University of Arkansas, Fayetteville
ScholarWorks@UARK

Biological and Agricultural Engineering Undergraduate Honors Theses

Biological and Agricultural Engineering

5-2014

A SWAT model for a cocoa growing region in Ghana

Russell Thomas Bair
University of Arkansas, Fayetteville

This thesis is approved.

Thesis Advisor:

Thesis Committee:

A SWAT model for a cocoa growing region in Ghana

An Undergraduate Honors College Thesis

in the

Department of Biological Engineering

College of Engineering
University of Arkansas
Fayetteville, AR

by

Russell Thomas Bair

Contents

1. ABSTRACT ... 4
2. INTRODUCTION ... 4
   - *2.1 Project Goal statement* ... 6
3. MATERIALS AND METHODS ... 6
   - *3.1 Study Area Description* ... 6
   - *3.2 SWAT Model Description* ... 8
4. *Model* Inputs ... 9
   - *4.1 DEM* ... 9
   - *4.2 Subwatershed and HRU Delineation* ... 9
   - *4.3 Land Use* ... 10
   - *4.4 Cocoa Crop Parameters* ... 11
   - *4.5 Soil* ... 13
   - *4.6 Weather* ... 14
   - *4.7 Management Practices* ... 14
   - *4.7.1 Cocoa Management Practices* ... 15
   - *4.7.2 Fertilizer and Pesticide Data* ... 17
   - *3.7 Streamflow data* ... 19
5. *Model* Sensitivity *Analysis, Calibration, and Validation* ... 19
   - *5.1 Model Sensitivity Analysis* ... 19
   - *5.2 Calibration and Validation* ... 20
6. Results *and Discussion* ... 21
   - *6.1 Calibration* ... 21
   - *6.2 Validation* ... 23
7. Conclusions *and Discussion* ... 24
   - *7.1 Error* ... 24
   - *7.2 Future Work* ... 25
8. Acknowledgements ... 26
9. References ... 27

1. ABSTRACT

For agricultural outputs to rise with population, more sustainable and productive methods must be identified. Watershed modeling is a way to relatively quickly compare possible impacts of large scale agricultural practice changes. The goal of this project was to develop a watershed model for the Pra River basin in southern Ghana, a cocoa growing region, that could be used for future impact studies of land management practice options. The model was developed using the Soil Water Assessment Tool (SWAT) and calibrated using the best daily stream flow data that could be readily located. With an R^2 value of 0.57 and a Nash-Sutcliffe Efficiency coefficient (NSE) of -0.43, the model is not yet accurate enough to be used in predictive studies for land management practices changes. The project is moving in the right direction though and more time should see the model become a useful tool for making decisions concerning the sustainability of different practices of cocoa agriculture in the region.

2. INTRODUCTION

Sustainable agriculture may be defined as practices that minimize their detrimental impacts on the environment and allow humans to meet current and future societal needs. Agriculture provides humanity with many benefits but the demand for agricultural products will continue to increase with world population, which is projected to reach 10 billion by 2050 (Tilman et al., 2002). Researchers are challenged with facilitating this increased agricultural yield without compromising environmental integrity (Wade et al., 2010).

Two important aspects of environmental integrity that must be considered are water quantity and quality. “Water is a primary component of the biosphere. The ability of the biosphere to support life as well as the health and enjoyment of that life depends on water quality” (Huffman et al., 2011). Nonpoint source pollution into waterways from agricultural runoff can lead to the loss of beneficial use and degradation of the health of humans, wildlife, or ecosystems (Mihelcic & Zimmerman, 2010) but, engineered solutions can be implemented to minimize unintended effects.

Different land management strategies can be implemented to increase agricultural yields, but may also affect water runoff quantity and quality. These impacts resulting from land management changes must be examined. Watershed modeling can be an effective tool to analyze these types of impacts because of the range of scales that can be considered. Watershed modeling also gives the ability to predict the results of possible future land management changes. Analyzing how water quantity changes in relation to land management practices will provide land managers with the information to make the best decisions regarding yields and environmental integrity.

There is a need to measure these impacts for cocoa production because confectioners have made commitments to source 100% certified sustainable cocoa by the year 2020 (Graham, 2012), and projected increases in global demand has led cocoa producing countries to make efforts to increase production. This means that cocoa farmers will have financial motivation to employ production land management strategies that can be quantifiably shown to be in the best interest of environmental integrity. Cocoa is usually grown in rainy, tropical regions and the countries of West Africa currently produce more than 70% of the world's cocoa supply (Cocoa, 2012). Of these countries, Ghana is annually the second largest producer.

Major management decisions in cocoa production include: whether to use shade or a monoculture system, whether or not to use fertilizers and agrochemicals, and tree planting density. There are tradeoffs between these different practices in terms of increasing biodiversity, soil nutrient depletion, and economic benefits in the short and long term (Asase et al., 2008;

Franzen et al., 2007). More research and modeling is called for to better understand the effects of these different systems of production in Ghana (Bambury et al., 2003; Franzen et al., 2007). Watershed modeling can be used to help differentiate between the different practices by examining their impacts on water runoff quantity and quality, which will play a role for confectioners in deciding which practices are more environmentally sustainable. For watershed modeling to be an effective tool, a comprehensive and accurate model must be created.

2.1 Project Goal statement

The goal of the project was to use the Soil and Water Assessment Tool (SWAT) (Arnold et al., 1998) to create a hydrologic model for a cocoa producing region in the West African country of Ghana. The specific objectives are to develop, calibrate and validate the SWAT model using historical stream flow data to represent current watershed conditions.

3. MATERIALS AND METHODS

3.1 Study Area Description

The Pra River and upper Ankobra River basins in the country of Ghana comprise an area with a concentrated amount of cocoa agriculture. That means that these two major watersheds will be heavily influenced by any possible changes in cocoa land management. The area modeled is very large in size because the only river discharge data readily available was for locations near the outlets of the Pra River and Ankobra River (Figure 1). The combined watershed has an area of 2,702,881 ha and ranges in elevation from sea level to 862 meters (Figure 2). The gauging station on the Pra River is located at 5.17°N and 1.63°W and the gauging station on the Ankobra River is located at 5.45°N and 2.12°W. The watersheds fall within the Ashanti, Eastern, Central, and Western regions of Ghana, with most of the cocoa production occurring in the Ashanti and

Western regions. Because of the size of the study area, there are many types of land use associated with it including forest, savanna, agricultural areas, cocoa plantations, and urban areas.

The model was developed covering the Pra and Ankobra River basins for its long term purpose to evaluate the impacts of cocoa agriculture in the region as a whole. However, the focus of this thesis is only the Pra River basin. That being said, some of the geographic information systems (GIS) spatial data and representations in this report will include both of the rivers. This will be pointed out where important. This is being done to avoid the time consuming task of rebuilding the model multiple times. The fact that there are two river basins will not affect the model output at the outflow of the Pra River because the two river basins are not hydrologically connected.

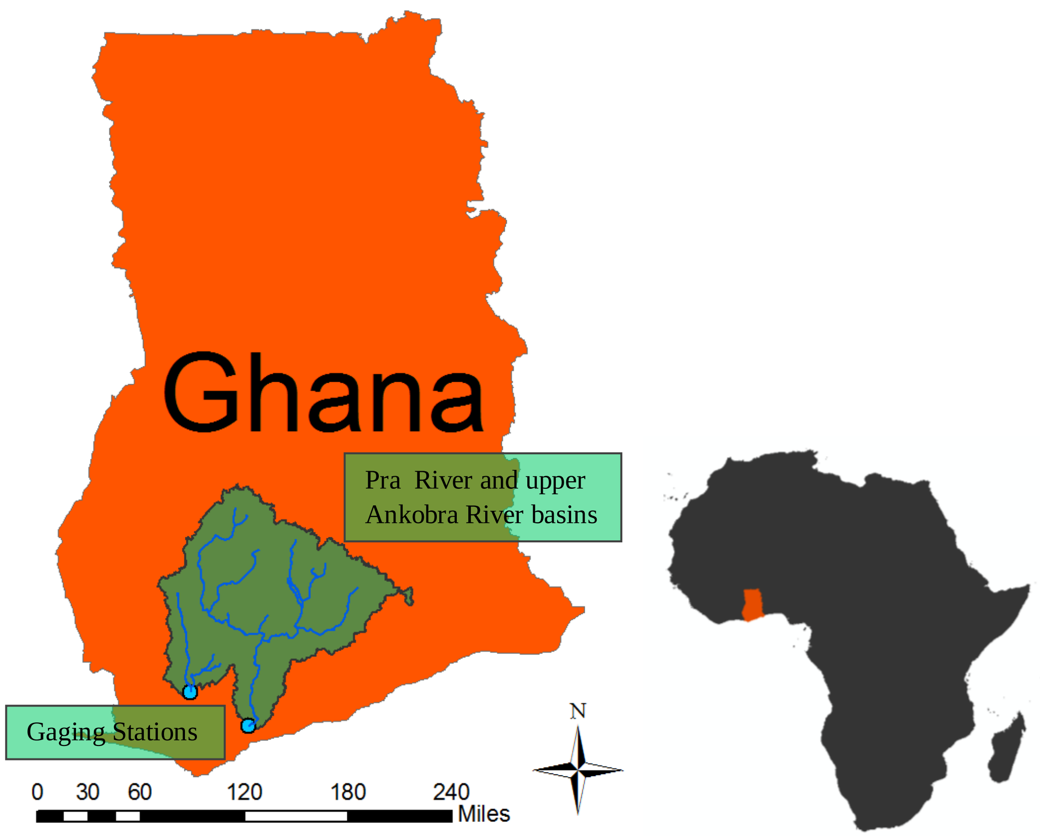

Figure 1. Study area relative location

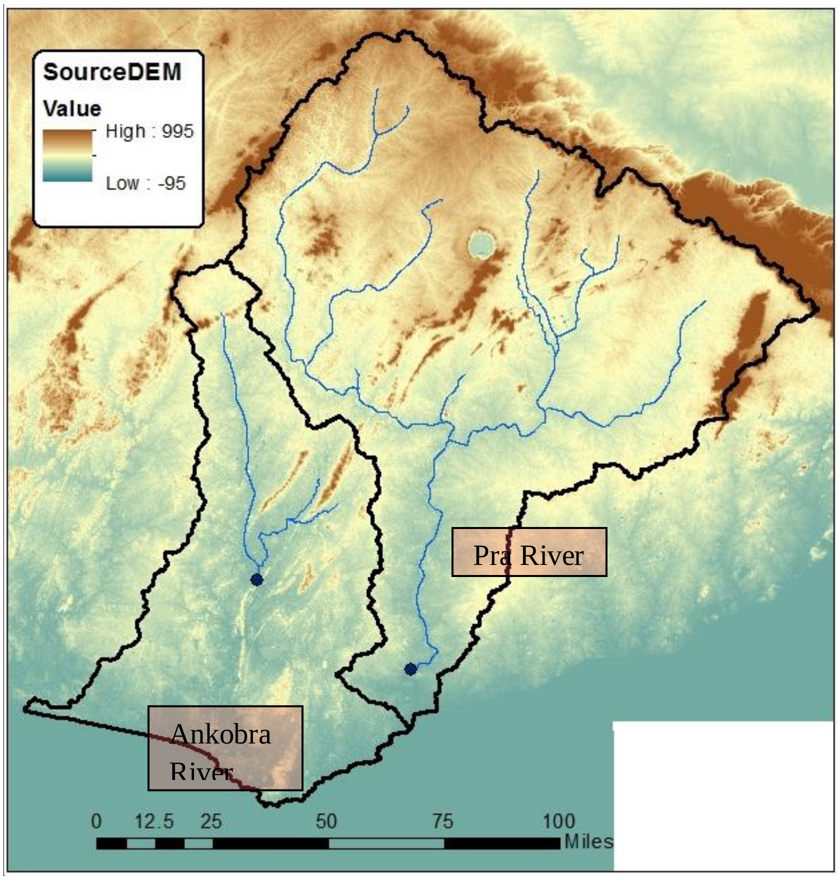

Figure 2. Study area elevation (m)

3.2 SWAT Model Description

The Soil and Water Assessment Tool (SWAT) is a public domain model developed by the USDA Agricultural Research Service (USDA-ARS) and Texas A&M AgriLife Research. The primary objective of the model is to predict the effect of management decisions on water, sediment, nutrient, and pesticide yields with reasonable accuracy on large, ungauged river basins. Studies using the model have shown that it can be an effective and accurate tool in determining the effects that different management practices have on non-point source pollution and water runoff within a watershed (Arabi et al., 2006; Santhi et al., 2006; Santhi et al., 2001).

SWAT is a physically based model that operates on a continuous basis. It requires specific information about weather, soil properties, topography, vegetation, and land management practices within the watershed. The model divides the watershed into hydraulic response units

(HRUs) that represent areas of homogeneous land use, management, topography, and soil characteristics (Arnold et al., 2008). In SWAT, the driving force for everything that happens in the watershed is the water balance. This hydrologic cycle is divided into two parts: the land phase and the water phase. The land phase deals with sediment and nutrient loading of the water on its way to the HRU's main channel. The water phase deal with the water's movements through the channel network. Further details for the processes can be found in the SWAT theoretical documentation (Neitsch et al., 2011).

In this project, the ArcGIS interface for SWAT, ArcSWAT was used to facilitate the large heterogeneous study area and to facilitate the projects goal of changing variables across the entire area to reflect changes in cocoa production practices. The ArcSWAT graphical interface also allows for some model set up decisions to be made based on visual inspection; for example, sub watershed monitoring points were placed based on visual inspection, discussed later.

4. *MODEL* INPUTS

4.1 DEM

A 30 m resolution digital elevation model (DEM) for the region which is a product of the Advanced Spaceborne Thermal Emission and Reflection Radiometer global digital elevation model was downloaded from the ASTER GDEM website (ASTER, 2011) and used in the model to determine stream flow paths.

4.2 Subwatershed and HRU Delineation

The study watershed was delineated in ArcSWAT by using the DEM layer and a burning in a stream network (ArcGIS HYDRO, 2003) obtained from FAO.org. The stream network had to be burned in because of one incorrect cross boundary flow predicted by delineating the DEM alone.

Monitoring points were placed on the stream network with the goal of creating separate sub-watersheds for areas of cocoa agriculture, based on the land use shapefile. A total 47 monitoring points were placed; creating 47 sub-watersheds and 47 reaches (35 each for the Pra River water shed). Monitoring points were intentionally placed at the points on the Ankobra River and Pra River where historic stream flow data is available from. These two points were then selected as the whole watershed outlets, and then the watershed was delineated.

The watershed was modeled using 3 slope classes; 0-5%, 5-12%, and 12-9999%.This class distribution was used because it gave a fairly equal distribution in the number of cells in each class.

For the hydrologic response unit (HRU) Definition, Multiple HRU's were used. The initial values used were those suggested in the SWAT online tutorial; Land Use = 5%, Soil = 20%, Slope = 20%. This means if a grouping of land use, soil, or slope class makes up more than 5%, 20%, 20% of an individual sub watershed respectively, the spatial area which it occupies will be defined as an HRU. This resulted in 326 individual HRUs (251 for the Pra River watershed). This is a small number, but it allowed the model to run quickly and streamlined the calibration process.

4.3 Land Use

Land use within the study watershed included forest, savanna, agricultural areas, cocoa plantations, and urban areas. A GIS shape file of Ghana land use was obtained from Foster Mensah of the University of Ghana. The land use definition was based on visual interpretation of landsat TM/ETM+ images of 1999 and 2000 (CERSGIS, 2000).

Some small areas of land use within the watershed were unclassified or cloud cover; these areas where then examined more closely by overlaying the land use areas onto Google Earth. Based on this examination, the unclassified areas were included in the COCA land use category because of the visual similarity and obvious crop areas.

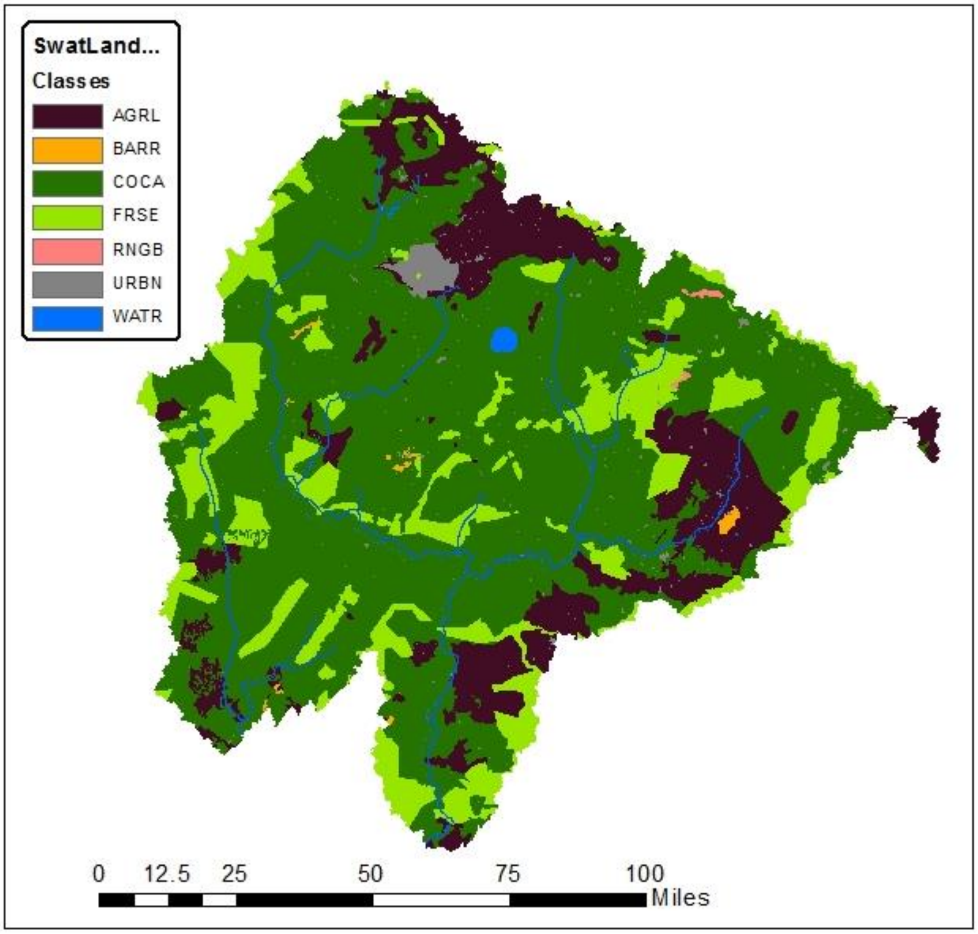

Figure 3. Land use of the Pra Watershed modeled in SWAT.

4.4 Cocoa Crop Parameters

A cocoa crop database had to be created since it is not included in the default SWAT database. Data from literature was used were possible but where no data could be located, the values for comparable tropical tree crops already in the SWAT database were examined. These crops included oil palm, coconuts, and coffee. Detailed descriptions of the parameters can be found in the SWAT documentation. The model input data is shown in Table 1 below.

Table 1. SWAT Crop Input Parameters for Cocoa

Parameter	Amount	Unit	Source	Comment
BIO_E	16.25	kg/ha / MJ/m2	a	Est. using photo active radiation and avg solar radiation
HVSTI	.03	kg/ha / kg/ha	a, b	(3000 kg ha^{-1} yr^{-1}) / (100 t ha^{-1})
BLAI	5.7	M2/m2	a	Max for range cited
FRGRW1	.1	fraction	j	Value is avg. of similar crops
LAIMX1	.09	fraction	j	Value is avg. of similar crops
FRGRW2	.4	fraction	j	Value is avg. of similar crops
LAIMX2	.8	fraction	j	Value is avg. of similar crops
DLAI	.99	fraction	j	
CHTMX	5	m	c	
RDMX	1.5	m	a	
T_OPT	30	C	a	
T_BASE	10	C	a	
CNYLD	.021	kgN/kgyield	a, b	(62 kgN ha^{-1} yr^{-1}) / (3000 kg ha^{-1} yr^{-1})
CPYLD	.003	kgP/kgyield	a, b	(9.8 kgP ha^{-1} yr^{-1}) / (3000 kg ha^{-1} yr^{-1})
PLTNFR(1)	.018	kgN/kgbiomass	d	Value is for cocoa foliage at one year, best source found
PLTNFR(2)	.0165	kgN/kgbiomass	d,e	Value found by linear interpolation using pts 1 and 3
PLTNFR(3)	.0154	kgN/kgbiomass	e	Value for 8 yr old cocoa monoculture plantation
PLTPFR(1)	.0017	kgN/kgbiomass	d	Value is for cocoa foliage at one year, best source found
PLTPFR(2)	.0014	kgN/kgbiomass	d,e	Value found by linear interpolation using pts 1 and 3
PLTPFR(3)	.0012	kgN/kgbiomass	e	Value for 8 yr old cocoa monoculture plantation
WSYF	.01	kg/ha / kg/ha	a,b	(1000 kg ha^{-1} yr^{-1}) / (100 t ha^{-1})
USLE_C	.001	NA	j	
GSI	.006	m/s	f	Value est. from shaded tree data
VPDFR	4	kPa	j	
FRGMAX	.75	fraction	j	
WAVP	7	rate		Avg. suggested value
CO2HI	660	uL/L	j	
BIOEHI	18	ratio	j	Value is avg. of similar crops
RSDCO_PL	.05	fraction	j	
ALAI_MIN	.75	m^2/m^2	j	
BIO_LEAF	.3	fraction	j	
MAT_YRS	5	Years	g	
BMX_TREES	100	metric ton/ ha	b	
BMDIEOFF	.1	NA	j	
EXT_COEFF	.719	NA	h	Value is average of several clones
CN	64, 74, 81, 85	NA	i	

a(Alvim c Kozlowski, 1977)
[b](Bacon, 1995)
[c](Sonwa, 2004)
[d](Isaac et al., 2007)
[e](Isaac, Timmer, and Quashie-Sam, 2007)
f(Hernandez et al., 1989)
[g](ICCO How much time, 1998)
[h](Daymond et al., 2002)
[i](Shamshad et al., 2008)
[j]Similar Crops

4.5 Soil

Soil characteristics of the study area were obtained from the Harmonized World Soil Database, HWSD (FAO, 2012). HWSD is the best available soil database for Ghana especially considering its available GIS layer that makes for easy interfacing with the SWAT model. Since it is not a US soil database, the HWSD had to be loaded as a custom soil database into SWAT.

The soils in the study area belonged to 11 different soil groups. These soil groups are all classified into hydrologic groups C and D. Soils classified into hydrologic groups C and D have low infiltration rates (USDA-SCS, 1972).

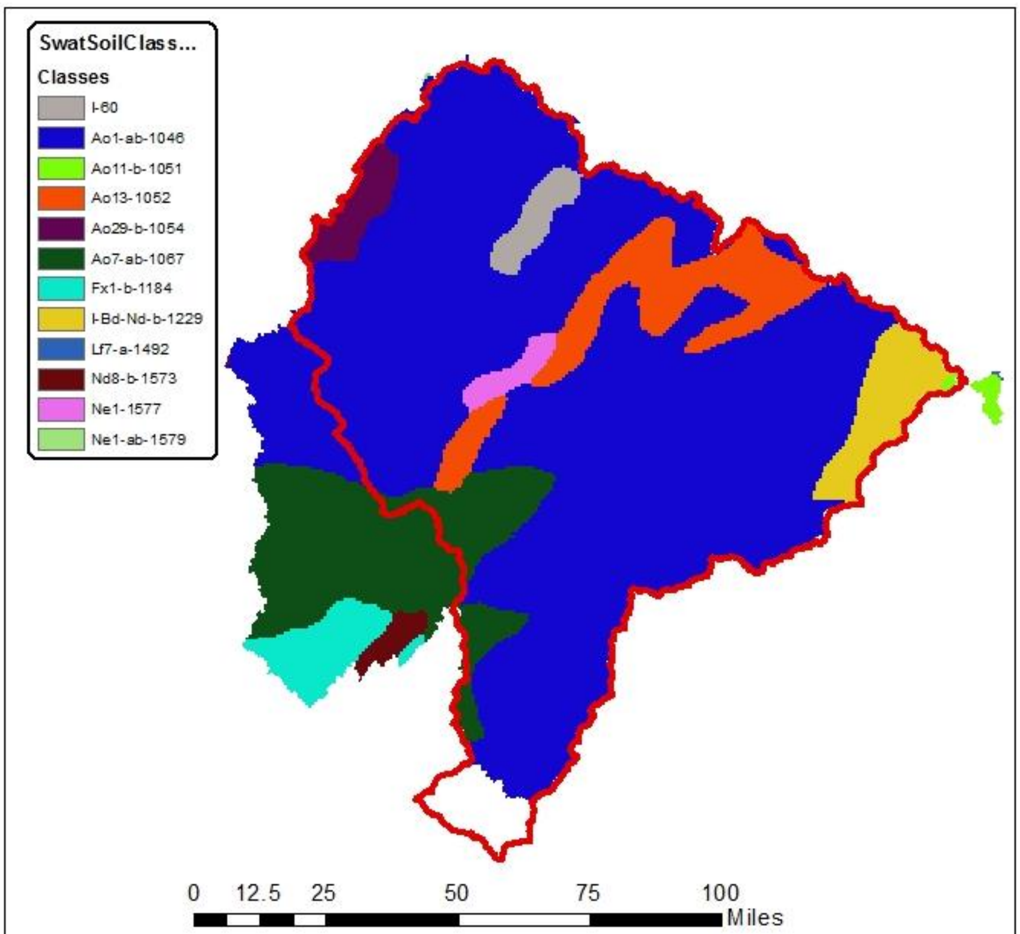

Figure 4. Study area showing soil distribution and soil codes

.

4.6 Weather

Historical daily climate estimations for 32 years (1979-2010) were obtained from the National Centers for Environmental Prediction Climate Forecast System Reanlysis. This data is made available to download in the SWAT file format by the creators of SWAT (Global Weather, 2013). Data from 26 gridded locations within the study watershed were obtained. This data included precipitation, relative humidity, solar radiation, minimum temperature, maximum temperature, and wind. Several weather statistics (min, max, stdv) needed to be calculated for the weather generation module within the SWAT model. These statistics were calculated using a computer script using the methods described in the SWAT documentation. The one exception to this was the RAINHMX statistic, which is the maximum 0.5 hour rainfall total for a given month. Precipitation data was not available at this time resolution, so this simple formula was used to calculate it instead:

$$RAINHMX(mon) \; = \; Max\; daily\; rainfall(mon) \times \frac{1}{3}$$

Evapotranspiration was simulated using the Penman-Monteith method, and routing was simulated suing the variable storage method. Both of these are the default methods in ArcSWAT.

4.7 Management Practices

For all land uses except COCA, the predefined management practices found in the default SWAT database that match the land use names that were used. This was done to save time and because these land uses closely align with premade ones. One slight exception to this was the AGRL land use, it was actually given the management practice of an evergreen forest because the dominant crop in the areas is oil palm, which was assumed to be similar to a true evergreen forest for simplicity’s sake.

4.7.1 Cocoa Management Practices

A custom management schedule was created in SWAT for the cocoa (COCA) land use areas. Data was gathered concerning the land preparation, planting season, fertilization rates, fungicide and pesticide application rates, and harvesting season. This information is presented below.

The land must first be cleared before cocoa seedling can be planted (ICCO How much time, 1998). Reports show using a disk plow is one method of land clearing for cocoa production (Ohulehule, 2013) so this was modeled in SWAT using a default disk plow, GE23ft, operation.

Cocoa seedlings are planted at the beginning of the rainy season, which is around March for the study area. Cocoa trees take about 5 years to mature and are then productive for about 25 years (ICCO How much time, 1998). This 30 year cycle is about the same length as the simulation period of the model.

Cocoa is harvested over two periods throughout the year. In Ghana, the main crop is harvested around the beginning of December and the mid-crop is harvested around July and accounts for about 20% of the Harvest (ICCO Cocoa Harvest, 2013).

The information needed for fertilizer, fungicide, and pesticide application rates were given by Joseph Ocran, an employee of the fertilizer company Yara. Crop scientists have been encouraging the increased use of fertilizers to increase cocoa production (Cocoa Farmer, 2013) and this management schedule reflects those suggestions. The suggested management schedule for cocoa is as follows:

Table 2. Suggested cocoa management schedule from Joseph Ocran (Ocran, 2014)

Fertilizer Application
Immature Cocoa Tree (0-4yr):
Rock Phosphate in the hole of planting
70 grams of Sulphate of Ammonia (Yara Bela Sulfan)/tree 1 foot around the tree once a year
Mature Tree (5-25yr):
3 bags of ASAASE WURA/Acre, broadcast. Applied prior or during rainy season (March to June)
1 bag of Yara Liva Nitrabor/ acre, broadcast. Applied 6 weeks after application of AW.
Spraying Against BlackPod Disease
- Ridomil Gold
Applied every 3 to 4 weeks from May to December
Spraying Against Mirids/Capsid
- Confidor Otec – 150 ml/ha
Applied between August to October

This management data was incorporated into SWAT as an operation schedule, including conversions to the appropriate units, can be seen below (for 1100 tr/ha).

Table 3. ArcSWAT Management Operation Schedule

Duration	Operation	Year	Month	Day	Details
1 time	Land Clearing	1	2	25	Disk plow GE23ft
1 time	Planting	1	3	1	1100 tree/ha
1 time	Fertilizer	1	3	1	Rock posphate (00-06-00), 194 kg/ha, in hole, .05 surface
yr 1-4	Fertilizer	1	7	1	70 grams Yara Bela Sulfan /tree @ 1100 tr/ha = 77 kg/ha, .99 surface
yr 5-25	Fertilizer	5	5	1	370.5 kg Asaase Wura/ha, broadcast, .99 surface
yr 5-25	Fertilizer	5	6	12	123.5 kg Nitrabor/ha, broadcast, .99 surface
yr 5-25	Pesticide	5	9	15	.03 kg Imidaproclid/ha, spray
yr 5-25	Pesticide	5	5	1	.8 kg/ha metalaxyl, every 3-5 weeks May-Dec
yr 5-25	Pesticide	5	6	1	.8 kg/ha metalaxyl, every 3-5 weeks May-Dec
yr 5-25	Pesticide	5	7	1	.8 kg/ha metalaxyl, every 3-5 weeks May-Dec
yr 5-25	Pesticide	5	8	1	.8 kg/ha metalaxyl, every 3-5 weeks May-Dec
yr 5-25	Pesticide	5	9	1	.8 kg/ha metalaxyl, every 3-5 weeks May-Dec
yr 5-25	Pesticide	5	10	1	.8 kg/ha metalaxyl, every 3-5 weeks May-Dec
yr 5-25	Pesticide	5	11	1	.8 kg/ha metalaxyl, every 3-5 weeks May-Dec
yr 5-25	Pesticide	5	12	1	.8 kg/ha metalaxyl, every 3-5 weeks May-Dec
yr 5-25	Harvest	5	7	15	mid harvest, HI_OVR = 0.018, 20% of the calculated biomass harvest index
yr 5-25	Harvest	5	12	1	main harvest, HI_OVR = 0.072, 80% of the calculated biomass harvest index

4.7.2 Fertilizer and Pesticide Data

Fertilizer and pesticide parameters were added to the model using the ArcSWAT input interface. The following are descriptions of the input data.

Rock phosphate typically has a NPK value ranging from 00-3-00 to 00-8-00 (Rehm et al., 2002) so the pre-defined 00-6-00 fertilizer found in the ArcSWAT database was used.

The sulphate sulfate of data was based off of Yara's SULFAN fertilizer (Yara SULFAN, 2014). The model input data can be seen below.

Table 4. SWAT Fertilizer Input Parameters for SULFAN

Variable Name	**Units**	**Value**
FERTNM		YBSULFAN
FMINN	kg min-N / kg fertilizer	.24
FMINP	kg min-P / kg fertilizer	0.0
FORGN	kg org-N / kg fertilizer	0.0
FORGP	kg org-P / kg fertilizer	0.0
FNH3N	kg NH3-N/ kng min-N	0.0

Yara's Asaase Wura PK blend (News Yara, 2012) was included in the management schedule as suggested by Joseph Ocran (Ocran, 2014). The model input data can be seen below.

Table 5. SWAT Fertilizer Input Parameters for Asaase Wura

Variable Name	**Units**	**Value**
FERTNM		ASAASWUR
FMINN	kg min-N / kg fertilizer	0.0
FMINP	kg min-P / kg fertilizer	.18
FORGN	kg org-N / kg fertilizer	0.0
FORGP	kg org-P / kg fertilizer	0.0
FNH3N	kg NH3-N/ kng min-N	0.0

Yara's Nitrabor (YaraLiva NITRABOR, 2014), the use of which has recently been increasing because of farmer (News Yara, 2012) was included in the management schedule as suggested by Joseph Ocran (Ocran, 2014). The model input data can be seen below.

Table 6. SWAT Fertilizer Input Parameters for NITRABOR

Variable Name	**Units**	**Value**
FERTNM		NITRABOR
FMINN	kg min-N / kg fertilizer	.154
FMINP	kg min-P / kg fertilizer	0.0
FORGN	kg org-N / kg fertilizer	0.0
FORGP	kg org-P / kg fertilizer	0.0
FNH3N	kg NH3-N/ kng min-N	0.0

The recommended insecticide, Conidor, is represented in the model as its active ingredient Imidacloprid. Imidacloprid is present in Confidor at a concentration of 200 g/L (MSDS Confidor, 2007), which means that Imidacloprid will be applied at a rate of .03 kg/ha when Confidor is applied at the suggested 150 ml/ha. This chemical is surface applied. The model input data can be seen below.

Table 7. SWAT Pesticie Input Parameters for Imidacloprid

Variable Name	**Value**	**Source**	**Comment**
SKOC	221	a	
WOF	.2	b	est. from turf value
HLIFE_F	1	a	est. from similar data
HLIFE_S	100	a	est. from similar data
AP_EF	.75		Default Value
WSOL	514	a	

[a](Fossen, 2006)
[b](Thuyet et al., 2012)

The recommended fungicide, Ridomil, is represented in the model as its active ingredient metalaxyl. Metalaxyl is present in Ridomil at a concentration of 40 g/kg, and estimating a Ridomil application rate of 20 kg/ha/spray, this gives a metalaxyl-m application of 0.8 kg/ha/spray (Syngenta Ridomil, 2007). Metalaxyl is already present in the default ArcSWAT database, so no further inputs were needed. This chemical is surface applied.

3.7 Streamflow data

Daily stream flow data was obtained from the Global Runoff Data Centre (GRDC, Koblenz, Germany) for the Pra River to be used in model calibration. The data was collected at the GRDC No. 152600 Daboasi station, Latitude 5.1667°, Longitude -1.6333°, altitude -.07 m.a.s.l. The data spanned the time period of 1/1/1979 to 12/31/2006, but was missing several days of data. The most notable amount of missing flow data spanned the range of 3/1/1997-12/31/2001. This issue was overcome by using this period as the break point between calibration and validation.

The stream flow was separated into surface flow and base flow components using the Baseflow Filter Program found on the SWAT website. This allowed the model to be calibrated to both base flow and surface flow which makes for a more accurate model. The calibration is discussed in later section.

5. *MODEL* SENSITIVITY *ANALYSIS, CALIBRATION, AND VALIDATION*

5.1 Model Sensitivity Analysis

Because of the large number of calibration parameters in the SWAT model, it was important to identify those which have the greatest impact on the model output before starting calibration. A brief literature review was conducted and 15 parameters that are commonly used to calibrate flow were identified (Arabi et al., 2008; Arnol et al., 2012; Cibin and Chaubey, 2010; Holvoet et al., 2005; Rojas and Zambrano-Bigiarini, 2012; Van Griensven et al., 2006). Then their relative sensitivity was determined using the hydroPSO R script (Zambrano-Bigiarini and Rojas, 2013), which uses the Latin Hypercube One-factor-At-a-Time (LH-OAT) method developed by van Griensven et al.(2006).

The selected parameters and their relative importance can be seen below (Table 8). It should be noted that the ESCO parameter below is the one found in the .bsn file. It has a low relative importance, but the ESCO parameter in the .hru file has a higher relative importance and was included in calibration.

Table 8. Sensitivity analysis results showing parameters of relative importance

Rank	SWAT Parameter	Parameter Name	Relative Importance
1	CN2	SCS runoff curve number for moisture condition II	0.3696
2	SOL_Z	Soil Depth	0.1279
3	GW_REVAP	Groundwater “revap” coefficient	0.1117
4	RCHRG_DP	Deep aquifer percolation fraction	0.1036
5	GW_DELAY	Groundwater delay time	0.0946
6	CANMX	Maximum canopy storage	0.0929
7	SOL_K	Soil Saturated hydraulic conductivity	0.0445
8	SLSUBBSN	Average slope length	0.0424
9	CH_K2	Effective hydraulic conductivity in main channel	0.0085
10	CH_N2	Manning's "n" value for the main channel	0.0027
11	ALPHA_BF	Baseflow alpha factor	0.0007
12	GWQMN	Depth of water in shallow aquifer for return flow to occur	0.0006
13	SURLAG	Surface runoff lag coefficient	0.0003
14	ESCO	Soil evaporation compensation factor	0
15	SOL_AWC	Available water capacity of the soil layer	0

5.2 Calibration and Validation

After the sensitivity analysis, the model had to be calibrated for flow. Calibration is the process of running the model multiple times while making small changes to parameters to make the model more accurately predict the output of interest. The parameters identified in the literature review as the most important to flow where used to calibrate, as well as several other parameters identified by the SWAT website as appropriate for calibration in certain situations (SWAT Calibration, 2014). An example situation would be varying the soil available water parameter, SOL_AWC, for over predicted surface flow. The sensitivity analysis that was done was used as a guide to which parameters would yield the largest changes while calibrating.

The calibration period was from 1/1979-2/1997. The model was first calibrated manually to gain an idea of the directional effects of parameters with respect to the total, surface, and base flows. This was done at the yearly then monthly levels. After some rough calibration had been done manually, parameters were then varied using the hydroPSO R script (Zambrano-Bigiarini and Rojas), a package which implements the Particle Swarm Optimisation (PSO) algorithm. Simultaneously, the SWATCUP SUFI-2 uncertainty analysis routine (Abbaspour, 2014) was used for calibration as well. Using both of these methods sped up the calibration process by providing more feedback information that could then be used to further adjust parameters.

To fully evaluate the performance of the calibrated model, it is necessary to validate its performance against a data set that was not utilized in the calibration process. During validation, the same statistics are examined as during calibration. During validation, the model parameters are not adjusted. If statistical analysis results of the validation period are not considered to be acceptable, then further calibration of the model is required.

6. RESULTS *AND DISCUSSION*

6.1 Calibration

To analyze the simulation results, two main measures were used, these measures were suggested in the paper by Moriasi et al (2007). The coefficient of determination (R^2) describes the degree of collineartiy or the proportion of variance measured between simulated and measured data. It ranges from -1 to 1 with values greater than 0.5 being considered acceptable. The Nash-Sutcliffe Efficiency coefficient (NSE) determines the relative magnitude of the residual variance ("noise") compared to the measured data variance ("information"). It is generally more sensitive to peaks in the data than R^2. Results can be deemed acceptable if NSE is greater than zero, and satisfactory if NSE is greater than 0.5 (Moriasi et al., 2007).

Based on the measures presented and using the best monthly calibration of the model, the model was found to be acceptable for total flow and base flow based upon the R^2 value, and unacceptable for all flows based upon the NSE value. The results can be seen in the table and figure below, all flow is in cubic meters per second (CMS).

Table 9. Monthly Calibration Statistical Values

Goodness of fit Statistic	Total Flow
Avgerage Observed (CMS)	211.05
Average Predicted (CMS)	330.80
RSQ:	0.57
NSE:	-0.43

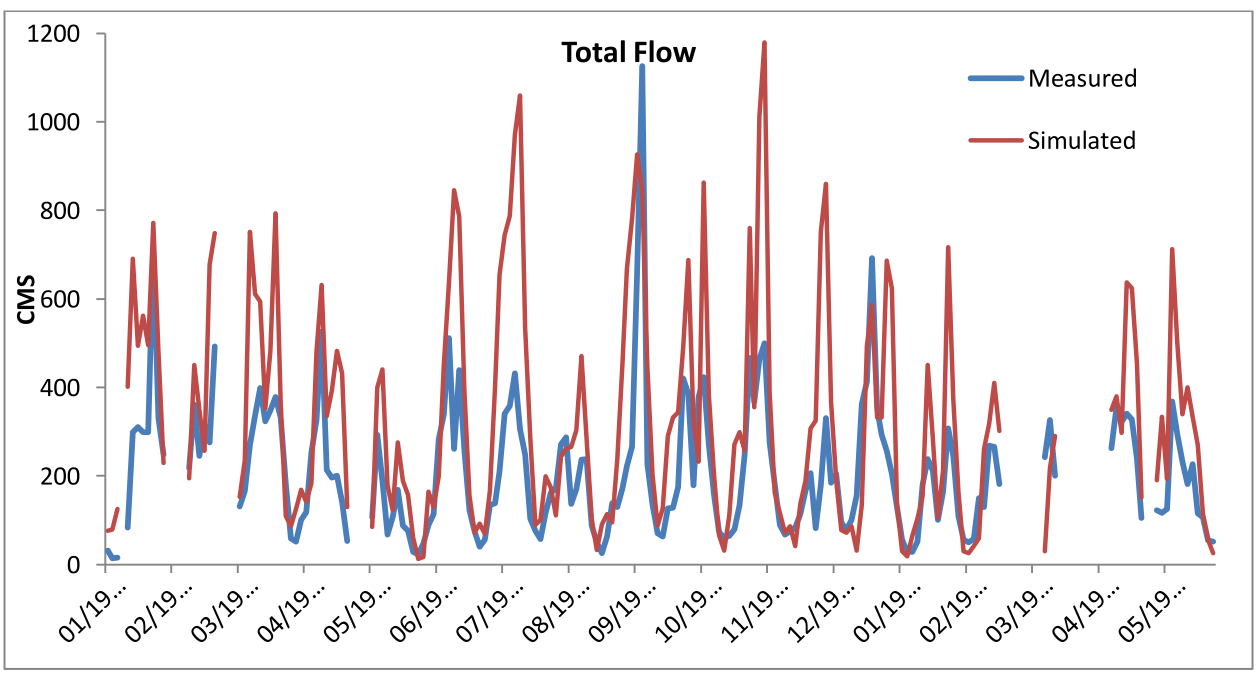

Figure 5. Monthly Calibration Flow Comparison

6.2 Validation

The validation period used was the period from 1/2002-12/2006. The validation period was evaluated using the same criteria as calibration. Neither the validation R^2 or NSE values were found to be acceptable (Table 10). It should be noted that the validation period base flow had a positive NSE, which is a good sign that the model is moving in the right direction.

Table 10. Monthly Validation Statistical Values

Goodness of fit Statistic	Total Flow
Average Observed (CMS)	165.64
Average Predicted (CMS)	201.01
RSQ:	0.37
NSE:	-0.34

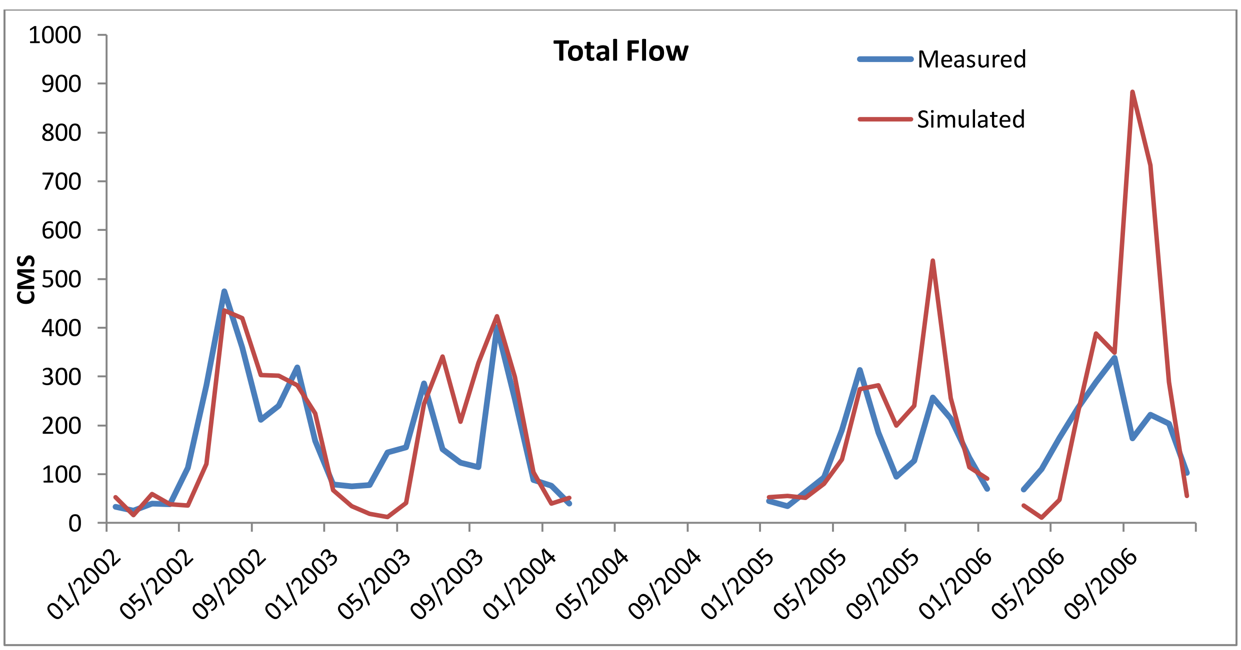

Figure 6. Monthly Validation Flow Comparison

7. CONCLUSIONS *AND DISCUSSION*

Thus far, the objective of this project has not been completed. The model showed some ability to accurately predict flow out of the water shed, but has not been proven acceptable by the indicators decided upon.

7.1 Error

The study area as a whole lacked detailed data. The land use map that was used in this project is based on a 2000 analysis of 1999 satellite data, even though the model runs from 1979-2006. Even this data took several months and many contacts to track down.

Likely causes of error in the model include inaccuracies in the weather data and stream flow data. The weather data is not actually station collected, historical data. It is data that is generated from known global weather patterns during the time period. That means that while the overall average patterns is likely a good approximation, day-to-day rainfall events are not exactly represented. The issue with the stream flow data, was that it had many data gaps. Some were for extended periods, while others were for a single day. Also, other than missing data, there was no data flagged for potential issues. Since it is likely that there should be at least some flagged data, the reliability of the gauge station where this data was collected is called into question. There might be some days' data that is not complete or accurate that was not flagged when it should have been.

Cocoa as a crop also lacked information in the literature to accurately define all of the parameters required by SWAT. SWAT requires many detailed parameters that take time to accurately determine through measuring of crop growth, chemical makeup, and similar factors.

The input parameters had to be estimated as well as possible from the limited literature information.

7.2 Future Work

The model presented in this report is not the final destination of the project. The final goal is to use this model's output for information such as sedimentation, nutrient runoff, and pesticide runoff as a baseline to which other management strategies can be compared. This will be useful because of the paucity of data available for the watershed in question, since no sediment data exist to calibrate the model against it will be impossible for the model to predict the actual amount of sediment that should be expected. By creating a baseline scenario and finding the relative changes that will be expected with land management changes, management decisions can be made in a more informed way. Also, if data is collected it can be used to quickly make estimations of actual outflow amounts that would be expected with a certain change.

To complete the project and allow the model to make the relative predictions, the model needs to be further calibrated first. This will be a time consuming process which I did not have time to complete before the submittal of this thesis. The next steps to take are known, but will be time consuming. The threshold values needed to create a new HRU need to be lowered which will increase the resolution of the model and may affect predictions. Longer calibration runs in hydroPSO and SWAT-CUP need to be completed as this will help to narrow down the range of parameters. And other sources of rainfall data need to be located to double check the current values, especially the peak flow values during periods of over simulation. Eventually the Ankobra River basin could also be modeled based on the final parameters determined for the Pra basin. This would add an additional layer of confidence to the predictions of the overall model.

These steps and some more time spent with the model could help make it into a useful tool for analysis cocoa agriculture in Ghana.

8. ACKNOWLEDGEMENTS

This project would not be possible with the help and support of many people. Dr. Mansoor Leh taught and mentored me during the entirety of this project. His readiness to always help and teach allowed me to gain several new skills in the process of working on this project. Dr. Matlock introduced me to the project and provided support and encouragement throughout. Also, thanks to Dr. Osborn and Dr. Carrier for serving on my thesis committee. Lastly, thank you to the University of Arkansas Honors College for providing some funding for this research.

9. References

Abbaspour, Karim C. 2014. SWAT-CUP 2012 SWAT Calibration and Uncertainty Programs. Eawag.

Arnold, J.G., Srinivasan, R., Muttiah, R.S., Williams, J.R. 1998. Large area hydrologic modeling and assessment. Part I: Model development. J. Am. Water Resour. Assoc. 34, 73–89.

Alvim, P. D. T., Kozlowski, T. T. 1977. Ecophysiology of tropical crops. Academic Press.

Arabi, M., Frankenberger, J. R., Engel, B. A., & Arnold, J. G. 2008. Representation of agricultural conservation practices with SWAT. Hydrological Processes, 22(16), 3042-3055.

Arabi, M., Govindaraju, R.S., Hantush, M.M., Engel, B.A. 2006. Role of Watershed Subdivision on Modeling the effectiveness of Best Management Practices with. Journal of the American Water Resources Association 42, 513-528.

ArcGIS Layer. 2003. HYDRO-1 Kilometer Watershed Model.

ArcGIS Layer. 2000. Centre for Remote Sensing and Geographic Information Services (CERSGIS).

Asase, A., Wade, S., Ofori-Frimpong, K., Hadley, P., Norris, K. 2008. Carbon storage and the health of cocoa agroforestry ecosystems in south-eastern Ghana. Africa and the Carbon Cycle, 131.

NASA. ASTER Global Digital Elevation Map Announcement. 17 Oct. 2011. Web. 15 June 2013.

Bacon, Peter, ed. 1995. Nitrogen fertilization in the environment. Vol. 42. CRC Press.

Bambury, M., Elgy, J., Bogen, J., Fergus, T., Walling, D. 2003. Development of a sediment yield model for Ghana using sediment transport data. Iahs Publication, 96-102.

Cibin, R., K. P. Sudheer, I. Chaubey. 2010. "Sensitivity and identifiability of stream flow generation parameters of the SWAT model." Hydrological processes 24.9: 1133-1148.

"Cocoa Farmers Urged to Apply Certified Fertilizer." GhanaWeb. 13 Apr. 2013. Web. 12 Apr. 2014.

Daymond, A. J., Hadley, P., Machado, R. C. R., Ng, E. 2002. Canopy characteristics of contrasting clones of cacao (Theobroma cacao). Experimental Agriculture, 38(03), 359-367.

Esri, 2012. ArcGIS. 10.1, http://resources.arcgis.com/en/home/.

FAO. 2012. Rome, Italy and IIASA, Laxenburg, Austria. Harmonized World Soil Database (version 1.2).

Fossen, M. 2006. Fate_of_imidacloprid. Sacramento: Department of Pesticide Regulation. PDF.

Franzen, M., Mulder, M.B. 2007. Ecological, economic and social perspectives on cocoa production worldwide. Biodivers. Conserv. 16, 3835-3849.

Global Weather Data for SWAT.. Web. June 2013.

Graham, L. 21012. A History of Commitment to West African Cocoa Communities. Just Means.

Hernandez, A. del P., James H. Cock, and Mabbouk A. El-Sharkawy. 1989. "The responses of leaf gas exchange and stomatal conductance to air humidity in shade-grown coffee, tea and cacao plants as compared with sunflower." Revista brasileira de fisiologia vegetal 1.2: 155-161.

Holvoet, K., van Griensven, A., Seuntjens, P., & Vanrolleghem, P. A. 2005. Sensitivity analysis for hydrology and pesticide supply towards the river in SWAT. Physics and Chemistry of the Earth, Parts A/B/C, 30(8), 518-526.

"How Much Time Does It Take for a Cocoa Tree to Become Productive?" www.icco.org. International Cocoa Organization, 21 July 1998. Web. Mar. 2014.

Huffman, R.L., D. D. Fangmeier, W.J. Elliot, S.R. Workman, G.O. Schwab. 2011. Soil and water conservation engineering. St. Joseph, MI: ASABE. Print.

"HydroPSO - Model-Independent Particle Swarm Optimisation for Environmental Models - RForge.net." HydroPSO - Model-Independent Particle Swarm Optimisation for Environmental Models - RForge.net. Web. Feb. 2014.

India SWAT Dataset | Soil and Water Assessment Tool. Soil and Water Assessment Tool. 2012. Web. Sept. 2013.

Isaac, M. E., Ulzen-Appiah, F., Timmer, V. R., & Quashie-Sam, S. J. 2007. Early growth and nutritional response to resource competition in cocoa-shade intercropped systems. Plant and soil, 298(1-2), 243-254.

Isaac, M. E., V. R. Timmer, S. J. Quashie-Sam. 2007. "Shade tree effects in an 8-year-old cocoa agroforestry system: biomass and nutrient diagnosis of Theobroma cacao by vector analysis." Nutrient cycling in agroecosystems 78.2: 155-165.

"Material Safety Data Sheet: Confidor 20 SC Insecticide." 19 Nov. 2007. www.herbiguide.com. Web. Mar. 2014.

Mihelcic, James R., Julie B. Zimmerman. 2010. "Chapter 8 Water Quality." Environmental Engineering Fundamentals, Sustainability, Design. Hoboken: Wiley. Print.

Moriasi, D. N., Arnold, J. G., Van Liew, M. W., Bingner, R. L., Harmel, R. D., Veith, T. L. 2007. Model evaluation guidelines for systematic quantification of accuracy in watershed simulations. Trans. ASABE, 50(3), 885-900.

Neitsch, S., Arnold, J., Kiniry, J., Williams, J. 2011. Soil and water assessment tool: theoretical documentation, version 2009. Texas, USA.

"News Yara Ghana Successful Introduces Nitrabor on Cocoa Production in" 10 May 2012. Yara Ghana News about Our Company. Web. Mar. 2014.

Ocran, Joseph. 15 Mar. 2014. "Cocoa Application Rates." E-mail.

Ohulehule Forest Conservancy. September 2013. Ohulehule Forest Conservancy Cacao Farm Final Environmental Assessment.

Rehm, George, Michael Schmitt, John Lamb, Gyes Randall, and Lowell Busman. 2002. "Understanding Phosphorus Fertilizers." University of Minnesota Extension. Web. 13 Mar. 2014.

Rojas, Rodrigo, and Mauricio Zambrano-Bigiarini. 2013. "Tutorial for interfacing hydroPSO with SWAT-2005 and MODFLOW-2005."

Santhi, C., Arnold, J.G., Williams, J.R., Dugas, W.A., Srinivasan, R., Hauck, L.M. 2001. Validation of the SWAT Model on a Large River Basin with Point and Nonpoint Sources. Journal of the American Water Resources Association 37, 1169-1188.

Santhi, C., Srinivasan, R., Arnold, J.G., Williams, J. 2006. A modeling approach to evaluate the impacts of water quality management plans implemented in a watershed in Texas. Environmental Modelling & Software 21, 1141-1157.

Shamshad, A., Leow, C. S., Ramlah, A., Wan Hussin, W. M. A., & Mohd Sanusi, S. A. 2008. Applications of AnnAGNPS model for soil loss estimation and nutrient loading for Malaysian conditions. International Journal of Applied Earth Observation and Geoinformation, 10(3), 239-252.

Sonwa, D. J. 2004 Biomass management and diversification within cocoa agroforests in the humid forest zone of southern Cameroon. Cuvillier Verlag.

STCP, 2010. Fine flavor and certified cocoa financial analysis 2. Sustainable Tree Crop Program Analysis.

“SWAT Calibration Techniques.” PowerPoint Presentation. Web. swat.tamu.edu. April, 2014

Syngenta. Aug. 2007. RIDOMIL GOLD MZ WG LABEL TEXT AUG07. Auckland. PDF.

Thuyet, D. Q., Jorgenson, B. C., Wissel-Tyson, C., Watanabe, H., Young, T. M. 2012. Wash off of imidacloprid and fipronil from turf and concrete surfaces using simulated rainfall. Science of the Total Environment, 414, 515-524.

Tilman, D., Cassman, K.G., Matson, P.A., Naylor, R., Polasky, S. 2002. Agricultural sustainability and intensive production practices. Nature 418, 671-677.

USDA-ARS, 1999. Soil and Water Assessment Tool — Model Documentation. http://www.brc.tamus.edulswatimanual.

USDA-SCS. 1972. National Engineering Handbook. Hydrology Section 4, chapter 4-10. Washington, D.C.: USDA Soil Conservation Service.

Van Griensven, A., Meixner, T., Grunwald, S., Bishop, T., Diluzio, M., Srinivasan, R. 2006. A global sensitivity analysis tool for the parameters of multi-variable catchment models. Journal of hydrology, 324(1), 10-23.

Wade, A.S., Asase, A., Hadley, P., Mason, J., Ofori-Frimpong, K., Preece, D., Spring, N., Norris, K. 2010. Management strategies for maximizing carbon storage and tree species diversity in cocoa-growing landscapes. Agric. , Ecosyst. Environ. 138, 324-334.

"What Time of Year Is Cocoa Harvested?" 27 Nov. 2013. International Cocoa Organization.. Web. Mar. 2014.

World Cocoa Foundation, 2012. Cocoa Market Update.

Yara. Yara Ghana SULFAN. Web. Mar. 2014.

Yara. YaraLiva NITRABOR. Web. Mar. 2014.