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**Estimation of impact of land use changes on
catchment hydrology and sediment load in
southern Benin**

*A thesis submitted in partial fulfillment of the
Master of Science in
Agricultural Science, Food Security and
Natural Resource Management*

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1. INTRODUCTION

1.1 Background Information

Agriculture is the most important economic sector in Benin, 60% of the active population is engaged in agricultural activities. There has been an increase in cultivated surface in Benin from 1,080,000 ha in 1961 to 1,717,000 ha in 1994, which means a relative increase of 59 % (FAO 1997). Benin's population is unevenly distributed. More than two-thirds of the people live in the south, where population densities are among the highest in West Africa. The northern half of the country is only sparsely populated.

The Abomey plateau on which the catchment area is located, is heavily influenced by its history as central territory of a formerly important kingdom. It has a population density of 225 inhabitants per km² according to the 1992 census. Nowadays, the plateau is characterised by soil degradation, scarcity of forest cover and low agricultural yields.

In the original farming systems of southern Benin there was abundant fallow land, which made it possible to practice shifting cultivation. However, due to population pressure and migration, land became scarce and as a result cropping intensity has increased and fallow period shortened. With this increasing population pressure and increasing cropping intensity, farming systems are changing from semi-permanent to continuous cropping system thus making the traditional ways of restoring soils fertility via fallow impracticable, consequently resulting in reduction of agricultural productivity.

The challenge is to bring to a halt the negative trend in agricultural productivity due to soil loss and soil degradation, and to reverse the deterioration of the productive base (soil).

The major concern of watershed management is the control of water transfer from the upper to the lower parts of a river catchment area; thus directly, affecting all the people living in the river catchment region. Water moving out of the upper part depends on the difference between the rainfall and the evapotranspiration modified by the vegetation, the depth and the water-holding capacity of the soil and the surface runoff. Through the vegetation component, the amount of water leaving the

area, and the flow of the river are dependent on land use management in this area and as such have very serious consequences for the management of land in the lower reaches of the river.

1.2 Problem Definition

One of the major strategies of soil conservation planning is the promotion of vegetation cover, because vegetation is a factor that can be easily manipulated by careful management. But the major problem of this approach is that it requires continuous, sensitive and knowledgeable management of both soil and the crop to be fully effective.

The destruction of vegetation in southern Benin is mainly a result of human action and additionally natural factors play a role (Herrmann, 2000), with this destruction and significant changes in land use it is expected that there will also be a change in hydrology of watershed in the area and other adjoining areas.

The Soil and Water Assessment Tool (SWAT) was developed to predict the impact of land management practices on water, sediment and pollution by agricultural chemicals in large complex watersheds with varying soils, land use and management conditions over long periods of time. This research applies the SWAT model to a catchment area in Southern Benin to quantify changes in

- the hydrologic parameters (water yield, soil moisture etc), and
- the sediment load into the water bodies

based on the changes in land use over the years.

The purpose of the work is to use the model

- to assess the effect of changes in land use on selected hydrologic characteristics and sediment load;
- to assess the effect of changes in weather data on the same hydrologic characteristics and sediment load with a given pattern of land use.

2. LITERATURE REVIEW

2.1 Characterization of the Study Area

The Zagbo river catchment is located in the Abomey-Bohicon region. This region is situated in the south of the Zou department (state) and covering an area of 1487 km², the Abomey plateau stretches 43 km EW between 1°53' and 2°27' eastern longitude and 37 km NS between 7°00' and 7°23' northern latitude. It is limited by the Zou river and the Zagnanando plateau in the east, in the west by the Couffo river and the Aplahoue plateau, in the north by crystalline outcrops of Dan and in the south by the Lama depression.

Three morphological units can be distinguished: a high plain exists in the north, and an inundated plain in the south, separated by a dissected plateau – Figure 1 (Houndagba, 1985). The southern plateau of the 'Terre de Barre' dominates the landscape of southern Benin, gently rising from the south to the north to a height of 250m. The sediment of the 'continental terminal' forms these plateaus, which is a fluvial continental Miocene sequence of sands, clayey sandstone and sandy clays (Stahr, 2000). The sediments belong to the quaternary, tertiary and cretaceous period (Igue & Weller 2000).

The Abomey-Bohicon region belongs to the Guinea-Congolian vegetation zone (Wezel & Böcker, 2000), this zone is characterized by a mosaic of forest and savannas, where most of the original vegetation has been replaced by secondary grasslands or savannas due to human intervention. Existing forest belongs to the semi-deciduous types, with *Albizia adiatifolia*, *A. glaberrima*, *Azelia africana*, *Cieba pentandra* and *Cola cordifolia* prevailing on ferralitic soils while *Anogeissus leiocarpus*, *Dialium guineense*, *Diospyros mespiliformis* and *Lonchocarpus sericeus* prevails on Vertisols (Adjanooun, 1989).

The savannas are mostly dominated by trees and shrubs of *Daniella oliveri* and *Parkia spp.* (Adjakidje, 1984). *Imperata cylindrica* and *Panicum maximum* are the dominant grasses on the savanna and the secondary grasslands and the latter intermix with shrub thickets consisting of various woody species (Wezel & Böcker, 2000).

The climate of southern Benin is summer humid tropical (V2) (Troll, 1965). The average daily temperature is about 27°C and the air humidity is about 95%. In the very south it is made up of two rainy and two dry seasons (Adam & Boko, 1983), towards the center the two rainy season (main raining season – March to July and minor – September to November) get closer to each other and form one big rainy season although the rainfall distribution remains bimodal and the average bimodal rainfall amounts to 1070 mm/annum in the Abomey-Bohicon region (Vodougnon & Vennemann, 1999). Rainfall distribution is highly irregular and varies strongly in time and space (Weller, 2002).

2.2 Land Use Systems and Farming Systems of the Study Area

The prevailing land use in southern Benin is food crop cultivation, with maize as the dominant food crop. Its planting dominates in the first rainy season and it is grown on almost all types of soils. In the Zou department where the study area is located the two most common crops are cotton - 26% and maize - 20% (Igue et. al., 2000). Other common crops include groundnut (13%), cassava and beans (11% each), yam, sorghum, sesame, pepper, tomato, okra and rice. Rice and vegetable production dominates in the fringes and valley bottoms.

The agricultural production in this area is traditional and is characterised by low input. This system was based on an alternating crop and fallow system (shifting cultivation). Mixed cropping systems are predominant in southern Benin due to insufficient and badly distributed rainfall. As stated earlier maize is the dominant crop and is planted sole or often mixed with other seasonal, annual or perennial crops (Cassava and groundnut). If the maize yield is relatively high, farmers' plant in the second rainy season beans and groundnuts otherwise maize is planted again in the second season (Abiassi, 2002).

Farming system and land use system differs according to environmental conditions and in the southern Zou region where the study area is located it can be classified under the southern guinea savannah zone (Wezel & Böcker, 2000). There exist also a great deal of diversity within each zone due to differences in ecological conditions, settlement patterns and access to market.

The southern part of Benin is home to about 60% of the country's total population with population density as high as 589, 469 and 250 – 300 per km² in Bohicon, Abomey and Aplahoue respectively (INSAE, 1994).

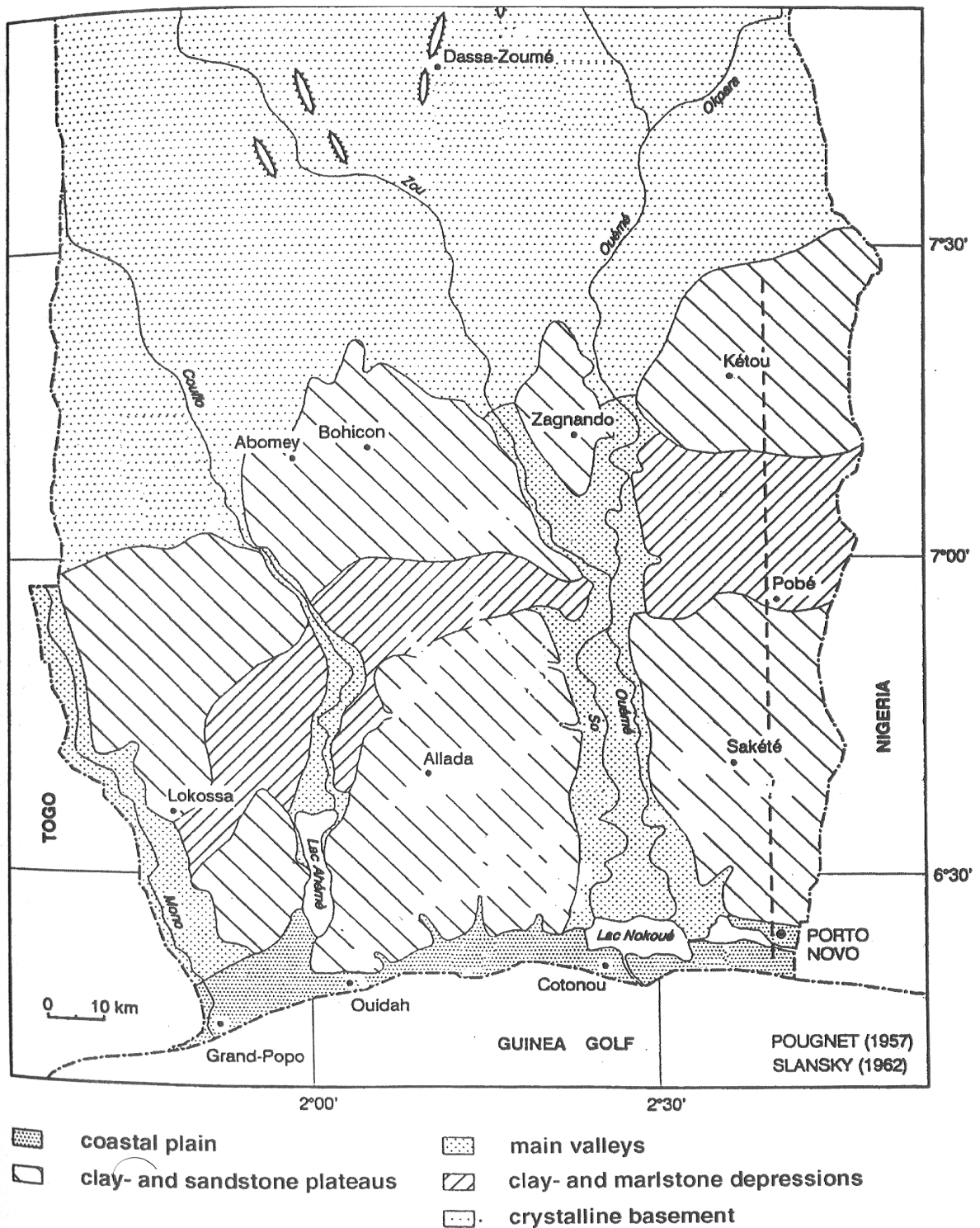


Figure 2.1: Major geomorphic units of south and central Benin (Fritz, 1996)

Most settlements can be found on the plateau while the depression and valleys are less populated. Due to this population pressure, land became scarce and as a result cropping intensity has increased and fallow period was shortened. Thus, changing farming systems from semi-permanent to continuous cropping systems thereby making the traditional ways of restoring soil fertility via fallow impracticable, leading to reduction of agricultural productivity.

2.3 Land Use Changes and Watershed Management

2.3.1 Land Use Changes

Land-use and land-cover change are significant to a lot of themes and issues and central to the study of environmental change. Alterations in the earth's surface hold major implications for the radiation balance and energy fluxes, contribute to changes in biogeochemical cycles, alter hydrological cycles and influence ecological balances and complexity. Through these environmental impacts at local, regional and global levels, land-use and land-cover changes driven by human activity have the potential to significantly affect food security and the sustainability of agricultural and forest product supply systems as it is evident in the agricultural productivity of the study area. Changes in land use and land cover will have profound regional environmental implications, such as alterations in surface runoff dynamics, lowering of groundwater tables, impacts on rates and types of land degradation and reduced biodiversity.

2.3.2 Tropical Watershed Management

According to Black (1991) watershed is an area, which catches the water from precipitation and then is drained by a river and its tributaries. It is a "resource region" where the eco-system is closely interconnected around a basic resource - water. Managing a watershed is concerned with the control of water and particularly with the transfer of water from the upper to the lower part of the catchment area. Perennial rivers in the tropics often arise in highlands with an excess of rainfall over transpiration and they then run through regions where the rainfall is less than the potential transpiration for periods of the year. So the agricultural productivity there is limited by lack of water (Russell, 1981). Therefore, making use of excess water from the upland can increase the productivity of lower reaches. The success of any watershed management scheme to increase agricultural productivity of the lower

reaches of the river therefore greatly relies on the land use system of the upland. The best land use system therefore will be a system, which maintains the infiltration rate of rain water into the soil at least as high as the normal maximum intensity of rainfall, and this condition usually prevails where the natural vegetation has been little disturbed. Most often this is a rare case, thus the amount of water the catchment can hold temporarily during prolonged or heavy rain, and the proportion of the rain that percolates into the soil, are seriously reduced.

The concept of watershed development is based on the idea that rain water can be harvested. The direct run-off of water is reduced and the groundwater recharged. Typically, it therefore encompasses the use of mechanical and vegetative structures installed across gullies and rills and along contour lines; erosion prone and less favourable lands are put under perennial vegetation, and areas are earmarked for particular land-use based on their sustainability (Shah, 1999) but without leaving out the development of the human resources as well.

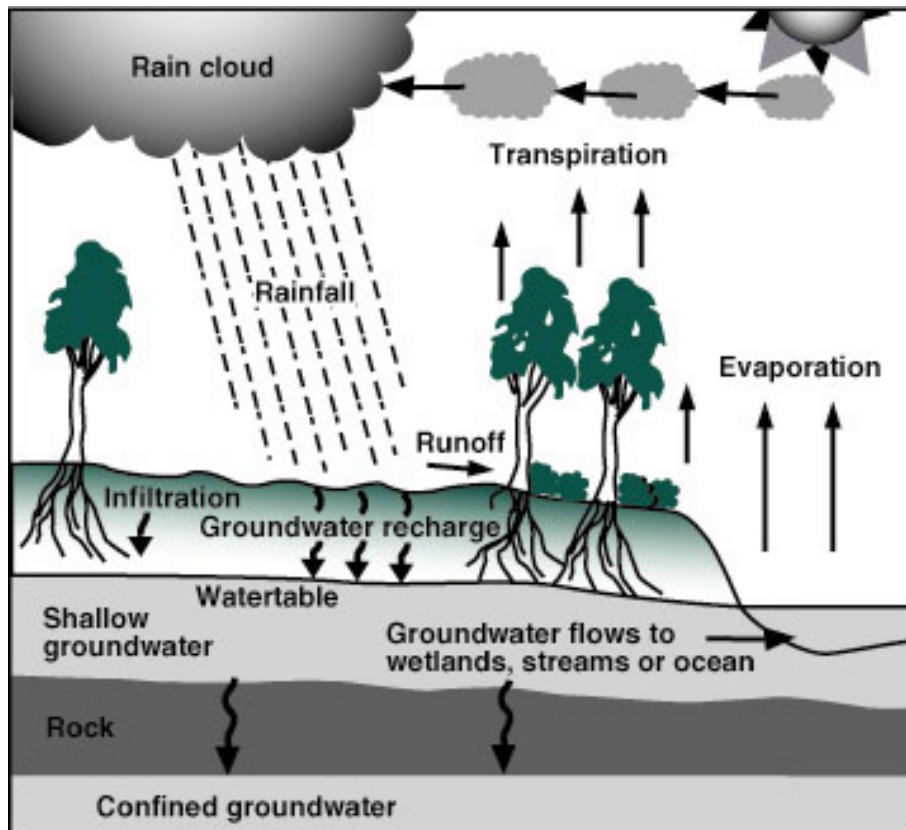
2.4 Watershed Hydrology

From the above discussion it is quite obvious that the influence of land misuse directly weigh on the watershed hydrology, thus producing unfavourable changes in the environment. Furthermore, it is not only important to discuss the impact without also making reference to the components of watershed hydrology.

Water is constantly recycled on Earth as rain, snow, oceans, lakes, streams, hail and glaciers and this is referred to as the water cycle (Fig. 2.2) and there are several parts to this.

Beginning from the atmosphere water condenses to form drops of water. When they grow to a sufficient size, they fall as precipitation (rain, snow, hail etc). Part of the precipitation intercepted by natural vegetative cover is redistributed to runoff or may evaporate directly back to the atmosphere. Precipitation also moves into the soil in one of the most important process of the hydrologic cycle- Infiltration. Percolation is the downward movement of water through the soil profile after infiltration and it may be saturated (flow governed by gravity potential) or unsaturated (flow governed by capillarity potential). The movement of water from the liquid phase to the vapor phase and then to the atmosphere, occurring from any wet surface referred to as evaporation, effectively reduces the moisture in the soil. There may also be

interception of the downward movement of water causing redistribution or it may also



indicate the amount of water lost through evaporative process following precipitation.

Figure 2.2: The hydrologic cycle or Water cycle (WRC, 2004).

Water also moves to the atmosphere through the stomata from the soil and roots via the plant's internal moisture supply system (transpiration). The combined evaporative processes are termed evapotranspiration. When the water reaches the stream it is referred to as streamflow, discharge and it may have been supplied by surface runoff, subsurface flow, storm flow and base flow (Black, 1991).

Several locations serve as storage in the hydrologic cycle, water could be stored in the aerated unsaturated portion of the soil mantle and beneath the water table under saturated conditions. Huge amount can also be stored on top of the soil in form of snow while a considerable amount could also be stored in vegetation. Surface storage could be in form of ponds, puddles, lakes and wetlands of all types as well as in rivers and stream channels.

During the period immediately following a runoff-producing event, the amount of water on the watershed naturally diminishes. As this occurs the source of water for the streamflow reduces in size, with the distant upper slopes drying out first and

according to Black (1991) in the last stages of runoff, if allowed to continue long enough, only the channel will be contributing to streamflow.

The amount of water precipitating in any given year in the hydrosphere is about 0.00046% of the total water on earth (Black, 1991). This is what makes up the part of the hydrologic cycle with which man most commonly interacts forming links between various storages and serving as the source of floods or drought. Watershed runoff exhibits different characteristics, which are dependent on the storage from which it is derived.

2.5 Soil Erosion and Sediment Yield

The rapid erosion of soil by wind and water has been a problem ever since land was first cultivated. Consequences of soil erosion are both on and off-site. Onsite are particularly important on agricultural land where the breakdown of soil structure, redistribution of soil within field, the loss from a field, and the decline in organic matter and nutrient result in a reduction of cultivable depth and a decline in soil fertility. Erosion also reduces available soil moisture, resulting in more drought-prone conditions. The net effect is a loss of productivity, which at first restricts, what can be grown and results in increased expenditure on fertilizers to maintain yield but later threatens food production and lead to land abandonment. Offsite problem result from sedimentation downstream or downwind.

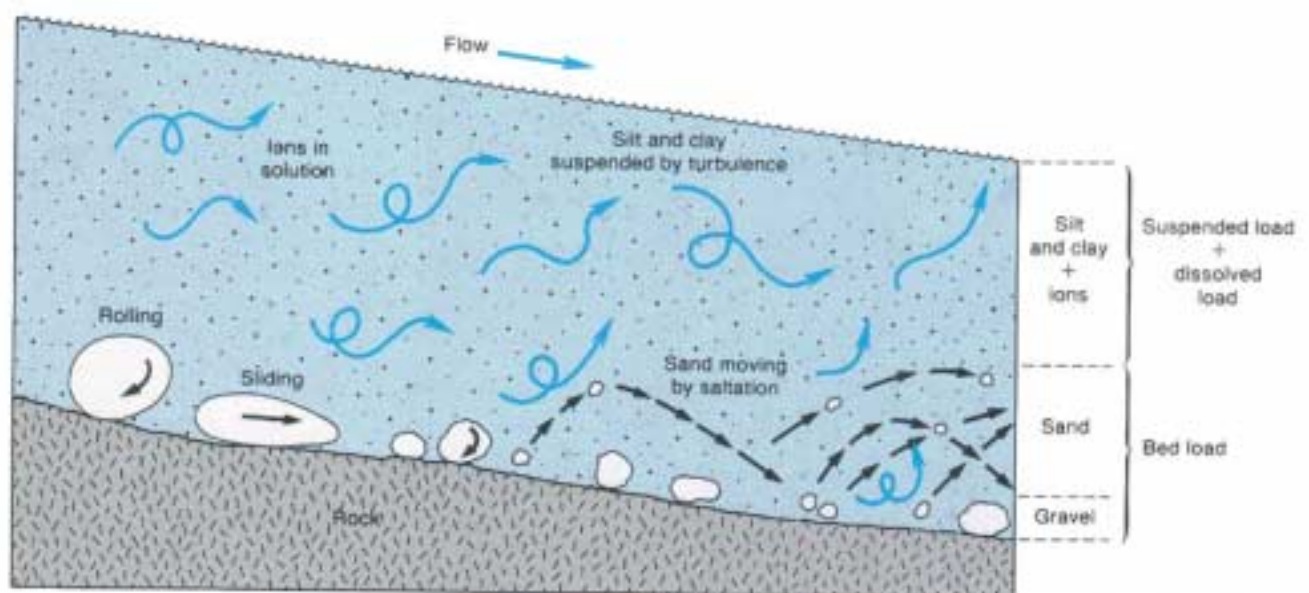


Figure 2.3: Composition and movement of sediment within the stream and along the stream bed (Stoelting, 2004).

The impact of erosional processes can be summarized under three major headings namely a) soil productivity to crops, b) flood hazards and c) the life expectancy of water storage structures. But, environmental impact of delivered sediment also represents a major concern (El-Swaify & Dangler, 1982).

Peak rainfall seasons often produce uncontrolled runoff, which may result in floods. However, natural vegetation in high rainfall areas is most adequate to minimize runoff and erosional losses during those periods. Increasing human activities have been reported to disturb the natural hydrologic pattern, thus producing floods. These were previously unknown, increasing the destructiveness of existing floods, inducing water deficit at the locations of the disturbance due to excessive water losses by runoff and evaporation.

The term sediment yield is the total sediment outflow from a watershed or drainage basin during a given time. It is the material, which is carried to some point of interest. As it is known, that not all soil loss is delivered to the stream system – deposited at various locations in the watershed. Streams transport coarse sediments as bed load, while fine sediment is transported as suspended load (Fig. 2.3).



Figure 2.4: Channel erosion as a contributor of sediment in streams

Sources of sediment include soil erosion usually carried as suspended load and material eroded from the stream channel (Fig. 2.4), which is transported as both suspended load and bed load.

The major controlling factors for sediment yields are the climate and vegetation, basin size, elevation and relief, rock and soil type, land use and human activity all which in turns determines soil erosion rate and stream capacity.

Three main procedures to estimate sediment yield are:

1. Predictive equations,
2. Gross erosion and sediment delivery ratio computations, and
3. Suspended sediment load or reservoir sediment deposition measurements.

(Mitchell & Bubenzer, 1980)

2.6 Survey of Previous Studies with SWAT

Many studies have been carried out using the SWAT model and this section intends to showcase the opinions and conclusions made by the authors in the application of this model. Arnold et al. (1999) in their studies of hydrological balance for the conterminous U.S. reported that the model gave realistic average annual runoff results without even calibration. Kin and Balogh (2001) used the model to examine the water quality impacts, which may be associated with conversion of farmland and forest to turfgrass and concluded that the model and the associated simulation and analysis strategy is a useful tool in evaluating risk associated with land use changes. The model also received the same assessment from the work of Spruill et al., (2000), where it was used to simulate the daily and monthly stream discharge and from their result they stated that it could be an effective tool for describing monthly runoff from a small watershed in central Kentucky. Bingner (1996) in his comment stated, that SWAT has the capability of adequately simulating the effects on runoff from the temporal and spatial variability of watershed characteristics, which can in turn improve the prediction of the movement of chemicals, nutrients and sediments. Using the model to estimate hydrologic budgets for three watersheds in Illinois, Arnold and Allen (1996) compared the measured and predicted values on (field-scale) and reported, that each component of the model gave reasonable output and that the interaction among components was realistic.

Marlos et al. (2003) reported the successful application of the AV2000 (Arcview Interface version of the SWAT model) in their studies in Australia but commented on the initial poor prediction (runoff) of the model and attributed this to default values of curve number (CN) and soil available water values which were based on the U.S. characteristics as well as the small size (1.8ha) of the catchment used for the study. But they indicated that the final prediction after adjustments, showed the model's flexibility to configure a catchment in an environment outside the U.S.

Applying the SWAT model by Eugenio et al (2003) in the Alban Hill (Central Italy), they reported that it was difficult to prepare dataset in the appropriate format for the simulations but opined that the model allows detailed representation of the hydrological cycle to be performed which is the basis for the reconstruction of the input of a more extensive hydrogeological model. Potential and applicability studies of the SWAT model in Check dam management was carried out by Ashok et al. (2003) and they reported that SWAT made an accurate estimation of the sediment yield and water yield after calibration as well as the sediment deposition in the check dams. The studies of Guiseppe et al. (2003) reported that the result from experimental data compared with SWAT output confirms that the model is reliable in studying the issues (diffuse pollution, damages to water resources and ecosystems etc) in their study area (Celone Creek basin, Apulia – Italy).

Numerous works has been done using the SWAT model and it has received quite good recommendation by researchers and the proceedings of the 2nd SWAT International conference of 2003 (July 1-4, 2003, Bari, Italy) attests to this. But there were also comments on difficulties of data preparation for simulation, need for appropriate adjustment for application of the model in areas apart from the U.S. and also the need for further modification of some components (e.g. tile drain and pothole components) of the model to better predict hydrological balance of watershed/catchment areas (TWRI, 2003).

3. MATERIALS AND METHODS

3.1 Zagbo Catchment

The Zagbo river catchment covers an area of about 5574 hectares, and after the processing of the DEM and the streamlines SWAT 8 subbasins were identified.

3.2 Modelling

Integrated water management of large areas can be viewed as multidimensional process centered on the need for water, the policy to meet the needs and the management to implement the policy. Therefore to say that large area water resources development and management requires an understanding of basic hydrologic processes and simulation capabilities at the river basin scale is not an unknown fact. Current concern like climate change, management of water supplies in arid regions and large scale flooding are some of the motivating factors for this kind of models.

SWAT is an operational or conceptual model that operates on a daily time step with the objective to predict the impact of land management on water, sediment and agricultural chemical yields in large ungauged basins. Satisfying this objective the model, uses readily available input for large areas, is computationally efficient to operate on large basins in a reasonable time and is continuous and capable of simulating long periods for computing the effects of management changes. (Arnold et al., 1998)

The model operation can be placed into eight major subcomponents:

- (1) Hydrology – based on water balance equation, which relates interception, soil water, runoff, evapotranspiration, daily amounts of precipitation, percolation and return flow
- (2) Weather variables for driving the hydrologic balance are precipitation, air temperature, solar radiation, wind speed and relative humidity, daily inputs can be entered directly or the weather generator can be used to simulate daily values for these variables from aggregated monthly values.
- (3) Sedimentation – sediment yield is computed from the MUSLE equation

- (4) Soil temperature – daily average simulated at the center of each soil layer for use in hydrology and residue decay.
- (5) Crop growth model is a simplification of EPIC crop model with the concepts of phenological crop development based on daily accumulated energy units, harvest index for partitioning grain yield, Monteith's approach for potential biomass and water, nutrient and temperature stress adjustments.
- (6) Nutrients – Amount of $\text{NO}_3\text{-N}$ contained in runoff, lateral flow and percolation are estimated as the products of the volume of water and the average concentration. Estimating soluble P in surface runoff is based on the concept of partitioning of pesticides into the solution and sediment phases as described by Leonard and Wauchope (Knisel, 1980) as P is mostly associated with the sediment phase.
- (7) Agricultural Management – provides submodels, that simulate tillage systems, application of irrigation water, fertilizer and pesticides and grazing systems
- (8) Pesticides - GLEAMS technology for simulating pesticide transport by runoff, percolate, soil evaporation and sediment is used in the pesticide subcomponent.

The water transfer algorithm allows water to be transferred from any reach or reservoir to any other reach or reservoir in the watershed. It also allows water to be diverted and applied directly to irrigate a subwatershed. More detailed description of SWAT, can be found in Arnold *et al.*, (1998); Neitsch *et al.*, (2001a); (2001b)

AVSWAT-2000 (Di Luzio *et al.*, 2002) is an ArcView extension and a graphical user interface for the SWAT (Soil and Water Assessment Tool) model. The AVSWAT-2000 ArcView extension evolved from AVSWAT, an ArcView extension developed for an earlier version of SWAT (Di Luzio *et al.*, 1998). Functional components and the analytical capability of ArcView GIS are implemented in several sets of customized and user friendly tools designed to:

- (1) generate specific parameters from user-specified GIS coverages;
- (2) create SWAT input data files;
- (3) establish agricultural management scenarios;
- (4) control and calibrate SWAT simulations;

- (5) extract and organize SWAT model output data for charting and display.

The system has components for complete and advanced watershed delineation, definition of Hydrologic Response Units (HRU), and the latest version of the SWAT model with a relative interface. AVSWAT software is developed as an extension of ArcView GIS for the Personal Computer (PC) environment. Within this system, ArcView provides both the GIS computation engine and a common Windows-based user interface. The basic map inputs required for the AVSWAT include digital elevation, soil maps, land use/cover, hydrography (stream lines) and climate. In addition, the interface requires the designation of land use, soil, weather, groundwater, water use, management, soil chemistry, pond and stream water quality data, as well as the simulation period, to ensure a successful simulation. Di Lizio *et al.* (2002) provides detailed information about AVSWAT Arc View Interface.

The SWAT model itself was a product of the modification of the SWRRB model (Simulator for Water Resources in Rural Basins) and key modifications include the addition of lateral subsurface flow and groundwater flow components (Khalil *et al.*, 2002). SWAT consists of three major components namely sub-basin, reservoir routing, and channel routing.

Surface runoff is predicted for daily rainfall by using the USDA Soil Conservation Service (now the Natural Resource Conservation Service) curve number equation (Mockus 1969). The curve number (CN) varies non-linearly from condition 1 (dry) at wilting point to condition 3 (moist) at field capacity, and approaches a maximum 100 at saturation. Four storage volumes represent the local water balance of SWAT: soil profile (0–2 m), shallow aquifer (2–20 m) and deep aquifer (>20 m). The soil profile can be divided into multiple layers. Soil water processes include infiltration, evaporation, plant uptake, lateral flow and percolation to lower layers. SWAT uses a storage routing technique to predict flow/percolation through each soil layer, downward flow occurs, when field capacity of the soil layer is exceeded and if the layer below is not saturated. The downward flow rate is governed by the saturated hydraulic conductivity of the soil layer. Percolation from the bottom of the soil profile recharges the shallow aquifer. The groundwater flow contribution to total stream flow is simulated by routing a shallow aquifer storage component to the stream (Arnold *et al.* 1998). Upward flow may occur when the field capacity of the next lower layer is exceeded. The soil water to field capacity ratios of the two layers governs movement

from a lower layer to an adjoining upper layer. Percolation is also affected by the soil temperature. Three options are offered in SWAT for estimating potential ET viz: Hargreaves (Hargreaves & Samani, 1985), Priestley-Taylor (Priestley & Taylor, 1972), and Penman-Monteith (Monteith, 1965). The Penman-Monteith method was used in this study. It requires solar radiation, air temperature, wind speed, and relative humidity as inputs at 1m height. This method was because it has proved to be globally valid as a standardised reference for grass evapotranspiration and it has found recognition both by the International Commission for Irrigation and Drainage and by the World Meteorological Organization. Daily values of wind speed, relative humidity, and solar radiation were generated internally in SWAT from monthly weather statistics compiled for Bohicon. The model computes evaporation from soils and plants separately. Potential soil water evaporation is estimated as a function of potential ET and leaf area index. Actual soil evaporation is estimated by using exponential functions of soil depth and water content. Plant evaporation is simulated as a linear function of potential ET, leaf area index and root depth and can be limited by soil water content.

Erosion caused by rainfall and runoff is computed with the Modified Universal Soil Loss Equation (MUSLE) (Williams, 1975;1985) in SWAT. MUSLE is a modified version of the Universal Soil Loss Equation (USLE) developed by Wischmeier and Smith (1965, 1978). USLE predicts average annual gross erosion as a function of rainfall energy. In MUSLE, the rainfall energy factor is replaced with a runoff factor. This improves the sediment yield prediction, eliminates the need for delivery ratios, and allows the equation to be applied to individual storm events. Sediment yield prediction is improved because runoff is a function of antecedent moisture condition as well as rainfall energy. Delivery ratios (the sediment yield at any point along the channel divided by the source erosion above that point) are required by the USLE because the rainfall factor represents energy used in detachment only. Delivery ratios are not needed with MUSLE because the runoff factor represents energy used in detaching and transporting sediment. The hydrology model supplies estimates of runoff volume and peak runoff rate, which are with the subbasin area to calculate the runoff erosive energy variable. The crop management factor is recalculated every day and is a function of above-ground biomass, residue on the soil surface, and the minimum C factor for the plant. Other factors of the erosion equation are evaluated as described by Wischmeier and Smith (1978).

3.3 Model Input Data

3.3.1 Climate Data

The model requires daily input values of maximum and minimum air temperature, wind speed, solar radiation, relative humidity, and precipitation. But, for this study precipitation data from 1964 – 1993 was the only daily data set available for the Bohicon weather station. The daily solar radiation and relative humidity has to be generated in SWAT as mentioned previously. Monthly weather statistics for Bohicon weather station were used to generate these inputs for this study (Table 3.1). Weather data used for the weather generator are used to prepared the following files for the simulation:

1. Weather generator gauge location table - contains the coordinates of the weather station and the name of associated file with actual weather data.
2. Precipitation gauge location table – contains the coordinates of the precipitation gauge, elevation and the name of the associated file with the actual precipitation data.
3. Precipitation data table – contain the dates and daily rainfall record for the precipitation gauge location.

The weather data use for the weather generator was obtained from ASECNA through the BENSOTER (Benin Soil and Terrain Digital Data Base) and from the FAOCLIM (FAO, 2001) i.e. these databases provided information on monthly mean value for rainfall (and standard deviation), solar radiation, minimum and maximum temperature (as well as their standard deviation) and wind speed.

3.3.2 Soil Properties

The soil data used by SWAT can be divided into two groups: physical characteristics and chemical characteristics. The physical properties of the soil govern the movement of water and air through the profile and have a major impact on the cycling of water within the hydrologic response unit (HRU). Inputs for chemical characteristics are used to set initial levels for different nutrients in the soil. Input data for the physical properties are required while the chemical property data are optional. The model requires the division of the soil profile into horizons. For this study, the BJ20, BJ26, BJ28 soter units (SU) are the existing soil associations in the catchment

area (Table 3.2) and the soil profile data from the dominant soil type were used for the simulation (Table 3.3). The soil data used in the model were adapted from the work of Weller (2002).

Missing data were calculated using available pedotransfer functions e.g. the bulk density, available water content and saturated hydraulic conductivity were calculated using the Soil Water Characteristic - Hydraulic Properties Calculator developed by the USDA and Washington State University. It is based on the studies of Saxton et al. (1986). Data for soil albedo were deduced from the regression analysis of soil organic matter and soil albedo of about 100 tropical soils while data for the USLE K factor were derived from the K-value triangle (Krishna, 2001).

The watershed covers an area of about 5574ha with the percentage coverage of the SUs of 6,31%, 79,74% and 13,95% for BJ20, BJ26 and BJ28 respectively (Fig. 3.1).

Table 3.1: Summary of weather data used for the model simulation (long term averages)

Months	Tmax(°C)	Tmin(°C)	Precipitation (mm)	Solar Radiation (MJ/m ² day)	Dew Point (°C)	Wind Speed (m/s)
Jan.	33,66	21,43	2	18,17	21,73	2,03
Feb.	34,93	23,07	32	19,85	20,97	2,45
Mar.	34,66	23,53	66	19,51	23,33	2,44
Apr.	32,92	23,20	126	19,51	23,77	2,06
May	31,84	22,95	133	18,92	23,55	2,07
Jun.	30,09	22,03	152	17,58	23,02	2,21
Jul.	28,74	21,57	121	15,41	22,20	2,39
Aug.	29,18	21,21	100	14,65	21,76	2,40
Sept.	29,83	21,68	131	15,49	22,77	2,10
Oct.	30,99	21,93	99	19,09	22,95	1,71
Nov.	33,33	22,24	21	19,22	22,83	1,55
Dec.	33,20	21,48	14	17,33	20,58	1,76

Table 3.2: General Overview of Soter Unit found within the Study area

Soter Unit ID	No. of Soil Compt. *	Profile ID of Selected Compt.	% Contr. of Selected Soil Compt.	No. of Horizon	Maximum Root Depth (mm)	Hydrologic group	Soil Type (WRB 1998)	Depth to GW (m)
BJ20	2	BJR 331	60	4	400	C	Mollic Gleysol (GLm)	1
BJ26	3	BJR270	70	3	750	C	Ferric Lixisol (LXf)	>2
BJ28	3	BJR 321	70	3	750	B	Ferric Acrisol (ACf)	>2

*Number of soil components within the SU

Compt. => Component

NB. The profiles belong to the soil profile set BJ-VC1 (BJR 331) and BJ-CR2 (BJR 270, BJR 312)

Table 3.3: Selected properties of soil input data for the study area

Horizon No.	Depth (mm)	Bulk Density (g/cm ³)	Organic Carbon (%)	Particle Size Distribution (%)			USLE K-value	Sat. Hydraulic Conductivity (mm/hr)	Soil AWC (%vol)	Soil Albedo
				Clay	Silt	Sand				
BJ20 (BJR 331)										
1	50	1,20	0,98	43,3	38,9	17,8	0,20	6,70	0,16	0,09
2	200	1,12	1,15	60,3	18,5	21,2	0,07	9,30	0,13	0,08
3	500	1,26	0,30	41,5	42,4	16,1	0,20	2,10	0,16	0,13
4	1000	1,30	0,17	38,5	38,0	23,5	0,20	1,70	0,15	0,14
BJ26 (BJR 270)										
1	250	1,41	0,93	16,2	24,0	59,8	0,20	24,90	0,12	0,09
2	650	1,26	0,33	50,8	17,8	31,4	0,10	1,40	0,12	0,09
3	1000	1,25	0,20	55,4	18,0	26,6	0,10	1,10	0,13	0,14
BJ28 (BJR 312)										
1	200	1,53	0,97	8,2	8,6	83,2	0,19	75,70	0,10	0,09
2	600	1,31	0,52	39,5	7,9	52,6	0,10	1,80	0,09	0,12
3	1000	1,31	0,34	43,3	13,1	43,6	0,13	1,40	0,11	0,12

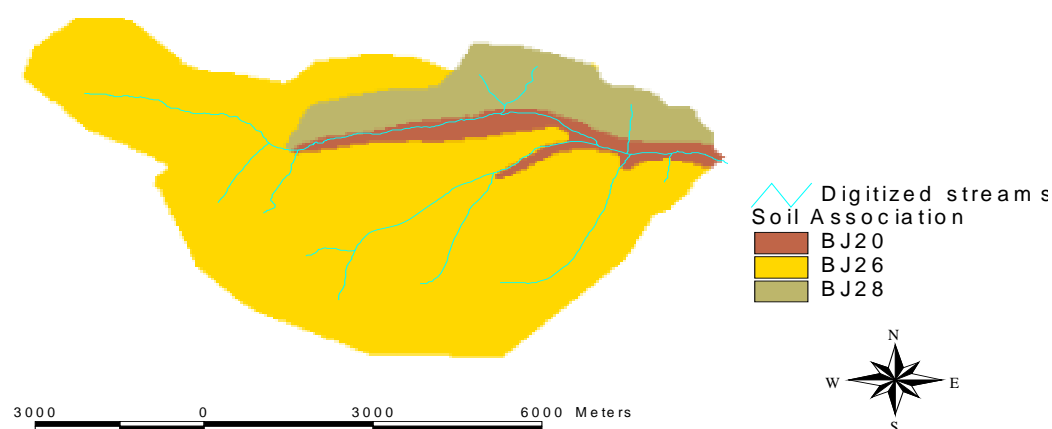


Figure 3.1: Map of SOTER units of Zagbo river basin.

3.3.3 Land Use/Land Cover and Land Management Data

Information about land use/land cover of the selected catchment area were extracted from the *Atlas of Natural and Agronomic Resources of Niger and Benin* (<http://www.uni-hohenheim.de/~atlas308>). The land use/land cover maps of 1954 and 1982 were used for this study (Table 3.4, Figs. 3.2 & 3.3).

Table 3.4: Land Use/Cover Distribution of Study area (1954 and 1982)

Land Use	Area Covered 1954 (ha)	Land Use	Area Covered 1988 (ha)
Farmland & Fallow	4927,21	Farmland & Fallow	4631,77
Gallery Forest	462,64	Gallery Forest	0
Plantation	0	Plantation	37,06
Settlement	28,42	Settlement	472,75
Shrub Savanna	106,13	Shrub Savanna	218,25
Tree Savanna	45,60	Tree Savanna	191,13
Woodland	3,51	Woodland	22,55

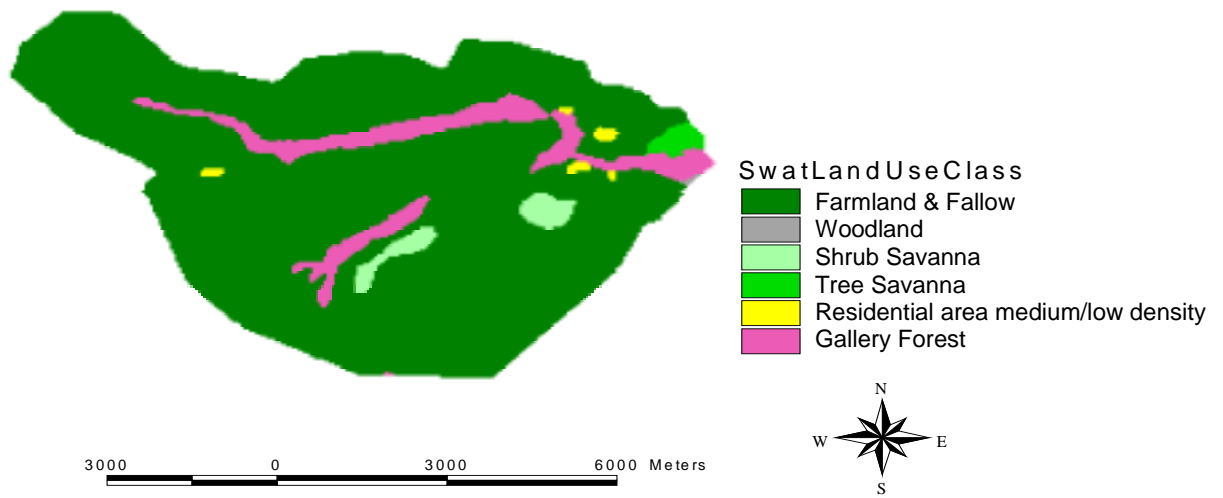


Figure 3.2: Map of Land use after reclassification by SWAT (1954)

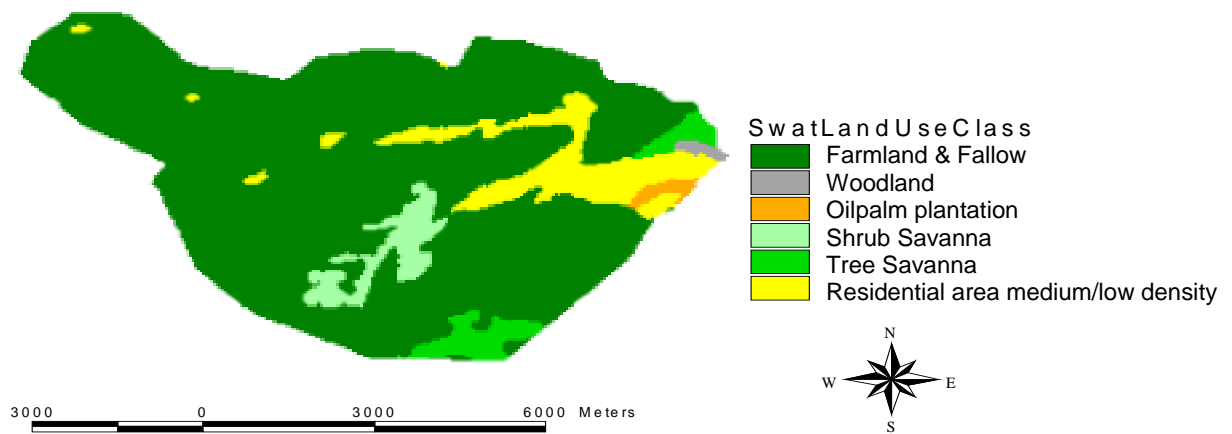


Figure 3.3: Map of Land use after reclassification by SWAT (1988)

The model requires data for planting, harvest, irrigation application, nutrient application, pesticide application, and tillage operations. There was no report of irrigation practice in this area.

3.3.4 Topographic and Hydrographic Data

The model also requires the Digital Elevation Model (DEM) and this was derived from the topographic maps of Benin, (IGN, 1954-68) obtained from the work of Weller (2002) on the southern part of Benin. Hydrography of the area in form of streamlines was derived from the topographic map of Zangnanado (IGN, 1987).

3.4 Data Pre-processing

The AVSWAT model also required a DEM mask, which encompasses the drainage basin for the streamlines. The DEM mask was created using the ArcMap edit feature to create a new shapefile and subsequently converted to a grid for use in AVSWAT.

The AVSWAT model provides a database for land cover/plant growth, fertilizer, pesticide and urban area. It contains tables used by the interface to set default input values and define the upper and lower limits for variable values. The land use/plant growth data need to be configured to fit to the situation in the study area (Tables 3.5 & 3.6).

3.5 Model Operation and Procedures

With all dataset prepared, the watershed delineation was the next step and this process produced eight subbasins. These were created based on the DEM and the streamline delineation maps. The model also automatically creates an outlet for each of these subbasins and the main outlet of the entire watershed was manually identified to be the point at which the river empties into the main Oueme river.

Table 3.5: Landuse types of the study area and equivalent landuse/plant growth types in AVSWAT Database

Landuse (Study area)	Landuse(SWAT Database)	Modification
Farmland & Fallow	Corn	No modification
Gallery Forest	Wetlands-Mixed*	No modification
Plantation (Oil palm)	Honey Mesquite	No fertilizer application
Settlement	Residential Area Low – High density	No modification
Shrub Savanna	Alamo Switch Grass	No modification
Tree Savanna	Alamo Switch Grass	Modification of leaf area index (5.50), USLE C factor (0.004) and maximum root depth (3m)
Woodland	Forest Mixed	Modification of USLE C (0.007)

*Mixed – implies there is a mixture of tree and grasses

Once the land use and soil themes have been imported and linked to the SWAT databases, the criteria for determining the HRU distribution need to be specified. One or more unique land use/soil combinations (hydrologic response units or HRUs) can be created for each subbasin. Subdividing the watershed into areas having unique land use and soil combinations enables the model to reflect differences in evapotranspiration and other hydrologic conditions for different land covers/crops and soils.

Runoff is predicted separately for each HRU and routed to obtain the total runoff for the watershed. This increases the accuracy of load predictions and provides a much better physical description of the water balance. There were two options in determining the HRU distribution: assign a single HRU to each subwatershed or assign multiple HRUs to each subwatershed. If a single HRU per subbasin is selected, the HRU is determined by the dominant land use category and soil type within each watershed, however multiple HRUs option was selected. A five percent threshold value was specified for both the land use and soil data to determine the

number and kind of HRUs in each subbasin. Land uses that cover a percentage of the subbasin area less than the threshold level are eliminated. After the elimination process, the area of the remaining land uses is reapportioned so that 100% of the land area in the subbasin is modeled. This was thought to be realistic to avoid over generalization by using the dominant land use and soil class. Thus a total of 30 and 32 HRUs were created for 1954 and 1988 respectively. Each of the HRU represents an area with unique land use and soil class combination.

Weather data used in the simulation were imported after the HRU distribution had been defined. The Weather Data Definition dialog is divided into six sections: weather simulation data, rainfall data, temperature data, solar radiation data, wind speed data and relative humidity data. In the weather simulation data section, the Weather Generator gauge location table was specified to point to the appropriate weather data that will be used to generate various weather parameters. The other five sections allow the user to choose between simulated or measured climate data and they were all set to simulated except when the effect of same rainfall data was investigated.

All other variables/input data were set to default values as there was no adequate information about them or they are optional input data e.g. water use data, water quality data. Reservoirs (lake or ponds) do not exist in this area, so there was no need for input data.

3.6 Simulation Runs and Achieving Objectives

The simulation run was made for a maximum of five years (two years before the year of interest and 2 years after) this was done to give a good impression of what might have happened and provide adequate information for statistical data analysis. The printout frequency was set to monthly output while the variable storage was selected as the channel water routing method. Change in channel dimension was selected as not active as there is no adequate information to implement this procedure so also the stream water and lake water quality processes and routing of pesticides.

Table 3.6: Distribution Hydrological Response Unit (HRU) and Soil type within each Subbasin (1954 and 1988)

1954				1988			
Subbasin	HRU	Land Use	Soil Type	Subbasin	HRU	Land Use	Soil Type
1	1	Farmland & Fallow	BJ28	1	1	Settlement	BJ26
1	2	Farmland & Fallow	BJ26	1	2	Settlement	BJ20
1	3	Farmland & Fallow	BJ20	1	3	Farmland & Fallow	BJ28
1	4	Gallery Forest	BJ28	1	4	Farmland & Fallow	BJ26
1	5	Gallery Forest	BJ26	1	5	Farmland & Fallow	BJ20
1	6	Gallery Forest	BJ20	2	6	Settlement	BJ28
2	7	Farmland & Fallow	BJ28	2	7	Settlement	BJ20
2	8	Farmland & Fallow	BJ20	2	8	Farmland & Fallow	BJ28
2	9	Gallery Forest	BJ28	2	9	Farmland & Fallow	BJ20
2	10	Gallery Forest	BJ20	3	10	Settlement	BJ26
3	11	Farmland & Fallow	BJ26	3	11	Settlement	BJ20
3	12	Farmland & Fallow	BJ20	3	12	Farmland & Fallow	BJ26
3	13	Gallery Forest	BJ26	3	13	Farmland & Fallow	BJ20
3	14	Gallery Forest	BJ20	4	14	Settlement	BJ26
3	15	Shrub Savanna	BJ26	4	15	Farmland & Fallow	BJ26
4	16	Farmland & Fallow	BJ26	4	16	Tree Savanna	BJ26
4	17	Shrub Savanna	BJ26	5	17	Settlement	BJ26
5	18	Farmland & Fallow	BJ28	5	18	Settlement	BJ20
5	19	Farmland & Fallow	BJ26	5	19	Farmland & Fallow	BJ28
5	20	Farmland & Fallow	BJ20	5	20	Farmland & Fallow	BJ26
5	21	Gallery Forest	BJ26	5	21	Farmland & Fallow	BJ20
5	22	Gallery Forest	BJ20	5	22	Oilpalm plantation	BJ26
5	23	Tree Savanna	BJ28	5	23	Tree Savanna	BJ28
5	24	Tree Savanna	BJ20	5	24	Tree Savanna	BJ20
6	25	Farmland & Fallow	BJ26	5	25	Woodland	BJ20
6	26	Gallery Forest	BJ26	6	26	Farmland & Fallow	BJ26
6	27	Gallery Forest	BJ20	6	27	Shrub Savanna	BJ26
7	28	Farmland & Fallow	BJ26	7	28	Settlement	BJ26
7	29	Shrub Savanna	BJ26	7	29	Farmland & Fallow	BJ26
8	30	Farmland & Fallow	BJ26	7	30	Tree Savanna	BJ26
				7	31	Shrub Savanna	BJ26
				8	32	Farmland & Fallow	BJ26

The output of the simulation runs provided information on variables like soil water content, percolation, water yield, sediment yield, potential evapotranspiration, actual evapotranspiration, surface runoff contribution to streamflow as well as sediment concentration in the reach. These were examined to achieve the objectives of quantifying the effect of land use changes on hydrology and sediment load in the study area.

The objectives of the study were achieved by using different input data combination (Table 3.7). The data combination scheme was based primarily on daily rainfall data availability for the representative weather station (Bohicon). The first objective was to assess the effect of land use changes, for this the Landuse patterns of 1954 and 1988 were compared using the rainfall data of 1964 –1968 for both periods. The second was to assess the effect of changes in rainfall distribution on hydrological characteristics and sediment load, therefore the rainfall data was varied here i.e. using rainfall data for 1964 – 1968 compared with that of 1986 –1990 using the Landuse pattern of 1988. The 1964 – 1968 rainfall data is the earliest available data for the Bohicon weather station used as the reference weather station and the closest to the land use pattern data of 1954 selected for this study.

Table 3.7: Input data combination for achieving research objectives

Land Use	Rainfall Data (1964 –1968)	Rainfall data (1986 – 1990)
1954	1	
1988	1 & 2	2

1 and 2 indicate the objective achieved by the data combination

3.6.1 Data Analysis

Output from the simulation was subjected to statistical analysis to achieve the objectives of the study. Variables like potential evapotranspiration, actual evapotranspiration (i.e soil evaporation and plant transpiration), soil water, percolation, groundwater contribution to streamflow, water yield, sediment yield and sediment concentration are analyzed to check the differences among the sub-basins as well as for differences between study periods.

Assessing the difference among sub-basins was carried out using the analysis of variance. Mean monthly values of four years are analyzed to reveal the effect of changes on subbasins in the catchment area. The Duncan's multiple range test was used to make pairwise comparisons using a stepwise order of comparisons of the means of all test variables in order to separate means that are different from one another (mean values of subbasins).

T-test analysis was carried out on the mean monthly values of all variables to assess the differences between different dataset combinations. The mean annual output was

also analyzed with the same statistical procedure with each year serving as a replicate.

4. RESULTS

Landuse changes have impact on the hydrological characteristics and sediment generation within a watershed. The following chapter presents the result of the study and reveals the effect of land use changes and changes in weather condition (especially rainfall distribution) on hydrological characteristics and sediment yield in the Zagbo basin.

4.1 Basin Scale Analysis

The analysis results presented explore the differences that exist among the subbasins, which were identified within the Zagbo catchment in respect to each of the selected hydrological parameters and sediment yield.

The dataset combinations used for the simulations are named as follows:

1. **Set 1:** Landuse 1954 and rainfall data 1965- 68
2. **Set 2:** Landuse 1988 and rainfall data of 1986- 90
3. **Set 3:** Landuse 1988 and rainfall data of 1965 –68

The result of the analysis of variance (Table 4.1) for Set 1 revealed that only sediment yield ($n=96$) was significantly different ($P \leq 0.05$) among the subbasins within the catchment area. The Duncan's multiple range test results shows the difference, which exist among the subbasins (Table 4.2).

Subbasin 2 exhibits a significantly different (higher) mean for sediment yield compared to subbasins 4 and 7. Mean soil water indicates that subbasin 2 has the lowest. This could be traced to the high value of bulk density (1.53g/cm^3 – topsoil) of the predominant soil association - BJ28 (84% of subbasin 2). The high bulk density could also be implicated in generating higher water yield (Table 4.3) due to reduced infiltration. The predominant land use (85%) under farmland (and fallow) could as well generate a lot of sediment from this subbasin. The predominant soil association (BJ28) was also reported by Weller (2002) to belong to major slope terrain of southern Benin (with high to moderate slope steepness).

Table 4.1: Analysis of variance of hydrological parameters and sediment yield (Set 1 - 4 years monthly average)

Parameters	Source of Variation	Sum of Squares	df	Mean Square	F	Sig.
Sediment yield	Between Groups	31,91	7	4,56	2,84	0,01
	Within Groups	141,35	88	1,61		
	Total	173,26	95			

However, subbasin 4 and 7 show not statistical difference between them while subbasins 1, 3, 6, and 8 are not statistically different from each other in respect to sediment yield. Subbasins 5 and 2 are also more similar than the rest of the subbasins (Table 4.2).

Table 4.2: Duncan multiple range test for sediment yield (Set 1 – monthly mean)

SUBBASIN	Mean sediment yield (t.ha ⁻¹)
4	0,81a
7	0,84a
8	1,01ab
6	1,09ab
1	1,51ab
3	1,55ab
5	2,04bc
2	2,54bc

Means followed by same letter in the column are not significantly different

Table 4.3: Means of variables considered per subbasin for Set 1(monthly mean)

Subbasin	Potential Evapotransp. (mm)	Actual Evapotransp. (mm)	Soil Water (mm)	Percolation (mm)	Surface Runoff (mm)	Groundwater Contribution to streamflow (mm)	Water yield (mm)	Sediment yield (t.ha ⁻¹)	Sediment Concentration (mg/l)
1	129,1	43,0	97,6	12,4	35,2	11,0	46,3	1,5	576
2	129,0	41,7	88,7	13,1	35,6	11,6	47,5	2,5	639
3	129,0	44,2	105,8	13,3	33,2	11,8	45,1	1,6	590
4	129,0	43,5	99,2	9,2	37,9	8,1	46,0	0,8	695
5	128,9	43,4	99,3	14,6	32,5	13,0	45,7	2,0	508
6	129,0	43,6	99,8	10,2	36,8	9,0	45,8	1,1	753
7	129,0	43,6	99,3	9,5	37,5	8,4	45,9	0,8	902
8	129,1	43,3	99,0	8,2	39,2	7,1	46,3	1,0	858

The annual mean potential evapotranspiration and actual evapotranspiration are more or less the same across the basin. This is expected as the important environmental factors like solar radiation, temperature, humidity and wind speed used in the Penman-Monteith formula are similar. But as reported earlier no other variable is statistically different among the subbasins. This could be attributed to the fact, that after reclassification by SWAT the predominant land use of the entire watershed is farmland (and fallow) covering about 90% of the area. Soil association BJ26 and BJ28 covered 80% and 14% of the area respectively, while BJ20 covered only 6% of the entire catchment. Therefore, giving the catchment somewhat similar characteristics in these two important respect (Appendix I).

Generally, among the subbasins hydrological characteristics, when compared are not significantly different. The coarseness of the soil map, used could have been responsible for this as well as the predominance of single type of land use pattern. Sediment yield showed significant differences among the subbasins, reflecting the combination of soil properties, land use pattern and terrain characteristics influence.

In set 2, the analysis of variance (Table 4.4) showed similar result like the set 1 i.e. sediment yield was the only variable significantly different among the subbasins on the long-term.

The result of the Duncan's multiple range test (table 4.5.) shows that subbasins 1 and 2 are quite unique while subbasins 4,7,8,6,3 and 5 show similarities in their mean sediment yield. Subbasins 4,6,7 and 8 are always occurring together in the same subset. This could be traced to the fact, that they all have the same soil association covering their whole extent (BJ26), thereby giving them almost similar characteristics (Appendix II).

Table 4.4: Analysis of variance of hydrological parameters and sediment yield (Set 2 - 4 years monthly average)

Parameters	Source of Variation	Sum of Squares	df	Mean Square	F	Sig.
Sediment yield	Between Groups	43,29	7	6,18	2,85	0,01
	Within Groups	191,26	88	2,17		
	Total	234,55	95			

This soil was found to be well drained i.e. water is removed from this soil readily but not rapidly and the infiltration rate was also rapid (6.0 – 12.5cm/h) according to Van Engelen and Ting-tiang (1993), which could account for the water yield values simulated (Table 4.6).

Generally, the hydrological characteristics as well as sediment concentration are also found not to be significantly different among the subbasins.

Table 4.5: Duncan multiple range test for sediment yield (Set 2 – monthly mean)

SUBBASIN	Mean sediment yield (t.ha ⁻¹)
4	0,66a
7	0,76a
8	1,10a
6	1,18a
3	1,40a
5	1,56a
1	1,85ab
2	2,91b

Means followed by same letter in the column are not significantly different

Table 4.6: Means of variables considered per subbasin for Set 2 (monthly mean)

Subbasin	Potential Evapotransp. (mm)	Actual Evapotransp. (mm)	Soil Water (mm)	Percolation (mm)	Surface Runoff (mm)	Groundwater Contribution to streamflow (mm)	Water yield (mm)	Sediment yield (t.ha ⁻¹)	Sediment Concentration (mg/l)
1	132,3	42,7	90,9	8,0	40,3	7,1	47,5	1,8	619
2	132,3	40,9	81,4	8,2	41,7	7,3	49,2	2,9	681
3	132,3	43,0	90,3	5,2	42,8	4,6	47,5	1,4	598
4	132,3	44,0	89,0	7,4	39,7	6,6	46,3	0,7	424
5	132,3	42,9	87,5	10,1	38,0	9,0	47,2	1,6	482
6	132,3	44,4	94,3	9,7	36,9	8,7	45,7	1,2	757
7	132,3	44,5	93,1	10,3	36,4	9,2	45,7	0,8	483
8	132,3	44,2	93,7	7,8	39,1	6,9	46,0	1,1	743

Sediment yield was found to possess a highly significant difference among the subbasins for Set 3 (Table 4.7).

Table 4.7: Analysis of variance of hydrological parameters and sediment yield (Set 3 – 4years monthly average)

Parameters	Source of Variation	Sum of Squares	df	Mean Square	F	Sig.
Sediment yield	Between Groups	39,96	7	5,71	3,71	0,00
	Within Groups	135,52	88	1,54		
	Total	175,48	95			

The mean separation (Table 4.8) shows that subbasins 1,3,4,5,6,7 and 8 are not statistically different while subbasin 2 is unique. The order of magnitude of the mean annual sediment yield is similar to that of Set 2 despite differences in rainfall distribution. The difference among the subbasins could also be identified by exploring the means values (table 4.9) of other variables, but there are no significant difference observed for these variable (i.e. hydrological characteristics and sediment concentration).

Table 4.8: Duncan Multiple range test for Sediment yield (Set 3 – monthly mean)

SUBBASIN	Mean sediment yield (t.ha ⁻¹)
4	0,60a
7	0,69a
8	0,98a
6	1,06a
3	1,23a
5	1,46a
1	1,67a
2	2,76b

Means followed by same letter in the column are not significantly different

Table 4.9: Means of variables considered per subbasin for Set 3 (long-term – monthly mean)

Subbasin	Potential Evapotransp. (mm)	Actual Evapotransp. (mm)	Soil Water (mm)	Percolation (mm)	Surface Runoff (mm)	Groundwater Contribution to streamflow (mm)	Water yield (mm)	Sediment yield (t.ha ⁻¹)	Sediment Concentration (mg/l)
1	129,7	43,6	92,9	8,3	38,7	7,2	45,9	1,7	601
2	129,7	41,6	83,5	8,5	40,2	7,5	47,9	2,8	674
3	129,7	43,6	91,9	5,6	41,2	4,8	46,1	1,2	561
4	129,7	44,9	91,1	7,6	38,1	6,6	44,7	0,6	869
5	129,7	43,8	89,3	10,2	36,4	8,9	45,5	1,5	484
6	129,7	45,5	96,5	9,9	35,3	8,7	44,0	1,1	779
7	129,7	45,5	95,2	10,2	34,9	8,9	43,9	0,7	753
8	129,7	45,3	95,9	8,1	37,3	7,0	44,4	0,9	896

Summarily, from the analysis of the result of the simulation from the 3 data combination sets, it is evident that subbasins 4,7,8 and 6 are more similar in respect to sediment generation as shown in the Duncan multiple range analysis while the subbasins 1,3 and 5 are most likely to belong to a different group. Subbasin 2 showed a unique characteristic in terms of sediment yield (as it recorded this highest for all the three data sets), but it showed membership to the group of subbasin 1,3 and 5 rather than to the subbasin 4,7,8 and 6. The implication of this will be the treatment of subbasin 2 as a hotspot for sediment generation, therefore any land use that will not reduce the sediment generation should not be considered for this subbasin.

4.2 Effect of land use changes on the basin

The comparison of the long-term datasets was made in order to assess the effect of land use changes. The long-term data set was subjected to a paired t-test procedure. The effect of land use changes was estimated by keeping constant the weather data (rainfall) while only land use was changed (comparison of set 1 and set 3).

The pairwise analysis revealed, that there was a significant difference ($P \leq 0.05$) for all the variables tested except potential and actual evapotranspiration and sediment concentration (Table 4.10).

The lack of significance observed in potential and actual evapotranspiration is due to the similarity in meteorological data for both periods.

Looking back at the hydrological response unit (HRU) distribution within each subbasin and changes across the basin could reveal the cause of the difference observed. Observed land use changes (Table 3.4) like the complete disappearance of gallery forest in 1988, slight reduction (5%) in area covered by farmland (and fallow), a 95% increase in settlements across the catchment area as well as 51%, 76% and 84% increase in shrub savanna, tree savanna and woodlands respectively could be expected to cause this observed differences.

Table 4.10: Effect of land use changes on hydrological parameters and sediment yield (Set 1 vs Set 3 monthly mean)

Variables	Set 1 total mean	Set 3 total mean	Std. Dev.	95% Confidence interval of the difference		t	Sig. (2-tailed)
				Lower	Upper		
PET (mm)	129	130	10,9	-2,9	1,5	-0,63	0,53
ET(mm)	43	44	6,3	-2,2	0,4	-1,43	0,16
Soil Water (mm)	99	92	7,9	4,9	8,2	8,06	0,00
Percolation (mm)	11,3	8,5	4,8	1,8	3,8	5,71	0,00
Surface Runoff (mm)	36	38	5,1	-2,8	-0,8	-3,42	0,00
Baseflow(mm)	10,0	7,5	3,9	1,7	3,3	6,33	0,00
Water yield (mm)	46	45	3,1	0,1	1,4	2,41	0,02
Sediment yield (t.ha ⁻¹)	1,4	1,3	0,34	0,05	0,19	3,41	0,00
Sediment Concentration (mg/l)	690	702	471	-107	84	-0,25	0,81

df = 95

PET and ET = Potential evapotranspiration and actual evapotranspiration.

4.3 Effect of rainfall distribution on basin hydrology and sediment yield

The paired t-test procedure was applied to test the effect of change in weather data (i.e. effect of rainfall change). The effect of weather changes (rainfall) was achieved by keeping constant the land use data while changing the daily rainfall data.

The trend in the 4 years average of the mean monthly rainfall (figure 4.1) indicates some differences. With differences in April, June and July well above 50mm but the mean annual total was 1087,8 and 1092,5mm respectively for 1965 – 1968 and 1987 –1990.

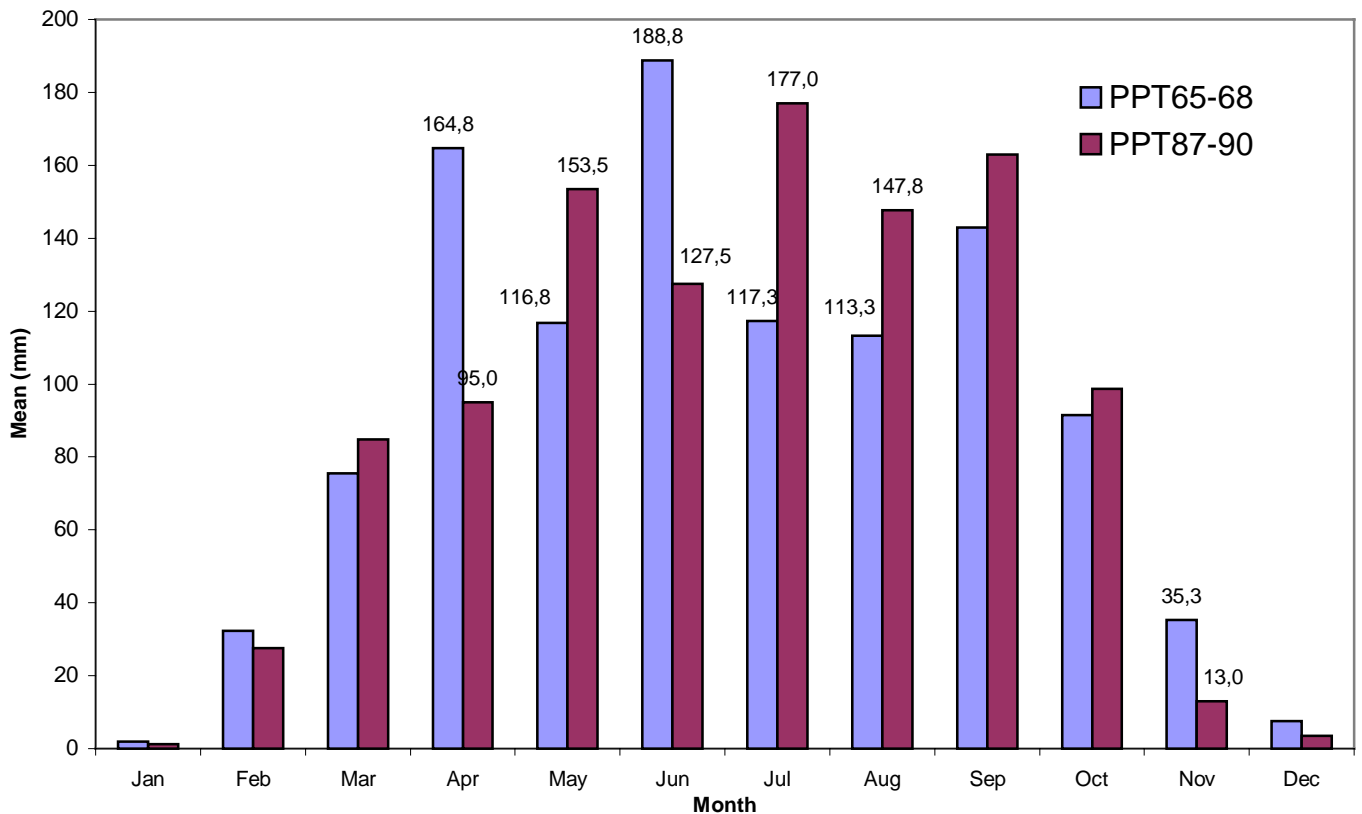


Figure 4.1: Mean monthly rainfall (4 years-average) of 1965-68 and 1987-90.

Analysis of the mean monthly values per subbasin (Table 4.11) revealed that a highly significant difference ($P \leq 0.01$) for potential evapotranspiration and soil water, while sediment concentration shows a significant difference ($P \leq 0.05$) between these periods. This gave an indication that changes in rainfall may induce changes in soil water content, potential evapotranspiration as well as the sediment concentration since the land use remain the same but not percolation, surface runoff, baseflow, water yield and sediment yield.

Table 4.11: Effect of weather changes on hydrological parameters and sediment yield (Set 2 vs Set 3)

Variables	Set 2 total mean	Set 3 total mean	Std. Dev.	95% Confidence interval of the difference		t	Sig. (2-tailed)
				Lower	Upper		
PET (mm)	132	130	3,8	-3,3	-1,8	-6,55	0,00
ET(mm)	43	44	6,1	-0,4	2,1	1,39	0,17
Soil Water (mm)	90	92	5,8	0,8	3,2	3,39	0
Percolation (mm)	8,3	8,5	7,5	-1,3	1,7	0,24	0,81
Surface Runoff (mm)	39	38	22,7	-6,2	3,0	-0,7	0,48
Baseflow(mm)	7,5	7,5	3,9	-0,8	0,8	0,07	0,94
Water yield (mm)	47	45	21,6	-6,0	2,8	-0,72	0,47
Sediment yield (t.ha ⁻¹)	1,43	1,31	1,02	-0,33	0,08	-1,17	0,24
Sediment Concentration (mg/l)	598	702	471	8	199	2,16	0,03

df = 95

PET and ET = Potential evapotranspiration and actual evapotranspiration.

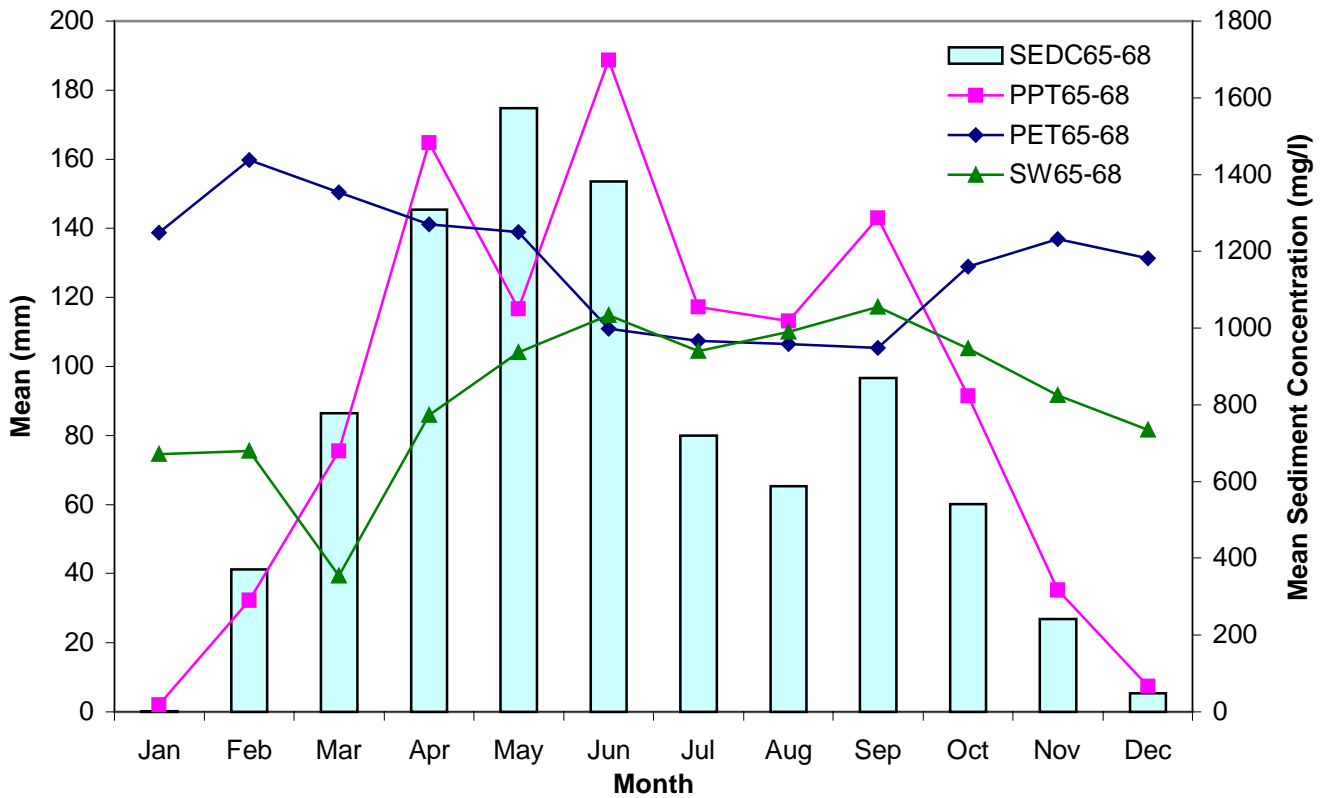


Figure 4.2: Relationship between mean monthly rainfall (1965 –68), soil water, potential evapotranspiration and sediment concentration (Set 3)

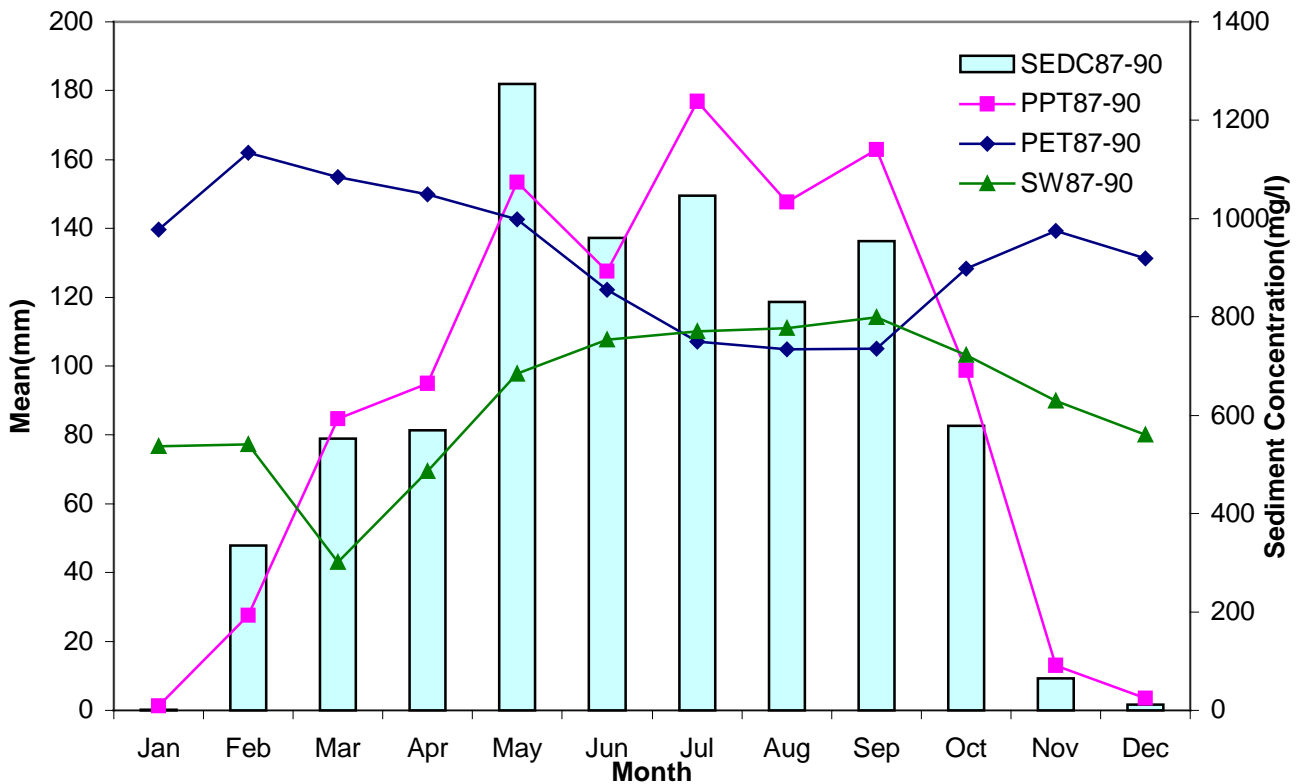


Figure 4.3: Relationship between mean monthly rainfall (1987 – 90), soil water, potential evapotranspiration and sediment concentration (Set 2)

There were differences between the mean monthly potential evapotranspiration (PET). Set 2 (Figure 4.3) has a higher value, when compared to set 3 across the basin (Figure 4.2). Reduced PET could subsequently increase the soil water as there is reduced potential for it to be taken away by evaporation or transpiration. The first peak of the set 3 rainfall data occurs at the time, when the field is still bare but land preparation has started thereby reducing or totally eliminating transpiration leading thereby to reduction of the real potential evapotranspiration. In case of set 2 the peak occur at time when transpiration has already began thereby combining the potential for evaporation and transpiration together to increase the value of PET.

The significant difference observed in the sediment concentration is related to the observed surface runoff and soil water. Surface runoff was found to contribute to the amount of sediment in the reach (Figure 4.4a&b) despite the fact that surface runoff was not significantly different for the two dataset (set 2 and set 3). This is because of the time at which the high runoff values were observed.

4.4 Yearly trend of selected hydrological parameters and sediment yield

Examining the result from basin analysis provided information about the differences that exist among the subbasins and offers an insight into how each of them is affected by land use and weather data (rainfall). These analyses could also provide information about sediment source within this subbasin and consequently serves as means of erosion prediction.

When analysing the basin-wide results evapotranspiration was found to be using a larger portion (48 –50%) of precipitation than the other processes associated with the hydrologic cycle across the entire catchment area. This is not usual in the tropics and is consistent with the empirical relationship that exists between rainfall and evapotranspiration (Table 4.12 – 4.14).

It is well established, that runoff increases, when the rain falls in heavy downpours (as frequently the case in West Africa), when slopes are steep, and when surface soil is compacted and lacks large pores and cracks in which the water will enter. This was reflected by the runoff amount in the study area, which was found to be between 40% and 42% of the rainfall amount across the catchment area.

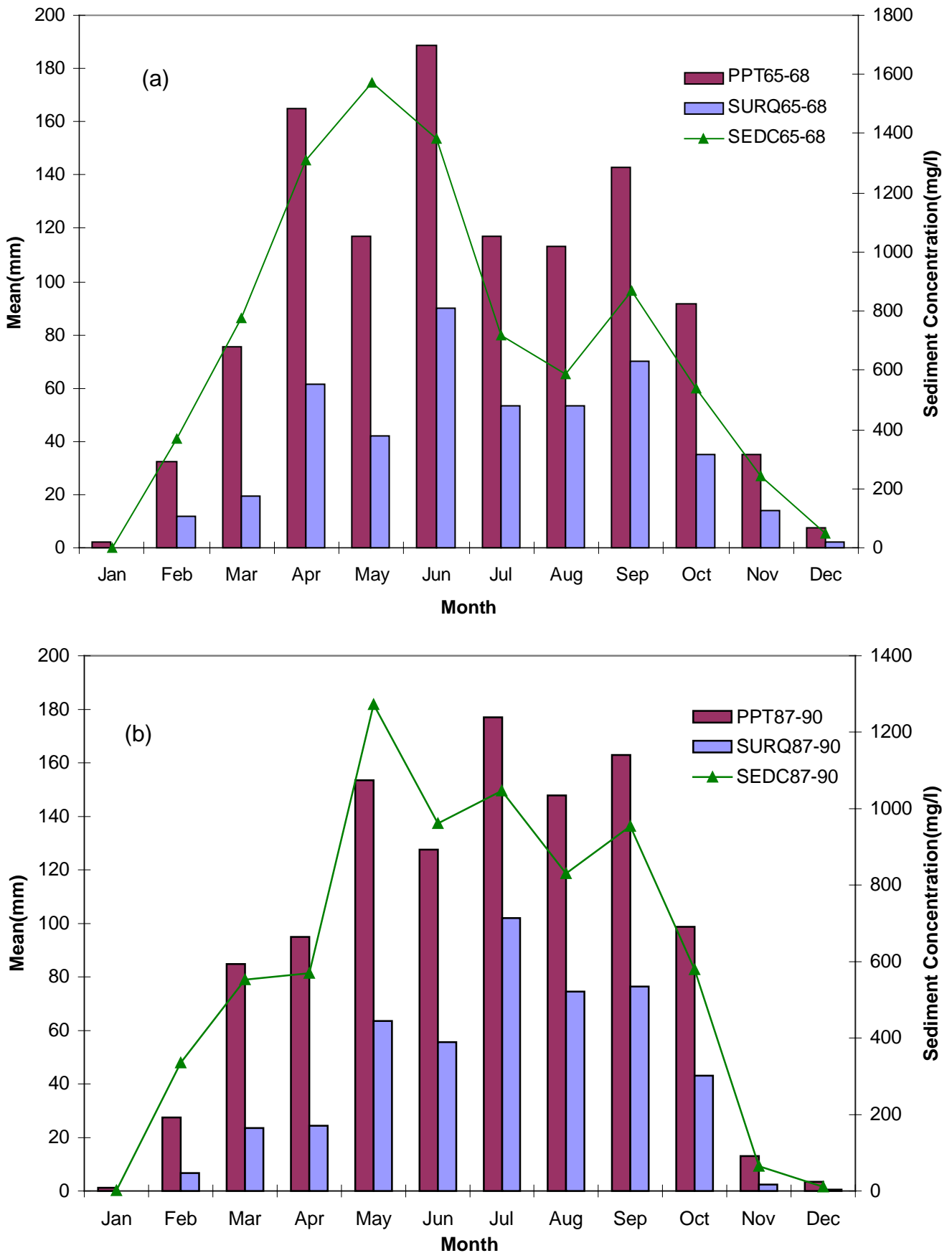


Figure 4.4: Comparison of the monthly difference in precipitation, surface runoff and sediment concentration for (a) set 3 and (b) set 2.

A highly significant ($P \leq 0,01$) positive correlation was found between mean monthly rainfall and surface runoff with coefficient values of 0,952; 0,960 and 0,969 for set 1,2 and 3 respectively ($n=96$).

Mean annual percolation ranges between 9 and 12% of the rainfall amount across the catchment area. This also reflects the characteristics of the soil i.e. their bulk density values (for topsoil 1,20 – 1,53 g/cm^3). Percolation amount could also give us the impression about ground water recharge. There is usually a lag between the time the water leaves the bottom of the root zone and reaches the shallow aquifer but over a long period of time, this variable should equal groundwater recharge (shallow aquifer).

Examining the difference between percolation and base flow, it was observed, that about 88 – 90% of the water, which percolates below the root zone contributes directly to stream flow.

Water yield, sediment yield and sediment concentration in the reach shows a very strong positive association with precipitation as well as surface runoff.

Soil loss and movement in watershed uplands is difficult to measure, and may go unnoticed until it is a severe problem but deposition is often easier to identify and measured. Therefore, estimation of sediment yield at the outlet of subbasins as implemented in SWAT can be very useful to assess the rate of erosion and soil loss in the watershed.

Sediment yield values obtained from the simulation indicate an average of 14 – 16 $\text{t}\cdot\text{ha}^{-1}$ (Tables 4.12 – 4.14) across the basin, and this is in agreement with the findings of Dunne & Dietrich (1982) in their work on some agricultural basins in Kenya. Morgan (1995) also reported a range of between 0,1 – 35 t/ha for cultivated land in nearby Nigeria citing various authors. Therefore, the simulation output for sediment is in the range of measured sediment yield and soil loss. Roose (1971) in his measurement of soil loss from hill slopes in West Africa ranging in steepness from 0,3° to 4° reported that annual yield of sediment after clearance for agriculture may increase to 8, 26 and 90 t/ha from 0,15, 0,20 and 0,03 t/ha for open savanna grassland, dense savanna grassland and tropical rain forest respectively.

Table: 4.12: Annual total value across the catchment area for selected hydrological parameters and sediment yield (Set 1- 1954 Landuse)

Year	Rainfall (mm)	ETP (mm)	Surface Runoff (mm)	Percolation (mm)	Baseflow (mm)	Water yield (mm)	Sediment yield (t/ha)
1953	918	501	346	81	72	417	10
1954	913	505	315	82	73	387	11
1955	1058	516	465	79	67	532	15
1956	1462	557	644	265	235	877	24
Total	4351	2079	1770	506	447	2213	60
Mean	1088	520	442	127	112	553	15

Table: 4.13: Annual total value across the catchment area for selected hydrological parameters and sediment yield (Set 2- 1988 Landuse)

Year	Rainfall (mm)	ETP (mm)	Surface Runoff (mm)	Percolation (mm)	Baseflow (mm)	Water yield (mm)	Sediment yield (t/ha)
1987	859	501	312	59	53	365	10
1988	1012	537	416	60	51	466	13
1989	1141	498	459	182	162	619	13
1990	1358	562	677	117	108	783	26
Total	4370	2098	1864	418	373	2233	63
Mean	1093	524	466	104	93	558	16

Table: 4.14: Annual total value across the catchment area for selected hydrological parameters and sediment yield (Set 3- 1988 Landuse)

Year	Rainfall (mm)	ETP (mm)	Surface Runoff (mm)	Percolation (mm)	Baseflow (mm)	Water yield (mm)	Sediment yield (t/ha)
1965	918	521	341	64	56	397	10
1966	913	508	325	68	61	385	10
1967	1058	542	464	56	47	509	14
1968	1462	571	656	237	210	864	23
Total	4351	2142	1786	425	374	2155	57
Mean	1088	535	446	106	93	539	14

5. DISCUSSION AND CONCLUSION

The major concern of watershed management is the control of water transfer from the upper to the lower parts of a river catchment area as well as the maintenance of its quality. Thus, it directly affects all the people living in the river catchment region. Water moving out of the upper part depends on the difference between the rainfall and the evapotranspiration (modified by the vegetation), the depth and the water-holding capacity of the soil and the surface runoff. Through the vegetation component, the amount of water leaving the area and the flow of the river are dependent on land use management in this area and as such have very serious consequences for the management of land in the lower reaches of the river.

5.1 Land use changes and basin response

From the analysis of the result of simulation runs for land use changes (from 1954 to 1988), there was a highly significant effect of land use changes on most of the major hydrologic balance parameters and sediment yield. This indicates that there is a significant contribution of the land use changes to the changes observed in the variables tested. This result is indicative of the significant impact of human activities in this area and its consequent effect on hydrological characteristics and sediment yield.

The observed differences include reduction in soil water content and percolation, baseflow and increase in runoff and sediment concentration (but not significant).

Mean monthly soil water in the profile was found to be lower in the 1988 land use compared to that of 1954, with 95% confidence interval (paired difference) of 4,93 and 8,15mm for lower and upper limit respectively across all the subbasins. This is a considerable high storage capacity, which could have a significant impact on plant survival in this area.

In terms of mean percolation the observation was also a decrease from 1954 land use to 1988 land use. The 95% confidence interval shows a lower limit of 1.83mm and an upper limit of 3,77mm across the entire catchment area when this value is multiplied by 12, then it can be seen that this difference is environmentally significant and its impact could be felt in terms of its contribution to water yield and also water supply for this catchment (deep wells). But 2 subbasins showed a different trend,

subbasin 8 showed no increase nor decrease in its mean monthly percolation. This was no surprise as the land use remained the same over the period under consideration. Subbasin 7 showed an increase in percolation. This is as a result of the improvement of soil structure which can be attributed to the emergence of tree savanna, increase in area covered by shrub savanna and decrease in farmland (18%). The subbasin also witnessed the emergence of settlement area (5% of the total subbasin). About 88–90% of percolation contributes directly to baseflow. This was also reflected in the significant difference observed for baseflow and consequently the same trend as observed in the mean monthly percolation value was also noticed here (i.e. decrease for subbasin 1–6 while subbasin 7 showed a decrease and no difference for subbasin 8 over the years under consideration). The paired difference confidence interval (95%) was found to range between 1,70 and 3,33mm for lower and upper limit respectively, which is environmentally significant for this area.

The mean monthly surface runoff was also found to be significantly different with an increase from 1954 land use to 1988 land use. The confidence interval (95%) for the paired difference shows a lower limit of $-2,81\text{mm}$ and an upper limit of $-0,75\text{mm}$. This difference, could amount to about 9–33mm more runoff for land use pattern of 1988 when compared to land use pattern of 1954 (same rainfall distribution).

Sediment yield (mean monthly) was found to be significantly different and a very slight reduction was noticed from 1954 to 1988 (land use patterns). But a look at this confidence interval of the paired difference showed a range of $0,05 - 0,19 \text{ t}\cdot\text{ha}^{-1}$ showed that this difference is not really environmentally or scientifically significant, therefore difference observed in sediment yield could not have any significant impact on the catchment area (i.e. at the catchment scale). It is not worthy also that there was an increase in sediment concentration but the difference was insignificant ($P \leq 0.05$) which could have been brought about by the increase in runoff or channel erosion as there is a complete loss of gallery forest on the river banks.

Mean monthly water yield was also found to be decreasing from 1954 to 1988, with confidence interval (95%) ranging from 0,13–1,39mm (lower and upper limit respectively). The significant difference observed here could also not be referred to as an environmentally significant difference.

Summarily, the changes in land use observed 1954, when compared to that of 1988, is significantly different. The differences in soil water, percolation, surface runoff and

baseflow are found to be of great importance due to the high differences observed between these two periods. These parameters adversely affect the hydrologic balance of the catchment for example crop growth and survival will be reduced due to decreasing soil water. While increasing runoff will result in increased soil loss as well as nutrient loss, thereby increasing land degradation, which will further reduce crop yield and consequently food security in the Zagbo catchment area.

5.3 Climate Changes and Basin response

Land use frequently governs erosion to a larger extent than climate (Evan, 1996, Morgan, 1995). The work of De Boer (1997) on Canadian lake sediment as well as the modeling studies of Favis-Mortlock et al (1997) on past land use and climate change also produce similar conclusions. This was also observed within this study as only soil water, PET and sediment concentration are statistically different between the two rainfall periods used while actual evapotranspiration, percolation, surface runoff, baseflow, water yield and sediment yield are not statistically different between these rainfall periods.

The mean monthly potential evapotranspiration was higher in set 2 (1965 – 1968 rainfall data) compared to set 3 (1986 –1990 rainfall data). The paired difference ranges from 1.78 –3.33mm (95% confidence interval). No significant importance can be ascribed to this variation. It is possible to observe greater differences in an area of 10km² in the southern part of Benin (Leihner et al., 1996).

The amount of water in the soil profile during the timestep (monthly value) was significantly different with paired differences for 95% of the data ranging between 0,84 – 3,20mm. The mean monthly soil water (4years) showed that set 2 has a between 2 - 4mm more water than set 3 from January to March while this difference was about 6mm for the month July. But for all the other months (April – June and September –December), set 3 has considerably higher mean soil water difference from set 2 ranging from 1 – 3mm from September to December while the differences are as much as 17, 6 and 7mm for April, May and June, respectively. This is will have significant effect on crop growth due to the period at which this difference occurs (especially April to June) which is the early stage of crop (Maize) development in the Zagbo catchment.

The difference in soil water observed could have significant effect on the sediment concentration in the reach, which was also found to be also significantly different between the 2 data sets (Set 2 and 3). When the saturation level of the soil is reached it is easier for surface runoff to take away soil particles to the reach. The difference observed was as high as 200mg/l and as little as 8mg/l (95% confidence interval paired difference). This is high value of variation for monthly sediment concentration could have a great impact on the quality of Zagbo river water. The quality is a function of its chemistry and its sediment characteristics (processes of erosion and sediment sources and transport), which are necessary for a variety of water management tasks.

Summarily, the erosional and hydrological systems in the Zagbo river catchment simulated by SWAT are more sensitive to the observed land use changes than to the observed climate changes.

5.4 Conclusion

Simulation of effect of land use changes implemented with the SWAT model was found to be useful in identifying effect of land use changes on hydrological properties and sediment yield.

The SWAT model simulation for the Zagbo catchment provides an estimate of changes in selected hydrological characteristics and sediment yield for the major land use patterns given the rainfall in Southern Benin (Bohicon) and the soil associations identified for this area (BJ20, BJ26 and BJ28). From the simulation results it could be concluded that:-

- Sediment yield was the only parameter that differs among the subbasins for all the data sets, thus indicating subbasins where measures for erosion control needs to be implemented. The order of need (subbasin) for erosion control in the catchment was identified: 2>1>5>3>6>8>7>4,
- Land use between 1954 and 1988 contributed more to changes in the hydrological balance and sediment yield in the Zagbo basin as compared to climate changes (rainfall changes),
- Changes in land use from 1954 to 1988 land use pattern caused a reduction in soil water, percolation and baseflow, while an increase in surface runoff

resulted in a slightly lower sediment yield and a higher but an insignificant difference in sediment load (from 1954 – 1988 land use pattern),

- The change of rainfall distribution resulted in significant changes in potential evapotranspiration, soil water and sediment concentration (load), while there was not significant changes to all other catchment hydrological characteristics and sediment yield.

The input parameters used for the simulation are subjected to considerable uncertainty. However, for the case studied estimates of water balance components are relatively robust as they are based on observed daily rainfall data.

The model is quite flexible, thereby making it possible to use only available information to predict but the quality of this prediction could definitely be improved, if more data are available like data on water use, groundwater (characteristics), more detailed soil map and use of more weather stations (due to high variability of rainfall). The inability of the model to delineate the HRU on the map reduces the possibility to examine in detail attribute of the each HRU and how they change over time. This also reduces the possibility for assessment of spatial variability of the parameters tested, as they are all lumped together into the value for each subbasin. Also the databases on land cover and land use as well as tillage are quite inadequate as they contain only major economic crops in the USA and other developed countries. The same can be said of the tillage implements. Allowing the inputs to vary within a realistic range also reduced uncertainty in the model inputs that could be attributed to spatial variability and measurement.

Unfortunately the accuracy of the predictions could not be rigorously tested. They should thus be considered as well based working hypotheses, which may be modified or refined as additional data become available. Therefore, further studies will be suggested to test the accuracy of the predictions.

Estimation of impact of land use changes on catchment hydrology and sediment load in southern Benin

SUMMARY

Agriculture is the most important economic sector in many developing countries. In Benin 80% of the active population is engaged in agricultural activities and agriculture contributes up to 37% of the GDP. Most of African countries have chosen the option to increase agricultural production via an expansion of the cultivated surface area. Due to its history as central territory of a formerly important kingdom, the Abomey plateau is heavily influenced by this process and currently has a population density of 225 inhabitants per km² by the census in 1992. Nowadays, the plateau is characterised by soil degradation, scarcity of forest cover and low agricultural yields. The challenge is to bring to a halt the negative trend in agricultural productivity due to soil loss and soil degradation, and to reverse the deterioration of the productive base (soil) to this come the importance of watershed management of which sediment movement is a vital part.

In order to assess changes to hydrological characteristics, sediment yield and load on a regional scale, which may result from such anthropogenic activities. A geographic information system on the relevant surface properties will be generated for regional modelling. This research applies the Soil and Water Assessment Tool (SWAT) model to the Zagbo River catchment area in Southern Benin to estimate the changes in hydrological characteristics and sediment yield (and load) based on the changes in land use and rainfall distribution.

Sediment yield was the only parameter, that differs among the subbasins for all the data sets, thus indicating subbasins where measures for erosion control needs to be implemented. The order of need (subbasin) for erosion control in the catchment was identified: 2>1>5>3>6>8>7>4.

The observed changes in land use from 1954 to 1988 land use pattern caused a reduction in soil water, percolation and baseflow, while an increase in surface runoff resulted in a slightly lower sediment yield and consequently a higher but insignificant difference in sediment concentration (from 1954 – 1988 land use pattern).

Changing the rainfall distribution resulted in significant changes in potential evapotranspiration, soil water and sediment concentration, while there was not

significant change to all other catchment hydrological characteristics and sediment yield.

Conclusively, land use changes of 1954 compared to 1988 were found to have contributed more to changes in the hydrological balance and sediment yield in the Zagbo basin than meteorological changes (rainfall changes). The model is quiet flexible, thereby making it possible to use only available information to predict. The quality of this prediction could definitely be improved, if more data are available like data on water use, groundwater (characteristics), more detailed soil map and use of more weather stations (due to high variability of rainfall).

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APPENDICES

Appendix I: Soil types and Land Use Distribution (Set 1)

Number of HRUs: 30

Number of Subbasins: 8

		Area [ha]	Area [acres]	%Wat.Area		
WATERSHED:		5573.5000	13772.3972			
LANDUSE:						
	Corn-->CORN	5004.7891	12367.0842	89.80		
	Wetlands-Mixed-->WETL	414.2253	1023.5715	7.43		
	Panicum Tree Savanna-->TRSV	47.4129	117.1597	0.85		
	Panicum-Shrub-Savanna-->SHSV	107.0726	264.5818	1.92		
SOIL:						
	BJ20	340.0297	840.2304	6.10		
	BJ26	4446.8849	10988.4751	79.79		
	BJ28	786.5853	1943.6917	14.11		
		Area [ha]	Area [acres]	%Wat.Area	%Sub.Area	
SUBBASIN #		1	813.5000	2010.1992	14.60	
LANDUSE:						
	Corn-->CORN	686.7764	1697.0588	12.32	84.42	
	Wetlands-Mixed-->WETL	126.7236	313.1403	2.27	15.58	
SOIL:						
	BJ26	417.7092	1032.1803	7.49	51.35	
	BJ28	275.1137	679.8196	4.94	33.82	
	BJ20	120.6771	298.1993	2.17	14.83	
HRUs:						
1	Corn-->CORN/BJ28	238.5830	589.5505	4.28	29.33	1
2	Corn-->CORN/BJ26	406.8760	1005.4109	7.30	50.02	2
3	Corn-->CORN/BJ20	41.3174	102.0974	0.74	5.08	3
4	Wetlands-Mixed-->WETL/BJ28	36.5307	90.2691	0.66	4.49	4
5	Wetlands-Mixed-->WETL/BJ26	10.8332	26.7695	0.19	1.33	5
6	Wetlands-Mixed-->WETL/BJ20	79.3597	196.1018	1.42	9.76	6

		Area [ha]	Area [acres]	%Wat.Area	%Sub.Area	
SUBBASIN #	2	429.2500	1060.6982	7.70		
LANDUSE:						
	Corn-->CORN	362.2932	895.2447	6.50	84.40	
	Wetlands-Mixed-->WETL	66.9568	165.4535	1.20	15.60	
SOIL:						
	BJ28	359.8546	889.2186	6.46	83.83	
	BJ20	69.3954	171.4796	1.25	16.17	
HRUs:						
7	Corn-->CORN/BJ28	326.8952	807.7744	5.87	76.15	1
8	Corn-->CORN/BJ20	35.3980	87.4702	0.64	8.25	2
9	Wetlands-Mixed-->WETL/BJ28	32.9593	81.4442	0.59	7.68	3
10	Wetlands-Mixed-->WETL/BJ20	33.9974	84.0094	0.61	7.92	4

		Area [ha]	Area [acres]	%Wat.Area	%Sub.Area	
SUBBASIN #	3	189.7500	468.8817	3.40		
LANDUSE:						
	Corn-->CORN	145.6459	359.8984	2.61	76.76	
	Wetlands-Mixed-->WETL	30.2574	74.7676	0.54	15.95	
	Panicum-Shrub-Savanna-->SHSV	13.8466	34.2157	0.25	7.30	
SOIL:						
	BJ26	148.7230	367.5019	2.67	78.38	
	BJ20	41.0270	101.3798	0.74	21.62	
HRUs:						
11	Corn-->CORN/BJ26	120.7733	298.4369	2.17	63.65	1
12	Corn-->CORN/BJ20	24.8726	61.4615	0.45	13.11	2
13	Wetlands-Mixed-->WETL/BJ26	14.1030	34.8493	0.25	7.43	3
14	Wetlands-Mixed-->WETL/BJ20	16.1544	39.9183	0.29	8.51	4
15	Panicum-Shrub-Savanna-->SHSV/BJ26	13.8466	34.2157	0.25	7.30	5

		Area [ha]	Area [acres]	%Wat.Area	%Sub.Area	
SUBBASIN #	4	641.0000	1583.9431	11.50		
LANDUSE:						
	Corn-->CORN	606.8609	1499.5836	10.89	94.67	
	Panicum-Shrub-Savanna-->SHSV	34.1391	84.3594	0.61	5.33	
SOIL:						
	BJ26	641.0000	1583.9430	11.50	100.00	

HRUs:						
16	Corn-->CORN/BJ26	606.8609	1499.5836	10.89	94.67	1
17	Panicum-Shrub-Savanna-->SHSV/BJ26	34.1391	84.3594	0.61	5.33	2
		Area [ha]	Area [acres]	%Wat.Area	%Sub.Area	
SUBBASIN #	5	347.0000	857.4543	6.23		
LANDUSE:						
	Corn-->CORN	224.2995	554.2554	4.02	64.64	
	Wetlands-Mixed-->WETL	75.2875	186.0393	1.35	21.70	
	Panicum Tree Savanna-->TRSV	47.4129	117.1597	0.85	13.66	
SOIL:						
	BJ26	101.9528	251.9304	1.83	29.38	
	BJ28	151.6171	374.6535	2.72	43.69	
	BJ20	93.4301	230.8705	1.68	26.93	
HRUs:						
18	Corn-->CORN/BJ28	116.9692	289.0368	2.10	33.71	1
19	Corn-->CORN/BJ26	75.0270	185.3955	1.35	21.62	2
20	Corn-->CORN/BJ20	32.3033	79.8231	0.58	9.31	3
21	Wetlands-Mixed-->WETL/BJ26	26.9258	66.5349	0.48	7.76	4
22	Wetlands-Mixed-->WETL/BJ20	48.3618	119.5044	0.87	13.94	5
23	Panicum Tree Savanna-->TRSV/BJ28	34.6479	85.6167	0.62	9.98	6
24	Panicum Tree Savanna-->TRSV/BJ20	12.7650	31.5430	0.23	3.68	7

		Area [ha]	Area [acres]	%Wat.Area	%Sub.Area	
SUBBASIN #	6	1314.0000	3246.9597	23.58		
LANDUSE:						
	Corn-->CORN	1199.0000	2962.7890	21.51	91.25	
	Wetlands-Mixed-->WETL	115.0000	284.1708	2.06	8.75	
SOIL:						
	BJ26	1298.5000	3208.6584	23.30	98.82	
	BJ20	15.5000	38.3013	0.28	1.18	
HRUs:						
25	Corn-->CORN/BJ26	1199.0000	2962.7889	21.51	91.25	1
26	Wetlands-Mixed-->WETL/BJ26	99.5000	245.8695	1.79	7.57	2
27	Wetlands-Mixed-->WETL/BJ20	15.5000	38.3013	0.28	1.18	3

		Area [ha]	Area [acres]	%Wat.Area	%Sub.Area	
SUBBASIN #	7	850.0000	2100.3925	15.25		
LANDUSE:						
	Corn-->CORN	790.9131	1954.3858	14.19	93.05	
	Panicum-Shrub-Savanna-->SHSV	59.0869	146.0067	1.06	6.95	
SOIL:						
	BJ26	850.0000	2100.3925	15.25	100.00	
HRUs:						
28	Corn-->CORN/BJ26	790.9131	1954.3858	14.19	93.05	1
29	Panicum-Shrub-Savanna-->SHSV/BJ26	59.0869	146.0067	1.06	6.95	2

		Area [ha]	Area [acres]	%Wat.Area	%Sub.Area	
SUBBASIN #	8	989.0000	2443.8684	17.74		
LANDUSE:						
	Corn-->CORN	989.0000	2443.8684	17.74	100.00	
SOIL:						
	BJ26	989.0000	2443.8684	17.74	100.00	
HRUs:						
30	Corn-->CORN/BJ26	989.0000	2443.8684	17.74	100.00	1

Appendix II: Soil types and Land Use Distribution (Set 2 and 3)

Number of HRUs: 32
 Number of Subbasins: 8

		Area [ha]	Area [acres]	%Wat.Area		
WATERSHED:		5573.5000	13772.3972			
LANDUSE:						
	Residential-High Density-->URHD	445.4301	1100.6800	7.99		
	Corn-->CORN	4664.9286	11527.2718	83.70		
	Oil palm-->OPLM	28.3112	69.9584	0.51		
	Panicum Tree Savanna-->TRSV	192.2193	474.9835	3.45		
	Panicum-Shrub-Savanna-->SHSV	220.0621	543.7845	3.95		
	Woodland-Tropic-->FRMX	22.5487	55.7191	0.40		
SOIL:						
	BJ20	320.8905	792.9365	5.76		
	BJ26	4464.5605	11032.1522	80.10		
	BJ28	788.0490	1947.3084	14.14		
		Area [ha]	Area [acres]	%Wat.Area	%Sub.Area	
SUBBASIN #		813.5000	2010.1992	14.60		
LANDUSE:						
	Residential-High Density-->URHD	55.1739	136.3374	0.99	6.78	
	Corn-->CORN	758.3261	1873.8617	13.61	93.22	
SOIL:						
	BJ26	417.7092	1032.1803	7.49	51.35	
	BJ28	275.1137	679.8196	4.94	33.82	
	BJ20	120.6771	298.1993	2.17	14.83	
HRUs:						
1	Residential-High Density-->URHD/BJ26	12.0929	29.8822	0.22	1.49	1
2	Residential-High Density-->URHD/BJ20	43.0810	106.4553	0.77	5.30	2
3	Corn-->CORN/BJ28	275.1137	679.8196	4.94	33.82	3
4	Corn-->CORN/BJ26	405.6163	1002.2981	7.28	49.86	4
5	Corn-->CORN/BJ20	77.5962	191.7440	1.39	9.54	5

		Area [ha]	Area [acres]	%Wat.Area	%Sub.Area	
SUBBASIN #	2	429.2500	1060.6982	7.70		
LANDUSE:						
	Residential-High Density-->URHD	64.9523	160.5004	1.17	15.13	
	Corn-->CORN	364.2977	900.1978	6.54	84.87	
SOIL:						
	BJ28	360.3555	890.4566	6.47	83.95	
	BJ20	68.8945	170.2417	1.24	16.05	
HRUs:						
6	Residential-High Density-->URHD/BJ28	27.3212	67.5121	0.49	6.36	1
7	Residential-High Density-->URHD/BJ20	37.6311	92.9883	0.68	8.77	2
8	Corn-->CORN/BJ28	333.0343	822.9445	5.98	77.59	3
9	Corn-->CORN/BJ20	31.2634	77.2533	0.56	7.28	4

		Area [ha]	Area [acres]	%Wat.Area	%Sub.Area	
SUBBASIN #	3	189.7500	468.8817	3.40		
LANDUSE:						
	Residential-High Density-->URHD	75.1935	185.8069	1.35	39.63	
	Corn-->CORN	114.5565	283.0749	2.06	60.37	
SOIL:						
	BJ26	149.3777	369.1197	2.68	78.72	
	BJ20	40.3723	99.7621	0.72	21.28	
HRUs:						
10	Residential-High Density-->URHD/BJ26	67.6237	167.1015	1.21	35.64	1
11	Residential-High Density-->URHD/BJ20	7.5698	18.7054	0.14	3.99	2
12	Corn-->CORN/BJ26	81.7540	202.0182	1.47	43.09	3
13	Corn-->CORN/BJ20	32.8025	81.0567	0.59	17.29	4

		Area [ha]	Area [acres]	%Wat.Area	%Sub.Area	
SUBBASIN #	4	641.0000	1583.9431	11.50		
LANDUSE:						
	Residential-High Density-->URHD	123.4350	305.0139	2.21	19.26	
	Corn-->CORN	437.7252	1081.6408	7.85	68.29	
	Panicum Tree Savanna-->TRSV	79.8399	197.2883	1.43	12.46	
SOIL:						
	BJ26	641.0000	1583.9431	11.50	100.00	
HRUs:						
14	Residential-High Density-->URHD/BJ26	123.4350	305.0139	2.21	19.26	1
15	Corn-->CORN/BJ26	437.7252	1081.6408	7.85	68.29	2
16	Panicum Tree Savanna-->TRSV/BJ26	79.8399	197.2883	1.43	12.46	3

		Area [ha]	Area [acres]	%Wat.Area	%Sub.Area	
SUBBASIN #	5	347.0000	857.4543	6.23		
LANDUSE:						
	Residential-High Density-->URHD	81.1755	200.5886	1.46	23.39	
	Corn-->CORN	155.0852	383.2233	2.78	44.69	
	Oil palm-->OPLM	28.3112	69.9584	0.51	8.16	
	Panicum Tree Savanna-->TRSV	59.8794	147.9650	1.07	17.26	
	Woodland-Tropic-->FRMX	22.5487	55.7191	0.40	6.50	
SOIL:						
	BJ26	103.4736	255.6886	1.86	29.82	
	BJ28	152.5798	377.0323	2.74	43.97	
	BJ20	90.9466	224.7335	1.63	26.21	
HRUs:						
17	Residential-High Density-->URHD/BJ26	61.8838	152.9179	1.11	17.83	1
18	Residential-High Density-->URHD/BJ20	19.2917	47.6707	0.35	5.56	2
19	Corn-->CORN/BJ28	112.2426	277.3571	2.01	32.35	3
20	Corn-->CORN/BJ26	13.2787	32.8123	0.24	3.83	4
21	Corn-->CORN/BJ20	29.5639	73.0539	0.53	8.52	5
22	Oil palm-->OPLM/BJ26	28.3112	69.9584	0.51	8.16	6
23	Panicum Tree Savanna-->TRSV/BJ28	40.3372	99.6752	0.72	11.62	7
24	Panicum Tree Savanna-->TRSV/BJ20	19.5422	48.2898	0.35	5.63	8
25	Woodland-Tropic-->FRMX/BJ20	22.5487	55.7191	0.40	6.50	9

		Area [ha]	Area [acres]	%Wat.Area	%Sub.Area	
SUBBASIN #	6	1314.0000	3246.9597	23.58		
LANDUSE:						
	Corn-->CORN	1193.4379	2949.0447	21.41	90.82	
	Panicum-Shrub-Savanna-->SHSV	120.5621	297.9150	2.16	9.18	
SOIL:						
	BJ26	1314.0000	3246.9597	23.58	100.00	
HRUs:						
26	Corn-->CORN/BJ26	1193.4379	2949.0447	21.41	90.82	1
27	Panicum-Shrub-Savanna-->SHSV/BJ26	120.5621	297.9150	2.16	9.18	2

SUBBASIN #		Area [ha]	Area [acres]	%Wat.Area	%Sub.Area	
7		850.0000	2100.3925	15.25		
LANDUSE:						
	Residential-High Density-->URHD	45.5000	112.4328	0.82	5.35	
	Corn-->CORN	652.5000	1612.3601	11.71	76.76	
	Panicum Tree Savanna-->TRSV	52.5000	129.7301	0.94	6.18	
	Panicum-Shrub-Savanna-->SHSV	99.5000	245.8695	1.79	11.71	
SOIL:						
	BJ26	850.0000	2100.3925	15.25	100.00	
HRUs:						
28	Residential-High Density-->URHD/BJ26	45.5000	112.4328	0.82	5.35	1
29	Corn-->CORN/BJ26	652.5000	1612.3601	11.71	76.76	2
30	Panicum Tree Savanna-->TRSV/BJ26	52.5000	129.7301	0.94	6.18	3
31	Panicum-Shrub-Savanna-->SHSV/BJ26	99.5000	245.8695	1.79	11.71	4

SUBBASIN #		Area [ha]	Area [acres]	%Wat.Area	%Sub.Area	
8		989.0000	2443.8684	17.74		
LANDUSE:						
	Corn-->CORN	989.0000	2443.8684	17.74	100.00	
SOIL:						
	BJ26	989.0000	2443.8684	17.74	100.00	
HRUs:						
32	Corn-->CORN/BJ26	989.0000	2443.8684	17.74	100.00	1

Appendix III: Mean monthly output per subbasin (Set 1)

SUBBASIN	MONTHS	PRECIP	PET	ET	SW	PERC	SURQ	GW_Q	WYLD	SYLD	SEDCONC
1	1,00	1,25	139,72	7,26	78,47	0,00	0,00	2,53	2,55	0,00	0,03
	2,00	27,50	163,68	20,45	79,93	0,00	5,50	0,91	6,43	0,26	320,43
	3,00	84,75	154,83	98,76	46,70	0,00	19,09	0,44	19,57	0,83	478,50
	4,00	95,00	151,51	43,60	76,85	0,49	20,53	0,20	20,79	0,81	506,55
	5,00	153,50	142,26	59,97	104,49	7,49	58,11	1,32	59,52	2,84	1072,38
	6,00	127,50	121,31	50,94	113,37	15,73	51,06	5,82	56,98	2,24	994,90
	7,00	177,00	107,66	52,01	112,36	32,26	94,10	13,39	107,59	4,52	1110,30
	8,00	147,75	103,35	45,98	112,04	33,70	67,98	21,48	89,56	3,33	916,20
	9,00	163,00	104,11	54,64	115,06	36,44	68,36	27,31	95,78	3,17	1056,53
	10,00	98,75	128,63	51,15	103,60	20,99	38,12	32,94	71,16	1,73	642,15
	11,00	13,00	139,08	23,31	90,96	0,31	1,97	20,40	22,41	0,06	68,77
	12,00	3,50	130,76	12,54	81,54	0,00	0,33	6,23	6,59	0,00	10,21
	Total	91,04	132,24	43,38	92,95	12,28	35,43	11,08	46,58	1,65	598,08
2	1,00	1,25	139,72	6,60	72,20	0,00	0,00	2,68	2,71	0,00	0,02
	2,00	27,50	163,71	20,99	72,58	0,00	6,01	0,97	7,03	0,51	375,18
	3,00	84,75	154,83	100,55	37,92	0,00	18,52	0,45	19,19	1,41	535,88
	4,00	95,00	151,51	42,09	69,35	0,38	20,66	0,20	21,14	1,32	577,80
	5,00	153,50	142,25	57,46	96,76	7,77	60,29	1,27	61,98	5,00	1212,45
	6,00	127,50	121,31	48,25	104,84	17,60	52,84	6,24	59,48	3,82	1061,30
	7,00	177,00	107,65	49,41	101,95	35,39	94,77	14,74	109,93	7,49	1198,63
	8,00	147,75	103,35	44,11	101,83	34,53	68,62	23,39	92,41	5,54	1019,25
	9,00	163,00	104,10	52,14	104,58	38,27	69,12	28,90	98,47	5,29	1175,33
	10,00	98,75	128,61	48,36	93,80	22,47	38,39	34,56	73,34	2,87	705,08
	11,00	13,00	139,07	21,39	82,83	0,44	2,08	21,39	23,58	0,10	77,93
	12,00	3,50	130,76	11,09	74,81	0,00	0,38	6,45	6,87	0,01	10,09
	Total	91,04	132,24	41,87	84,45	13,07	35,97	11,77	48,01	2,78	662,41

SUBBASIN	MONTHS	PRECIP	PET	ET	SW	PERC	SURQ	GW_Q	WYLD	SYLD	SEDCONC
3	1,00	1,25	139,72	7,96	84,62	0,00	0,00	2,65	2,67	0,00	0,05
	2,00	27,50	163,72	21,32	86,05	0,00	4,70	0,95	5,66	0,23	386,93
	3,00	84,75	154,84	96,25	56,20	0,00	18,25	0,44	18,72	0,85	666,55
	4,00	95,00	151,51	44,33	86,55	0,63	19,54	0,20	19,77	0,83	581,43
	5,00	153,50	142,24	61,53	114,00	9,67	54,66	1,54	56,25	2,91	1279,13
	6,00	127,50	121,30	52,73	122,27	17,67	48,26	7,03	55,35	2,27	993,13
	7,00	177,00	107,65	53,71	121,59	34,60	89,54	15,15	104,76	4,61	1098,13
	8,00	147,75	103,35	47,31	121,15	35,83	64,78	23,42	88,27	3,37	861,81
	9,00	163,00	104,09	56,35	124,41	38,51	64,52	29,29	93,88	3,25	985,80
	10,00	98,75	128,60	53,07	112,44	22,02	35,61	35,03	70,72	1,77	599,30
	11,00	13,00	139,07	24,67	98,70	0,30	1,75	21,72	23,52	0,06	66,21
	12,00	3,50	130,77	13,66	88,22	0,00	0,28	6,59	6,90	0,00	11,67
Total	91,04	132,24	44,41	101,35	13,27	33,49	12,00	45,54	1,68	627,51	
4	1,00	1,25	139,73	7,32	79,11	0,00	0,00	2,05	2,06	0,00	0,05
	2,00	27,50	163,72	18,45	82,24	0,00	5,82	0,75	6,57	0,13	326,75
	3,00	84,75	154,84	99,57	45,93	0,00	21,39	0,37	21,77	0,43	586,08
	4,00	95,00	151,51	44,79	73,90	0,06	21,90	0,17	22,08	0,43	569,20
	5,00	153,50	142,24	61,36	103,80	1,78	60,19	0,30	60,50	1,45	1267,78
	6,00	127,50	121,30	52,58	114,39	9,27	52,99	2,42	55,43	1,17	852,30
	7,00	177,00	107,65	53,63	115,51	22,82	101,06	7,77	108,85	2,42	910,20
	8,00	147,75	103,35	47,05	115,09	28,14	72,42	14,76	87,21	1,80	702,92
	9,00	163,00	104,10	56,04	118,18	29,45	73,59	20,88	94,49	1,69	801,68
	10,00	98,75	128,61	52,75	106,34	16,53	41,87	26,22	68,11	0,94	488,30
	11,00	13,00	139,08	24,50	92,53	0,13	2,10	16,32	18,43	0,03	54,02
	12,00	3,50	130,77	13,35	82,29	0,00	0,37	4,96	5,34	0,00	10,45
Total	91,04	132,24	44,28	94,11	9,02	37,81	8,08	45,90	0,87	547,48	

SUBBASIN	MONTHS	PRECIP	PET	ET	SW	PERC	SURQ	GW_Q	WYLD	SYLD	SEDCONC
5	1,00	1,25	139,72	7,51	80,26	0,00	0,00	2,90	2,93	0,00	0,04
	2,00	27,50	163,77	22,88	79,91	0,00	4,88	1,03	5,95	0,35	243,45
	3,00	84,75	154,84	98,56	49,35	0,00	16,51	0,47	17,12	1,13	383,38
	4,00	95,00	151,51	42,83	81,92	0,79	18,50	0,21	18,89	1,07	382,20
	5,00	153,50	142,23	59,60	108,80	11,22	55,38	1,81	57,48	3,97	827,80
	6,00	127,50	121,29	50,43	116,06	20,84	48,52	8,20	56,99	3,02	772,45
	7,00	177,00	107,64	51,46	113,64	39,23	88,38	17,62	106,28	6,03	978,15
	8,00	147,75	103,34	45,69	113,34	38,06	63,87	26,62	90,77	4,42	850,01
	9,00	163,00	104,08	54,20	116,40	41,84	63,39	32,25	95,96	4,25	974,85
	10,00	98,75	128,57	50,69	105,05	24,32	34,80	38,12	73,21	2,30	600,63
	11,00	13,00	139,06	23,03	92,82	0,42	1,74	23,43	25,29	0,08	64,62
	12,00	3,50	130,78	12,45	83,53	0,00	0,29	7,07	7,42	0,00	10,64
Total	91,04	132,23	43,28	95,09	14,73	33,02	13,31	46,52	2,22	507,35	
6	1,00	1,25	139,72	7,39	79,48	0,00	0,00	2,20	2,21	0,00	0,06
	2,00	27,50	163,70	18,88	82,40	0,00	5,60	0,80	6,40	0,17	455,80
	3,00	84,75	154,84	99,72	46,72	0,00	20,60	0,39	21,01	0,58	831,43
	4,00	95,00	151,51	44,77	75,31	0,20	21,16	0,18	21,36	0,58	824,20
	5,00	153,50	142,25	61,43	104,83	3,71	58,56	0,60	59,19	1,95	1730,75
	6,00	127,50	121,31	52,59	115,13	11,10	51,51	3,51	55,04	1,56	1091,78
	7,00	177,00	107,65	53,62	115,94	25,59	98,54	9,47	108,04	3,24	1201,80
	8,00	147,75	103,35	47,06	115,52	29,99	70,57	16,81	87,41	2,39	933,90
	9,00	163,00	104,10	56,03	118,65	31,64	71,38	22,89	94,30	2,26	1066,75
	10,00	98,75	128,62	52,75	106,75	17,91	40,52	28,36	68,91	1,25	650,33
	11,00	13,00	139,09	24,53	92,94	0,17	2,02	17,69	19,74	0,04	70,92
	12,00	3,50	130,77	13,40	82,67	0,00	0,36	5,37	5,74	0,00	13,36
Total	91,04	132,24	44,35	94,69	10,03	36,73	9,02	45,78	1,17	739,26	

SUBBASIN	MONTHS	PRECIP	PET	ET	SW	PERC	SURQ	GW_Q	WYLD	SYLD	SEDCONC
7	1,00	1,25	139,73	7,34	79,14	0,00	0,00	2,10	2,11	0,00	0,04
	2,00	27,50	163,71	18,63	82,18	0,00	5,74	0,76	6,51	0,13	337,78
	3,00	84,75	154,84	99,77	45,99	0,00	21,09	0,38	21,47	0,45	600,80
	4,00	95,00	151,51	44,78	74,25	0,08	21,66	0,17	21,84	0,44	606,10
	5,00	153,50	142,24	61,38	104,13	2,32	59,71	0,36	60,09	1,50	1337,35
	6,00	127,50	121,30	52,58	114,56	9,94	52,66	2,75	55,43	1,20	851,45
	7,00	177,00	107,65	53,62	115,55	23,74	100,24	8,32	108,58	2,49	914,38
	8,00	147,75	103,35	47,05	115,14	28,75	71,90	15,32	87,23	1,85	716,22
	9,00	163,00	104,10	56,03	118,24	30,20	72,95	21,51	94,48	1,74	813,35
	10,00	98,75	128,61	52,74	106,38	17,01	41,43	26,93	68,38	0,96	495,68
	11,00	13,00	139,09	24,51	92,57	0,15	2,08	16,69	18,79	0,03	55,96
	12,00	3,50	130,77	13,37	82,32	0,00	0,37	5,13	5,51	0,00	10,21
	Total	91,04	132,24	44,32	94,20	9,35	37,49	8,37	45,87	0,90	561,61
8	1,00	1,25	139,71	7,25	79,03	0,00	0,00	1,89	1,89	0,00	0,04
	2,00	27,50	163,64	17,86	82,43	0,00	6,16	0,69	6,85	0,16	394,53
	3,00	84,75	154,83	98,89	45,73	0,00	22,47	0,35	22,82	0,54	706,10
	4,00	95,00	151,51	44,83	72,75	0,00	22,90	0,16	23,08	0,53	788,98
	5,00	153,50	142,27	61,31	102,72	0,00	61,98	0,08	62,09	1,81	1875,00
	6,00	127,50	121,33	52,61	113,82	7,08	54,74	1,34	56,10	1,45	1440,58
	7,00	177,00	107,67	53,68	115,37	19,80	103,62	5,92	109,56	3,00	1136,80
	8,00	147,75	103,35	47,05	114,94	26,15	74,48	12,40	86,90	2,22	871,05
	9,00	163,00	104,12	56,10	117,99	26,98	76,10	18,64	94,76	2,10	985,88
	10,00	98,75	128,66	52,78	106,22	14,96	43,37	23,85	67,24	1,16	596,70
	11,00	13,00	139,10	24,44	92,39	0,08	2,23	14,70	16,95	0,04	67,15
	12,00	3,50	130,74	13,27	82,21	0,00	0,40	4,55	4,95	0,00	12,62
	Total	91,04	132,24	44,17	93,80	7,92	39,04	7,05	46,10	1,08	739,62

- PRECIP - Rainfall
- PET - Potential evapotranspiration
- ET - Actual Evapotranspiration
- SW - Soil Water
- PERC - Percolation
- SURQ - Surface runoff
- GW_Q - Baseflow
- WYLD - Water yield
- SYLD - Sediment yield
- SEDCONC - Sediment concentration

Appendix IV: Mean monthly output per subbasin (Set 2)

SUBBASIN	MONTHS	PRECIP	PET	ET	SW	PERC	SURQ	GW_Q	WYLD	SYLD	SEDCONC
1	1,00	1,25	139,65	7,00	77,66	0,00	0,01	1,88	1,90	0,00	1,05
	2,00	27,50	161,91	19,56	78,65	0,00	6,86	0,69	7,56	0,29	299,83
	3,00	84,75	154,97	93,64	45,71	0,00	23,90	0,35	24,28	0,96	470,55
	4,00	95,00	149,92	43,55	71,83	0,00	25,08	0,16	25,29	0,91	511,45
	5,00	153,50	142,75	59,11	99,97	0,33	65,64	0,08	65,81	3,21	1054,83
	6,00	127,50	122,17	51,17	109,50	8,18	57,64	1,66	59,39	2,51	1018,00
	7,00	177,00	107,15	51,62	110,75	20,47	104,09	6,57	110,75	5,05	1193,10
	8,00	147,75	104,91	46,34	110,69	25,22	75,82	12,97	88,88	3,73	973,63
	9,00	163,00	105,02	54,88	113,56	26,76	77,94	18,64	96,67	3,55	1134,15
	10,00	98,75	128,25	50,89	102,65	14,90	43,93	23,53	67,55	1,94	684,43
	11,00	13,00	139,26	23,00	89,99	0,12	2,48	14,48	17,00	0,07	74,70
	12,00	3,50	131,25	12,25	80,75	0,00	0,44	4,41	4,87	0,00	12,06
Total	91,04	132,27	42,75	90,97	8,00	40,32	7,12	47,50	1,85	618,98	
2	1,00	1,25	139,65	6,27	71,14	0,00	0,03	1,91	1,95	0,00	1,90
	2,00	27,50	161,93	20,41	70,22	0,00	7,88	0,70	8,62	0,53	356,68
	3,00	84,75	154,98	94,35	35,77	0,00	24,53	0,34	25,07	1,53	523,00
	4,00	95,00	149,92	41,76	62,16	0,00	26,41	0,16	26,82	1,39	556,98
	5,00	153,50	142,74	56,21	89,42	0,60	68,88	0,08	69,35	5,23	1186,85
	6,00	127,50	122,16	48,20	98,69	9,07	60,24	1,95	62,55	4,00	1089,33
	7,00	177,00	107,15	48,84	99,08	21,72	105,78	7,23	113,38	7,82	1284,93
	8,00	147,75	104,91	44,20	99,69	24,64	77,74	13,71	91,79	5,81	1077,95
	9,00	163,00	105,01	52,22	102,46	27,05	80,27	18,95	99,63	5,52	1246,48
	10,00	98,75	128,23	47,95	92,42	15,36	45,21	23,69	69,24	3,00	746,33
	11,00	13,00	139,25	20,85	81,50	0,21	2,79	14,60	17,48	0,11	83,53
	12,00	3,50	131,26	10,65	73,75	0,00	0,55	4,34	4,92	0,01	11,92
Total	91,04	132,26	40,99	81,36	8,22	41,69	7,30	49,23	2,91	680,49	

SUBBASIN	MONTHS	PRECIP	PET	ET	SW	PERC	SURQ	GW_Q	WYLD	SYLD	SEDCONC
3	1,00	1,25	139,66	7,18	79,44	0,00	0,07	1,30	1,39	0,00	1,05
	2,00	27,50	161,95	20,67	78,11	0,00	8,10	0,47	8,58	0,19	372,53
	3,00	84,75	154,98	88,74	44,30	0,00	29,71	0,24	29,97	0,74	621,63
	4,00	95,00	149,92	43,77	65,46	0,00	29,89	0,11	30,03	0,72	545,95
	5,00	153,50	142,73	58,70	91,32	0,12	68,64	0,06	68,73	2,46	1215,88
	6,00	127,50	122,15	52,04	102,47	4,62	59,17	0,92	60,14	1,89	956,33
	7,00	177,00	107,14	53,04	109,22	11,90	105,43	3,73	109,21	3,79	1059,25
	8,00	147,75	104,91	47,01	113,37	16,92	79,41	7,57	87,03	2,80	818,05
	9,00	163,00	105,01	56,30	117,41	19,42	82,91	12,02	94,98	2,68	940,45
	10,00	98,75	128,22	52,36	106,92	9,83	47,01	16,13	63,19	1,46	572,93
	11,00	13,00	139,25	23,79	92,91	0,03	3,15	10,19	13,37	0,05	63,73
	12,00	3,50	131,27	12,82	82,91	0,00	0,64	3,03	3,69	0,00	11,62
Total	91,04	132,26	43,03	90,32	5,24	42,84	4,65	47,52	1,40	598,28	
4	1,00	1,25	139,67	7,11	76,74	0,00	0,03	1,74	1,78	0,00	1,07
	2,00	27,50	161,95	20,00	77,39	0,00	6,78	0,64	7,42	0,10	246,98
	3,00	84,75	154,98	98,24	39,31	0,00	24,47	0,32	24,80	0,33	417,90
	4,00	95,00	149,92	44,48	65,24	0,00	24,34	0,15	24,49	0,32	417,23
	5,00	153,50	142,73	60,17	94,53	0,67	63,14	0,12	63,27	1,10	989,78
	6,00	127,50	122,15	52,53	105,43	7,33	55,22	1,64	56,87	0,88	709,08
	7,00	177,00	107,14	53,09	109,59	17,96	102,88	5,89	108,78	1,82	735,15
	8,00	147,75	104,91	47,08	111,45	23,05	75,29	11,60	86,91	1,34	536,03
	9,00	163,00	105,01	55,99	114,95	25,34	77,51	17,03	94,56	1,28	612,55
	10,00	98,75	128,23	52,21	103,89	13,84	44,10	21,97	66,09	0,71	374,70
	11,00	13,00	139,26	24,23	89,98	0,08	2,54	13,63	16,18	0,03	40,58
	12,00	3,50	131,27	13,12	79,84	0,00	0,47	4,13	4,61	0,00	7,75
Total	91,04	132,27	44,02	89,03	7,36	39,73	6,57	46,31	0,66	424,07	

SUBBASIN	MONTHS	PRECIP	PET	ET	SW	PERC	SURQ	GW_Q	WYLD	SYLD	SEDCONC
5	1,00	1,25	139,66	8,88	72,22	0,00	0,04	2,13	2,20	0,00	1,69
	2,00	27,50	161,99	23,00	70,20	0,00	6,43	0,77	7,23	0,25	219,10
	3,00	84,75	154,98	90,77	41,94	0,00	22,00	0,36	22,49	0,82	357,85
	4,00	95,00	149,91	43,53	69,22	0,11	23,77	0,16	24,11	0,76	370,90
	5,00	153,50	142,71	58,54	96,14	4,75	62,88	0,54	63,68	2,85	770,95
	6,00	127,50	122,14	50,60	105,04	13,21	54,35	4,20	58,81	2,14	726,35
	7,00	177,00	107,13	51,31	106,64	26,28	97,46	10,77	108,50	4,19	952,08
	8,00	147,75	104,91	46,05	108,84	27,26	71,83	17,44	89,53	3,12	815,68
	9,00	163,00	105,00	54,56	112,24	31,17	73,37	22,38	96,05	2,95	927,23
	10,00	98,75	128,19	50,73	101,39	17,63	40,96	27,45	68,68	1,61	565,18
	11,00	13,00	139,23	23,59	88,07	0,27	2,41	16,89	19,39	0,06	63,77
	12,00	3,50	131,28	13,38	77,67	0,00	0,47	5,13	5,65	0,00	11,05
Total	91,04	132,26	42,91	87,47	10,06	38,00	9,02	47,19	1,56	481,82	
6	1,00	1,25	139,66	7,39	79,17	0,00	0,00	2,16	2,17	0,00	0,06
	2,00	27,50	161,93	19,25	81,73	0,00	5,61	0,78	6,40	0,17	474,65
	3,00	84,75	154,98	98,97	46,52	0,00	20,86	0,39	21,26	0,60	823,65
	4,00	95,00	149,92	45,02	74,85	0,11	21,26	0,18	21,45	0,58	803,38
	5,00	153,50	142,74	61,42	104,56	3,05	59,04	0,45	59,52	1,96	1846,50
	6,00	127,50	122,16	53,20	114,14	10,90	51,82	3,16	55,00	1,57	1129,38
	7,00	177,00	107,15	53,39	115,68	24,45	99,18	8,98	108,19	3,28	1227,30
	8,00	147,75	104,91	47,55	115,06	29,37	70,90	16,22	87,15	2,41	943,00
	9,00	163,00	105,02	56,28	118,05	31,06	71,84	22,29	94,16	2,28	1085,90
	10,00	98,75	128,24	52,56	106,43	17,55	40,78	27,73	68,55	1,26	661,38
	11,00	13,00	139,26	24,59	92,61	0,14	2,02	17,21	19,26	0,04	74,05
	12,00	3,50	131,26	13,43	82,31	0,00	0,35	5,24	5,60	0,00	14,20
Total	91,04	132,27	44,42	94,26	9,72	36,97	8,73	45,73	1,18	756,95	

SUBBASIN	MONTHS	PRECIP	PET	ET	SW	PERC	SURQ	GW_Q	WYLD	SYLD	SEDCONC
7	1,00	1,25	139,66	7,40	78,60	0,00	0,01	2,23	2,25	0,00	0,72
	2,00	27,50	161,94	20,21	80,26	0,00	5,57	0,80	6,38	0,11	300,73
	3,00	84,75	154,98	99,86	44,44	0,00	20,62	0,39	21,02	0,38	509,05
	4,00	95,00	149,92	44,77	73,35	0,14	20,98	0,18	21,17	0,37	549,40
	5,00	153,50	142,73	61,12	103,04	4,23	58,27	0,57	58,86	1,27	1215,73
	6,00	127,50	122,15	52,99	112,43	12,32	51,28	3,89	55,19	1,01	699,70
	7,00	177,00	107,14	53,24	114,15	26,04	97,21	10,12	107,35	2,11	765,58
	8,00	147,75	104,91	47,42	114,23	29,85	70,01	17,30	87,33	1,55	596,47
	9,00	163,00	105,01	56,11	117,42	32,24	70,86	23,25	94,12	1,47	681,30
	10,00	98,75	128,23	52,42	105,87	18,29	40,01	28,74	68,77	0,82	417,50
	11,00	13,00	139,26	24,55	92,05	0,18	2,04	17,87	19,93	0,03	47,12
	12,00	3,50	131,27	13,43	81,73	0,00	0,37	5,45	5,83	0,00	7,96
	Total	91,04	132,27	44,46	93,13	10,27	36,44	9,23	45,68	0,76	482,60
8	1,00	1,25	139,65	7,26	79,02	0,00	0,00	1,87	1,88	0,00	0,04
	2,00	27,50	161,87	18,28	81,99	0,00	6,18	0,68	6,86	0,16	411,70
	3,00	84,75	154,97	97,76	46,18	0,00	22,70	0,35	23,06	0,56	700,88
	4,00	95,00	149,92	45,12	72,86	0,00	22,94	0,16	23,11	0,54	801,63
	5,00	153,50	142,76	61,35	102,68	0,00	62,11	0,08	62,21	1,83	1903,75
	6,00	127,50	122,18	53,22	113,16	7,13	54,70	1,30	56,02	1,47	1359,03
	7,00	177,00	107,16	53,47	115,44	19,26	103,63	5,81	109,46	3,05	1160,33
	8,00	147,75	104,91	47,57	114,79	25,93	74,40	12,25	86,67	2,25	881,93
	9,00	163,00	105,04	56,40	117,71	26,83	76,09	18,47	94,58	2,13	1006,03
	10,00	98,75	128,28	52,62	106,21	14,84	43,36	23,64	67,03	1,18	608,85
	11,00	13,00	139,27	24,50	92,36	0,05	2,23	14,50	16,75	0,04	70,24
	12,00	3,50	131,24	13,29	82,16	0,00	0,40	4,50	4,90	0,00	13,38
	Total	91,04	132,27	44,24	93,71	7,84	39,06	6,97	46,04	1,10	743,15

PRECIP	-	Rainfall
PET	-	Potential evapotranspiration
ET	-	Actual Evapotranspiratin
SW	-	Soil Water
PERC	-	Percolation
SURQ	-	Surface runoff
GW_Q	-	Baseflow
WYLD	-	Water yield
SYLD	-	Sediment yield
SEDCONC	-	Sediment concentration

Appendix V: Mean monthly output per subbasin (Set 3)

SUBBASIN	MONTHS	PRECIP	PET	ET	SW	PERC	SURQ	GW_Q	WYLD	SYLD	SEDCONC
1	1,00	2,0	138,8	8,9	76,5	0,0	0,0	0,3	0,4	0,0	1,6
	2,00	32,3	159,8	18,7	77,8	0,0	12,1	0,1	12,2	0,4	198,3
	3,00	75,5	150,6	91,2	42,5	0,0	19,6	0,1	19,7	0,6	329,0
	4,00	164,8	141,2	54,2	88,1	1,1	63,5	0,0	63,6	2,2	889,2
	5,00	116,8	138,9	51,8	106,2	2,3	43,8	0,7	44,6	1,8	786,7
	6,00	188,8	110,9	60,3	115,1	27,0	92,4	4,1	96,6	4,4	1492,8
	7,00	117,3	107,4	49,6	104,2	24,3	54,2	15,7	70,0	2,3	840,9
	8,00	113,3	106,4	41,2	109,5	11,8	54,7	17,8	72,5	2,4	697,1
	9,00	143,0	105,5	49,0	116,6	15,3	71,3	14,7	86,0	3,6	1009,1
	10,00	91,5	129,0	50,3	105,0	16,8	35,8	15,9	51,7	1,6	647,7
	11,00	35,3	136,9	33,3	91,8	0,6	14,6	13,1	27,7	0,5	269,4
	12,00	7,5	131,3	14,7	82,5	0,0	2,1	4,4	6,6	0,1	44,1
Total	90,6	129,7	43,6	93,0	8,3	38,7	7,2	46,0	1,7	600,5	
2	1,00	2,0	138,8	7,3	70,3	0,0	0,1	0,4	0,5	0,0	3,5
	2,00	32,3	159,8	19,5	69,7	0,0	13,2	0,2	13,4	0,8	256,3
	3,00	75,5	150,6	90,3	34,4	0,0	20,2	0,1	20,5	1,0	357,1
	4,00	164,8	141,2	52,6	77,8	1,5	66,7	0,0	67,1	3,6	1010,9
	5,00	116,8	138,9	48,9	95,5	2,7	46,8	0,9	48,1	3,0	885,5
	6,00	188,8	110,9	57,4	103,4	27,9	94,9	4,6	100,0	7,5	1694,0
	7,00	117,3	107,4	47,1	93,8	23,9	55,6	16,1	72,1	3,7	927,2
	8,00	113,3	106,4	39,2	99,1	11,9	56,5	17,8	74,5	4,0	773,9
	9,00	143,0	105,5	46,5	105,5	16,2	73,4	14,9	88,6	6,0	1122,5
	10,00	91,5	128,9	47,4	94,6	17,5	37,2	16,4	53,9	2,6	718,1
	11,00	35,3	136,8	30,9	82,7	0,9	15,2	13,5	28,8	0,9	289,2
	12,00	7,5	131,3	12,7	75,2	0,0	2,3	4,6	6,9	0,1	48,3
Total	90,6	129,7	41,6	83,5	8,5	40,2	7,5	47,9	2,8	673,9	

SUBBASIN	MONTHS	PRECIP	PET	ET	SW	PERC	SURQ	GW_Q	WYLD	SYLD	SEDCONC
3	1,00	2,0	138,8	9,5	74,0	0,0	0,1	0,1	0,3	0,0	2,2
	2,00	32,3	159,8	20,0	73,2	0,0	12,9	0,0	13,0	0,3	252,9
	3,00	75,5	150,6	84,1	39,9	0,0	24,6	0,0	24,7	0,5	350,7
	4,00	164,8	141,2	54,2	81,0	0,6	68,7	0,0	68,7	1,6	953,3
	5,00	116,8	138,9	51,8	98,1	1,2	46,1	0,4	46,6	1,3	851,6
	6,00	188,8	110,9	61,7	114,3	16,3	94,3	2,4	96,7	3,3	1357,5
	7,00	117,3	107,4	51,1	107,6	15,5	57,3	9,4	66,7	1,7	710,1
	8,00	113,3	106,4	41,7	112,6	8,2	58,3	11,1	69,5	1,8	571,8
	9,00	143,0	105,5	49,5	119,1	11,4	75,2	9,7	85,0	2,7	851,8
	10,00	91,5	128,9	51,2	106,9	13,1	39,3	11,5	50,8	1,2	524,3
	11,00	35,3	136,8	33,1	93,3	0,2	15,5	9,8	25,3	0,4	251,4
	12,00	7,5	131,3	15,2	83,1	0,0	2,4	3,1	5,6	0,0	52,8
Total	90,6	129,7	43,6	91,9	5,5	41,2	4,8	46,1	1,2	560,9	
4	1,00	2,0	138,8	9,8	73,5	0,0	0,1	0,3	0,3	0,0	5,3
	2,00	32,3	159,8	19,5	74,4	0,0	11,6	0,1	11,7	0,2	1043,0
	3,00	75,5	150,6	95,1	34,9	0,0	19,9	0,1	19,9	0,2	2377,0
	4,00	164,8	141,2	55,1	82,2	1,1	61,0	0,0	61,0	0,8	1292,9
	5,00	116,8	138,9	53,3	101,1	2,1	41,3	0,7	42,0	0,6	2772,6
	6,00	188,8	110,9	61,6	114,6	23,3	90,6	3,5	94,1	1,5	974,8
	7,00	117,3	107,4	50,9	105,1	21,8	54,1	13,7	67,8	0,9	468,6
	8,00	113,3	106,4	41,9	110,7	11,0	54,4	15,8	70,3	0,9	373,9
	9,00	143,0	105,5	49,8	117,9	14,7	71,0	13,5	84,5	1,3	573,6
	10,00	91,5	128,9	51,5	105,7	15,9	36,0	14,9	50,9	0,6	345,4
	11,00	35,3	136,8	34,3	91,7	0,6	14,5	12,4	26,9	0,2	167,0
	12,00	7,5	131,4	15,9	81,1	0,0	2,1	4,3	6,4	0,0	35,9
Total	90,6	129,7	44,9	91,1	7,5	38,0	6,6	44,7	0,6	869,2	

SUBBASIN	MONTHS	PRECIP	PET	ET	SW	PERC	SURQ	GW_Q	WYLD	SYLD	SEDCONC
5	1,00	2,0	138,8	9,9	69,5	0,0	0,1	0,7	0,8	0,0	2,5
	2,00	32,3	159,8	22,7	67,9	0,0	11,0	0,2	11,3	0,4	164,5
	3,00	75,5	150,6	85,3	39,4	0,0	18,5	0,1	18,7	0,5	249,5
	4,00	164,8	141,2	54,8	85,5	3,6	59,8	0,2	60,2	1,8	665,3
	5,00	116,8	138,9	51,8	103,0	5,3	41,8	2,1	44,2	1,6	599,0
	6,00	188,8	110,9	60,3	111,5	33,1	86,2	7,2	93,8	4,1	1175,3
	7,00	117,3	107,4	49,7	102,3	25,9	50,5	19,5	70,4	2,0	717,4
	8,00	113,3	106,4	41,6	108,2	14,0	51,4	20,5	72,1	2,1	610,3
	9,00	143,0	105,4	48,9	115,1	19,2	67,6	17,4	85,2	3,2	858,5
	10,00	91,5	128,9	50,5	102,5	19,3	33,9	19,1	53,3	1,3	516,1
	11,00	35,3	136,8	33,9	88,8	1,6	13,4	15,3	28,8	0,4	210,5
	12,00	7,5	131,4	16,0	78,2	0,0	2,0	5,4	7,5	0,1	35,6
	Total	90,6	129,7	43,8	89,3	10,2	36,4	9,0	45,5	1,5	483,7
6	1,00	2,0	138,8	10,0	78,1	0,0	0,0	0,5	0,5	0,0	0,0
	2,00	32,3	159,8	18,6	81,1	0,0	10,5	0,2	10,7	0,3	391,3
	3,00	75,5	150,6	97,5	42,3	0,0	16,8	0,1	16,9	0,4	529,6
	4,00	164,8	141,2	55,7	92,1	2,5	56,3	0,2	56,5	1,4	2099,0
	5,00	116,8	138,9	54,2	110,8	4,3	38,1	1,6	39,7	1,1	1315,1
	6,00	188,8	110,9	61,9	120,4	31,2	86,4	5,7	92,1	2,7	1576,8
	7,00	117,3	107,4	51,1	108,0	28,2	50,5	18,8	69,3	1,5	823,7
	8,00	113,3	106,4	42,4	113,9	14,2	50,3	21,1	71,4	1,6	659,9
	9,00	143,0	105,5	50,5	121,6	18,2	66,3	17,7	84,0	2,3	988,3
	10,00	91,5	129,0	52,1	109,5	18,6	32,6	18,7	51,3	1,1	608,8
	11,00	35,3	136,9	35,1	95,2	1,2	13,4	15,0	28,5	0,4	291,3
	12,00	7,5	131,3	16,3	84,5	0,0	1,9	5,3	7,2	0,0	64,6
	Total	90,6	129,7	45,5	96,4	9,9	35,3	8,7	44,0	1,1	779,0

SUBBASIN	MONTHS	PRECIP	PET	ET	SW	PERC	SURQ	GW_Q	WYLD	SYLD	SEDCONC
7	1,00	2,0	138,8	10,0	77,0	0,0	0,0	0,6	0,6	0,0	1,3
	2,00	32,3	159,8	19,7	79,0	0,0	10,4	0,2	10,6	0,2	237,6
	3,00	75,5	150,6	97,4	40,3	0,0	16,8	0,1	16,9	0,3	940,8
	4,00	164,8	141,2	55,5	90,2	3,0	56,0	0,2	56,2	0,9	1376,3
	5,00	116,8	138,9	54,1	109,1	4,7	38,0	1,8	39,8	0,7	3297,9
	6,00	188,8	110,9	61,8	119,0	32,0	85,2	6,2	91,5	1,8	1017,8
	7,00	117,3	107,4	51,1	107,3	28,2	49,9	19,3	69,2	1,0	516,1
	8,00	113,3	106,4	42,4	113,3	14,6	50,0	21,4	71,4	1,0	419,1
	9,00	143,0	105,5	50,3	120,9	18,9	65,9	18,0	83,9	1,5	629,8
	10,00	91,5	128,9	52,0	108,6	19,1	32,5	19,2	51,7	0,7	381,2
	11,00	35,3	136,8	35,0	94,3	1,4	13,2	15,4	28,7	0,2	184,4
	12,00	7,5	131,4	16,3	83,7	0,0	1,9	5,4	7,2	0,0	37,0
	Total	90,6	129,7	45,5	95,2	10,2	35,0	9,0	44,0	0,7	753,3
8	1,00	2,0	138,8	10,0	77,9	0,0	0,0	0,3	0,3	0,0	0,1
	2,00	32,3	159,7	17,5	81,1	0,0	11,3	0,1	11,4	0,2	417,3
	3,00	75,5	150,5	96,9	41,6	0,0	18,2	0,1	18,3	0,4	1093,9
	4,00	164,8	141,2	55,7	90,4	0,5	59,4	0,0	59,4	1,3	2186,3
	5,00	116,8	138,9	54,1	109,2	2,0	40,5	0,4	41,0	1,0	2071,0
	6,00	188,8	110,9	61,9	120,0	25,7	90,8	3,4	94,3	2,5	1774,0
	7,00	117,3	107,4	51,1	107,9	24,9	53,5	15,1	68,6	1,4	756,7
	8,00	113,3	106,5	42,3	113,5	11,8	53,3	17,7	71,0	1,4	600,5
	9,00	143,0	105,5	50,4	121,1	14,9	69,8	14,6	84,4	2,1	919,4
	10,00	91,5	129,0	52,0	109,2	16,4	34,7	15,6	50,3	1,0	581,4
	11,00	35,3	136,9	35,0	95,0	0,4	14,3	12,8	27,2	0,3	271,7
	12,00	7,5	131,3	16,2	84,3	0,0	2,0	4,3	6,3	0,0	74,3
	Total	90,6	129,7	45,2	95,9	8,1	37,3	7,0	44,4	1,0	895,5

PRECIP	-	Rainfall
PET	-	Potential evapotranspiration
ET	-	Actual Evapotranspiration
SW	-	Soil Water
PERC	-	Percolation
SURQ	-	Surface runoff
GW_Q	-	Baseflow
WYLD	-	Water yield
SYLD	-	Sediment yield
SEDCONC	-	Sediment concentration

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DECLARATION

I hereby declare that this thesis was written independently and without using any sources or mean other than those indicated.

Olanrewaju M. Lawal

Stuttgart , September 2004