Observed and simulated total nitrogen

Date	Total nitrogen observed(kg)	Total nitrogen simulated(kg)
Sep-01	3.50E+03	7.26E+03
Oct-01	2.34E+03	3.62E+03
Nov-01	2.81E+03	4.03E+03
Dec-01	2.68E+03	3.09E+03
Jan-02	5.15E+03	2.71E+03
Feb-02	1.40E+03	3.47E+03
Mar-02	2.19E+03	4.53E+03
Apr-02	3.36E+03	7.66E+03
May-02	8.37E+03	1.75E+04
Jun-02	5.17E+03	2.50E+04
Jul-02	6.48E+03	3.12E+04
Aug-02	6.10E+03	2.32E+04
Sep-02	2.10E+03	8.32E+03
Oct-02	1.43E+03	4.09E+03
Nov-02	2.03E+03	3.14E+03
Dec-02	2.18E+03	3.38E+03

Jan-03	3.79E+03	5.28E+03
Feb-03	3.53E+03	4.41E+03
Mar-03	4.73E+03	6.82E+03
Apr-03	1.98E+03	7.84E+03
May-03	3.32E+03	2.37E+04
Jun-03	1.07E+04	3.30E+04
Jul-03	9.58E+02	3.48E+04
Aug-03	1.09E+03	3.02E+04
Sep-03	6.55E+02	1.43E+04
Oct-03	1.62E+03	5.12E+03
Nov-03	2.15E+03	3.73E+03
Dec-03	3.12E+03	3.97E+03
Jan-04	2.59E+03	3.48E+03
Feb-04	2.05E+03	3.81E+03
Mar-04	3.11E+03	6.24E+03
Apr-04	5.75E+03	1.16E+04
May-04	8.86E+03	1.76E+04
Jun-04	1.65E+04	3.03E+04
Jul-04	2.19E+04	3.66E+04
Aug-04	1.29E+04	2.42E+04
Sep-04	7.98E+03	1.21E+04
Oct-04	2.70E+03	5.42E+03
Nov-04	1.59E+03	2.43E+03
Dec-04	2.36E+03	2.52E+03
Jan-05	2.23E+03	2.27E+03
Feb-05	6.92E+01	2.42E+03
Mar-05	4.98E+02	3.19E+03
Apr-05	2.09E+03	3.89E+03
May-05	2.27E+03	4.60E+03
Jun-05	6.86E+02	5.50E+03
Jul-05	1.25E+03	4.70E+03
Aug-05	1.25E+03	4.28E+03
Sep-05	1.01E+03	2.99E+03
Oct-05	9.91E+02	1.95E+03
Nov-05	1.45E+03	2.08E+03
Dec-05	1.47E+03	2.39E+03
Jan-06	2.11E+03	2.57E+03
Feb-06	2.57E+03	2.84E+03
Mar-06	3.27E+03	4.36E+03
Apr-06	1.89E+03	7.26E+03
May-06	1.42E+03	9.60E+03
Jun-06	3.12E+03	9.08E+03
Jul-06	2.54E+02	8.75E+03
Aug-06	2.81E+02	8.58E+03

Sep-06	2.25E+02	4.90E+03
Oct-06	9.95E+02	3.27E+03
Nov-06	2.39E+03	5.86E+03
Dec-06	2.50E+03	6.61E+03
Jan-07	3.43E+03	5.93E+03
Feb-07	4.29E+03	6.71E+03
Mar-07	4.98E+03	1.28E+04
Apr-07	6.53E+03	1.52E+04
May-07	1.04E+04	2.40E+04
Jun-07	1.17E+04	2.53E+04
Jul-07	1.58E+04	3.38E+04
Aug-07	1.38E+04	2.78E+04
Sep-07	7.79E+03	1.51E+04
Oct-07	3.90E+03	6.70E+03
Nov-07	1.92E+03	3.96E+03
Dec-07	4.76E+02	2.66E+03
Jan-08	1.80E+03	3.00E+03
Feb-08	2.67E+03	3.93E+03
Mar-08	5.68E+03	7.35E+03
Apr-08	2.88E+03	9.20E+03
May-08	2.74E+03	1.22E+04
Jun-08	3.67E+02	1.80E+04
Jul-08	1.39E+02	2.10E+04
Aug-08	7.55E+02	1.64E+04
Sep-08	4.50E+02	9.06E+03
Oct-08	9.90E+02	4.17E+03
Nov-08	9.28E+01	2.42E+03
Dec-08	2.07E+03	2.08E+03
Jan-09	3.08E+03	2.34E+03
Feb-09	2.60E+03	3.37E+03
Mar-09	4.75E+03	6.20E+03
Apr-09	5.68E+03	7.39E+03
May-09	5.79E+02	9.49E+03
Jun-09	3.29E+03	1.36E+04
Jul-09	3.37E+03	1.65E+04
Aug-09	2.70E+03	1.31E+04
Sep-09	9.63E+02	7.37E+03
Oct-09	3.16E+02	2.20E+03