Modeling of a Greater-Zab River Watershed Using Arc SWAT for Stream Flow and Hydrologic Budget

Dr. Thair S. K
Building and Construction Engineering Department, University of Technology, Baghdad
Email: thshkhma@yahoo.com

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ABSTRACT

Soil Water Assessment Tool (ArcSWAT2009) model is applied on the Greater-Zab River catchment at north of Iraq. The model was calibrated from 1993-2002 and validated from 2003-2013.The calibrated model for hydrological conditions was used to assess the water quantity (monthly stream flows).The study identified optimum parameters and with widest ranges of variation for better rates simulation. The water balance components were correctly estimated. The results showed that the average simulated stream flow for the study period (1993-2013) was 363 m^3/sec which is less than the average value of stream flow (417 m^3/sec) for the period (1930-1992) .The water shortage problem effects on the management of water resources. Based on statistical indicators, the evaluation indicates that the model had a good performance for both calibration and validation periods in Greater-Zab River watershed. The model can be used efficiently in semi-arid regions to support water management policies in Iraq. The model performance evaluation showed a good correlation between the observed and simulated monthly average stream flow for calibration and validation periods with R^2 (0.99, 0.87),$E_{N.S}$(0.99,0.86) and D (2.76,1.22) respectively. A sensitivity analysis was carried out on the major input parameters and the results showed that there are (11) out of (41) parameters sensitive. The most sensitive is the (CN2). Results of hydrologic budget show that the ratios of the annual base flow and the flow of the hydrograph shape to the total flow are 20 % (base flow index) and 42 % respectively. The lateral flow, computed as a percentage of average annual rainfall varies greatly from 4.8% to 38% and the actual evapotranspiration is much lower than potential evapotranspiration. The ratio between the average yearly precipitation and potential evapotranspiration was 45 %. In a future study, it is recommended to use land cover and climate change scenarios, their projected impacts and adaptation. The study results are helpful for the management and planner of water resources in Iraq which relate to the sustainability and water quantity.
Keywords: Greater-Zab River, ArcSWAT2009, Stream flow, Water balance.

INTRODUCTION

The SWAT model is a physically based model and requires data such as weather variables, soil properties, topography, vegetation and land management practices occurring in the catchment [1]. The model was developed for continuous simulation, as opposed to single event models. The physical processes associated with water flow, sediment transport, crop growth, nutrient cycling, etc are directly modeled by SWAT using the above mentioned input data. Some of the advantages of the model includes: modeling of ungauged catchments, prediction of relative impacts of scenarios (alternative input data) such as changes in management practices, climate, and vegetation on water quality, quantity or other variables. SWAT also has a weather simulation model that generates daily data for rainfall, solar radiation, relative humidity, wind speed and temperature from the average monthly variables of these data. This provides a useful tool to fill in missing daily data in the observed records. The demand for fresh water resources already exceeds the supply in many parts of the Earth [2]. In addition, it is very likely that the climate of the Earth is changing. The management of water resources under such circumstances is a complex task and should consider future climate scenarios in addition to plans for existing and projected water demand.

The impact of land use/cover change on stream flow pattern in a typical watershed called Chemoga in the Blue Nile basin of Ethiopia was investigated as in [3]. The finding of the study was a decrease in stream flow at a rate of 1-7 millimeters per year between 1960 and 1999 which can be partially explained by changes in land cover/use and a degradation of the watershed that involves destruction of natural vegetative covers, expansion of croplands, overgrazing and increased area under eucalyptus plantations .Many of the previous studies published in the extensive body of peer-reviewed and other SWAT literature describe calibration and validation approaches used for verifying the accuracy of the model for the simulated conditions. These testing procedures have been reported at varying levels of detail for a wide range of watershed scales, environmental conditions, and application goals worldwide. More in-depth procedures have also been reported for specific aspects of the calibration and validation process, such as the guidelines proposed as in [4], regarding specific statistical criteria to judge the success of SWAT (and other model) testing results. However, a comprehensive overview of all key facets required for an ideal SWAT calibration and validation process is currently lacking in the literature. Thus, the objectives of this study are as follows: (1) to provide a brief description of the key SWAT components, (2) present a general overview of a logical calibration and validation sequence, (3) describe calibration options and parameters in more detail, (4) show how the calibration and validation process is applied for two case studies, and (5) discuss weaknesses and future research needs regarding calibration and validation approaches with SWAT.

Reference [5] presents an overview of: (1) climatic inputs and HRU hydrologic balance; (2) cropping, management inputs, and HRU-level pollutant losses; and (3) flow and pollutant routing. Reference [6] describe current research on enhancements to SWAT to route water across discretized landscape units that simulate the impacts of spatial land use changes and land management on the hill slope-valley continuum.

SWAT is widely used in the united States and in other regions of the world: exploring the potential impact of reforestation on the hydrology of the upper Tana river catchment and the Masinga dam in Kenya (9753 Km^2) as in [7], hydrologic modeling of the Iroquois River watershed, simulation of hydrologic and sediment loading in Connonsville River basin (1200Km^2) as in [8].

SWAT is a proven tool for hydrological modeling to assess water quantity and quality at different spatial scales [9], from small watersheds as in [10] and to larger river basins as in [11]. This model is accepted around the world as a robust interdisciplinary watershed model, with hundreds of successful applications and related publications.

Wetland and conservation and restoration impact on water quantity and quality have also been studied with the SWAT model in Broughton’s Creek, Manitoba [12]. Different wetland conservation and restoration scenarios were examined, resulting in peak discharge reductions up to 23.4%, and annual sediment loading reductions up to 16.9% (approximately 50 tons yr-1). Wetland storage volumes were estimated based on a linear relationship with wetland surface areas, while other parameters were adjusted during calibration. While there was limited observation data in this study, the model was judged to perform well.

Thomas Brook is another watershed in Atlantic Canada that is being studied with SWAT to assess agricultural BMPs. Monthly stream flow simulations for the calibration and validation of this model achieved an R^2=0.9 and 0.73 and NSE=0.88 and 0.69, respectively. Monthly sediment simulations for the calibration and validation of this model achieved an R^2=0.66 and 0.48, and NSE=0.47 and 0.31, respectively [13].

Reference [14] shows that the Tigris and Euphrates river discharges in Iraq will continue to decrease with time, and they will be completely dry by 2040. Serious, prudent and quick measures need to be taken to overcome this problem. The mean temperature in the MENA region (Middle East and North African Countries, Iraq is one of these countries) are projected to increase by 3 ^{o}c to 5 ^{o}c , for the period from 2009-2099. It is needed to estimate the changes in water quantity within the Iraqi river basins.

In this study aims to test and evaluate the usefulness and the performance of ArcSWAT2009 to model the hydrological functioning of Greater-Zab river catchment , calibrate and validate the model for water quantity and predict the components of the water balance of the river basin which are important in predict the future impacts of land use and temperature changes in Iraq.

Watershed Description and Input Datasets:

The study area of greater-Zab watershed is located between 36- 37.5^o N and 43-45^0 E. The Greater Zab and its tributaries illustrated in Fig.(1). Annual precipitation ranges between 300 mm and 1100 mm.. Peak flows of the Greater Zab occur in May. The maximum, minimum and average annual flow were 1780, 34 and 417 m^3/sec respectively for the period of record 1930-1992. The Greater Zab supplies the Tigris River with an average annual flow volume of 13.2 BCM (measured at Eski Kalak , 12 BCM further upstream at the Bekhme Dam and (3.4-5.4) BCM flow from outside Iraq),65% of the total area of this river basin of 25810 Km^2 is in Iraq [15,16]. Measurements of the Greater Zab at Eski Kalak(Lat. 36^o 16$^'$ 00 N,Long.43^o 39’ 00 E) and at the upstream Bekhme Dam station for the period of record 1930-2013 are similar to those of the Feesh Khabour, with three major wet years (1963, 1969 and 1988) and one extremely dry year in 1989. The annual river flow time series shows a normal fluctuation with no clear trend of wet and dry years around the mean annual flow. The Greater Zab is one of the few unregulated rivers in the region as no dams have been built on the river to date. However, both riparian countries have plans to exploit the Greater Zab. Iraq has planned two dams in the basin: the Bekhme Dam and the Mandawa Dams that are still in a planning phase. Four dams are planned directly on the Greater Zab River in Van and Hakkari provinces (Turkey); the Hakkâri , the Doğanlı 1,2,3, and Çukurca dams. Those dams would give the major share of the projected 1100 MW electricity generation [17].

The rainfall and climate data as in [18-21], were provided by several meteorological stations (Soram, Erbil, Choman, mergasur and Amedy) that are operated within the Greater-Zab watershed area by the Iraqi Meteorological department, Table(1). Precipitation, temperature, solar radiation, wind speed and relative humidity are recorded at these stations. The available datasets are summarized in Table (2). The flow rates as in [22 ,23]), rainfall and Climate data from 1993-2013 were used in this study. This provided a two year model validated period (1993-2002) followed by a calibrated period from 2003-2013.

ArcSWAT2009 Model Setup:

1-ArcSWAT2009, allows a number of different physical processes to be simulated in a watershed. A watershed may be divided into a number of sub-watersheds or sub-basins. The use of sub-basins in a simulation is beneficial when different areas of the watershed are dominated by land uses or soils different in properties to impact hydrology. Input information for each sub-basin is grouped into the following categories (climate, hydrologic response units or HRUs, ponds, groundwater and the main channel or reach, draining the sub-basin).HRUs are lumped land areas within the sub-basin that are comprised of unique land cover ,soil and management combinations.

Fig.(1): Location of Greater-Zab river basin in Iraq.

Table (1): Weather station at Greater-Zab watershed

Name	Latitude,degree	Longitude,degree
Soram	36.87	44.63
Erbil	36.18	44.00
Choman	36.49	44.70
Mergasur	36.94	44.24
Amedy	37.10	43.50

Table (2): Available datasets for rainfall, temperature, solar radiation, wind speed and relative humidity,(Ministry of Water Resources-Iraq(2014).

Datasets	Min.	Max.	Mean
Rainfall, mm/year	291	1140	710
Temperature, C^o	-4	45	21.6
Solar radiation, $MJ/m^2/day$	7.65	24.6	16.6
Wind speed, m/sec	1.3	2.4	1.82
Relative humidity, %	22.33	70.26	42.6

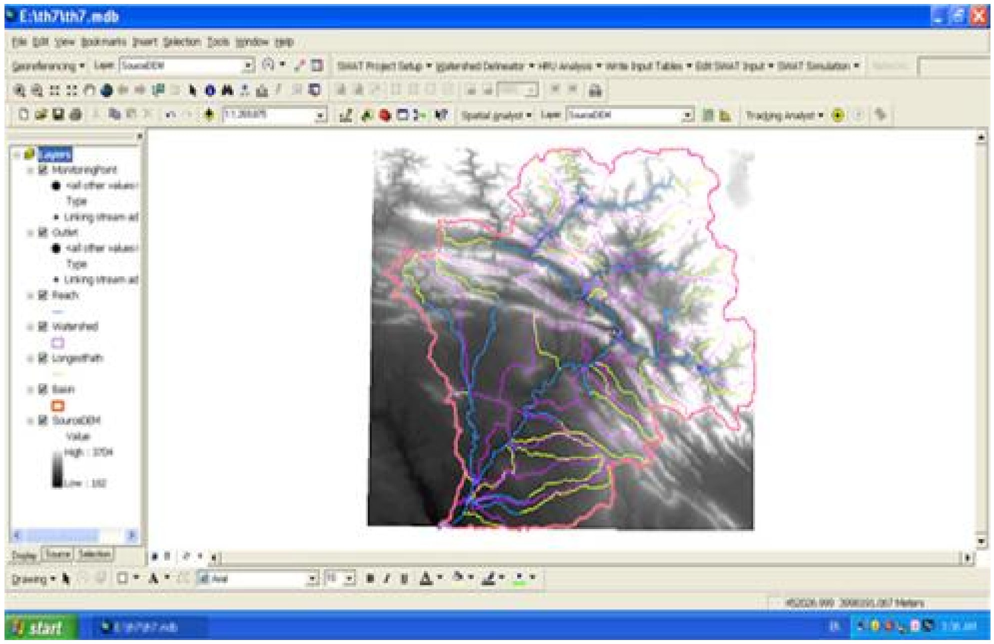
2-Water balance is the driving force behind everything that happens in the watershed. The hydrologic cycle as simulated by ArcSWAT2009 is based on the water balance Eq.(1) , [24]:

$$SW_t=SW_0+\sum_{i=1}^{t}(R_{day}-Q_{surf}-E_a-W_{seep}-Q_{gw}) \qquad ....(1)$$

Where SW_t is the final soil water content (mm), SW_0 is the initial soil water content on day i(mm),t is the time (days),R_{day} is the amount of precipitation on day i(mm),Q_{surf} is the amount of surface runoff on day I (mm), E_a is the amount of evapotranspiration on day I (mm), W_{seep} is the amount of water entering the vadose zone from the soil profile on day I (mm) and Q_{gw} is the amount of return flow on day I (mm).

3-Watershed delineation is based on an automatic procedure using Digital Elevation Model (DEM) data in ESRI grid format of the Greater-Zab river watershed .DEM for Greater-Zab river watershed was obtained from USGS [25] (United States Geological Surveys) website and from free on line source of The Shuttle Radar Topography Mission (SRTM).The GRID resolution was 30 m .The projected coordinate system of DEM of Iraq was UTM (zone 38N) with datum NAD83.Many parameters are specified which provide limits that influence the size and number of watersheds created. Watershed delineation is divided into: DEM setup; stream, outlet at Eski-Kalak (Iraq) and inlet at Cukurca (border between Iraq and Turkey) definitions; watershed outlet selection and calculation of sub-basin parameters. It carries out GIS functions to divide watershed into many sub-watersheds. 33 sub-watersheds were generated by this step. The watershed boundaries and the stream network in the watershed is calculated from the DEM using the flow direction and flow accumulation method. Fig.(2) ,shows the delineated watershed with sub-watersheds. The watershed report from this process, shows that the min. and max. land surface elevations were 182m and 3704m (a.s.l)respectively. The catchment area of the Greater –Zab basin was 17420 km^2 (in Iraq).

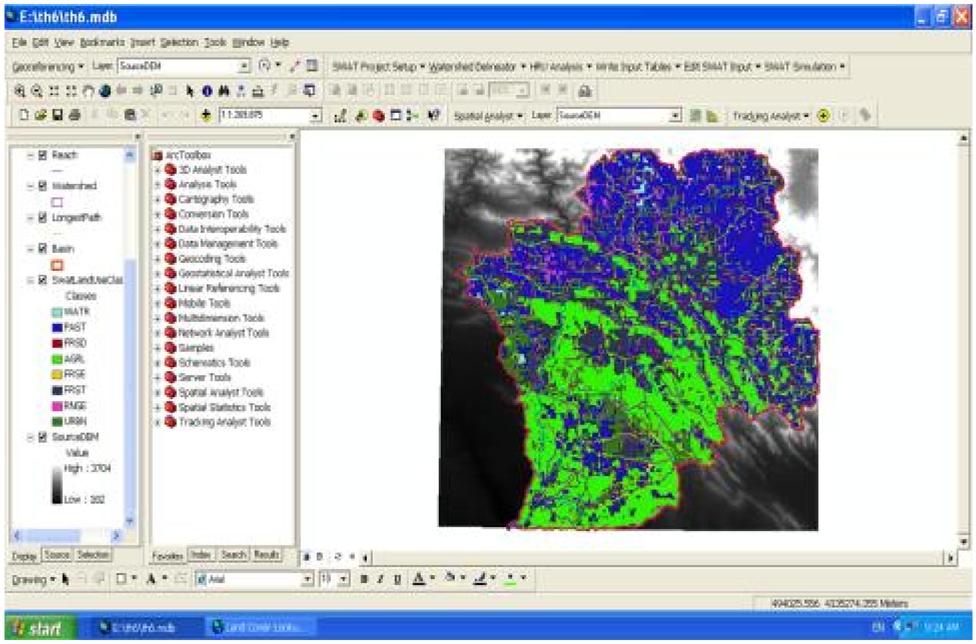
4-ArcSWAT2009 requires land use, soils and slope datasets to determine the area, the hydrologic parameters of each land, soil and slope category simulated within each sub-watershed and the distribution of hydrologic response units (HRUs) .Runoff is predicted separately for each HRU which have unique land use, soil combinations, different evapotranspiration and hydrologic conditions. Land use map for Greater-Zab river basin (raster datasets) was obtained from FAO (Food and Agriculture Organization) .Land use data comes with numbers for each land use type, so NLCD 1992(from USGS) classification was used to relate these numbers to specific land use types (urban, agricultural, range, forest, water, barren, tundra and perennial snow lands).An overlap between the land use dataset and watersheds must be exist. The land use map will be reclassified according to the above classification .The reclassified land use map is shown in Fig. (3).



Figure(2): Delineated watershed and sub- basins of Greater-Zab river watershed.

5-The Greater –Zab river basin area consists two regions (mountain and valley area). The soil in the mountain area is shallow (100-130cm) and has been create from the original rocks and it has a low potential for agriculture but it is rich in the natural range land .Its texture consists sandy clay, loam silt, loam clay sand and gravel. The valley area has suitable for agriculture as it consists of chesnut soils, brown soils and lithosolic soil. The texture of soils in the valley area consists of loam clay sand, loam silt and silt clay. The soil look up table in the ArcSWAT2009 is used to specify the type of soil to be modeled for each category in the soil map grid. The source of soils data for Iraq were from Buringh(1960) [26].To make an accuracy and to reflect the actual soil type in the simulation , the soil spatial data in the Greater-Zab catchment area was related to the hydraulic properties that were taken from the (USDA)data base. Texture, bulk density, available water capacity and saturated hydraulic conductivity parameters were used to obtain the name of soil type from USDA database. The most runoff curve numbers are for the hydrologic soil groups (type A and B). The soil data must be projected and converted to raster (grid) datasets by making a shape file (using Arc GIS 9.3). This process was used to make overlap between the soil datasets and the watershed. The reclassified soils grid is shown in Fig.(4).

6-multiple slope discretization was selected in the ArcSWAT2009.It is an important variable for water movement and delineating of HRUs. The slope is derived from the Digital Elevation Model (DEM), and classified into 5 slope percentage classes according to the FAO slope classification [27]. Table (3) shows the classification of slope in five zones. Three slope classes were selected for this process (2-15, 15-30 and >**30%)** for more practical and after reclassification, new layer (land slope) will be added to the map of the watershed.



Figure(3): Reclassified land use grid of greater-zab river basin.

7-For determination of the HRU distribution, more unique land use, soil and slope combinations were created for each 33 sub basin of the Greater-Zab river watershed. In this study, 34.5% of the total area of the watershed was cultivated and the land use, soil class and slope class percentages over area were 20%, 10% and 20% respectively. Many land uses were used in the watershed (1% corn,9% cucumber,3% eggplant,21% orchard ,1% sunflower,1% tobacco,23% tomato ,20% barely and 21% wheat) [28].The number of created HRUs were 632 after doing the HRU definition process.

8-Daily and monthly Weather data (rainfall, temperature, solar radiation, wind speed and relative humidity) and weather station locations were used in the watershed simulation. Weather generator data in the ArcSWAT2009, must be defined before performing the input data in order to generate weather parameters. For missing weather data, ArcSWAT2009 has an ability to generate data for simulations.

9-The ArcSWAT2009 inputs (point source discharge, reservoirs and inlet discharges) were added to the watershed. There are no point source discharge and reservoirs in the watershed of the Greater –Zab river. Only, average monthly inlet discharge at Cukurca (at the border between Iraq and Turkey) and at Deralook stream station in Iraq as in [29, 30] were used, Fig.(5).The mean annual discharge is 135.3 m^3/sec.

Model Calibration and Validation Results:

A-The ArcSWAT2009 model was calibrated and validated using measured stream flow data collected at Eski-Kalak (near the outlet of Greater-Zab river basin). The historical stream flow data (1994-2013) were divided into two sets: 10 years (1994-2003) for calibration and 10 years for validation (2004-2013).

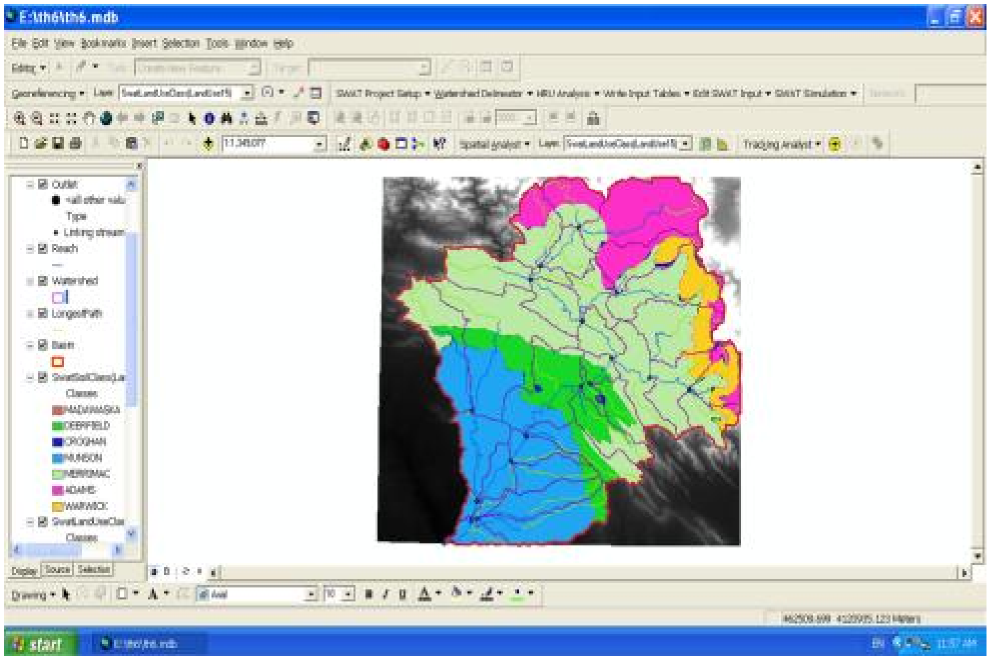
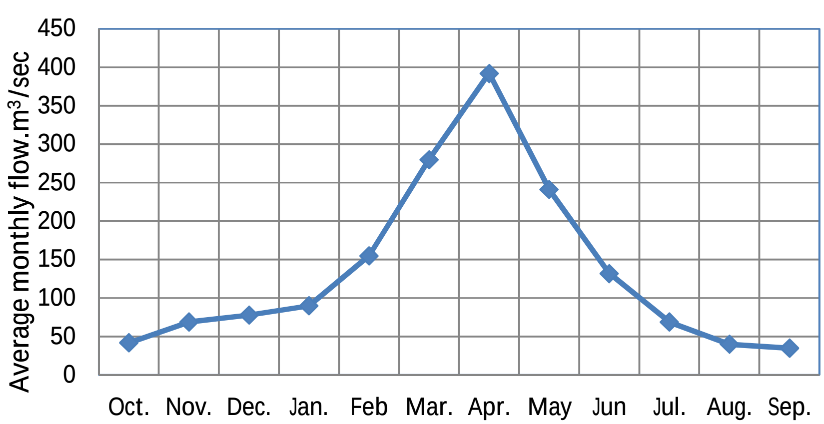


Figure (4): Soils grid reclassified by soil names for the Greater-Zab river basin.

Table (3) - Slope classification From: Winnaar [27].

No.	Slope class	Slope%
1	Flat	<2
2	Undulating	2-8
3	Rolling	8-15
4	Hilly	15-30
5	Mountainous	>30



Figure(5):Average monthly inlet discharge at Cukurca (border between Turkey and Iraq).

B-ArcSWAT2009 input parameters are process based and must be held within a realistic uncertainty range. There are two steps in the calibration and validation process in the model:

1-The first step is the determination of the most sensitive parameters for a given watershed.

The adjustable variables were determined based on expert judgment or on sensitivity analysis. Sensitivity analysis is the process of determining the rate of change in model output with respect to changes in model inputs (parameters)or reducing the number of parameters (41 parameters which are important for simulation processes in ArcSWAT2009) . It is necessary to identify key parameters and the parameter precision required for calibration [31]. In a practical sense, this first step helps determine the predominant processes for the component of interest.

2-The second step is the calibration process. Calibration is an effort to better parameterize a model to a given set of local conditions, thereby reducing the prediction uncertainty. Model calibration is performed by carefully selecting values for model input parameters .Calibration is done by reducing the discrepancies between model outputs and gage observations to a minimum. The differences between field measurements and model outputs are illustrated in an “objective function” defined as the weighted sum of squared deviations between gage observations and corresponding model outputs. As the calibration proceeds, the model progressively reduces this objective function until it can reduce it no more.

C-The 11 parameters which are relatively important in determining stream flow and water balance were used for the calibration, Table (4). The range of default values of the (41) parameters were taken from the ArcSWAT2009 user’s manual. Calibration for water balance and stream flow is first done for average annual conditions after this the data shift to monthly records.

D-For model performance evaluation, three criteria were used to evaluate the model predictions. These are the coefficient of determination ($R^2 \geq 0.60$), the Nash-Sutcliffe model efficiency coefficient($E_{N.S.} \gg 0.50$) and a percent difference statistic ($d\% \leq 15$) as in [6].

E-To calibrate the stream flow and water balance, the curve number (CN2) was adjusted until the surface runoff was acceptable. If the surface runoff were not reasonable in its values, the soil available water capacity (SOL_AWC) or the soil evaporation compensation factor (ESCO) was adjusted. After these steps, if the simulated base flow compared with the measured values are high, three steps were done, the ground water coefficient (GW_REVAP) was increased, the threshold depth of water in the shallow aquifer for “revap” to occur (REVAPMN) was decreased and the threshold depth of water in the shallow aquifer required for base flow to occur (GWQMN) was increased. If the simulated base flow is low, decrease, increase and decrease the three parameters respectively. If there are many problems that affect the shape of the hydrograph, the other parameters which are listed in Table (4), were adjusted.

F-The purpose of sensitivity analysis is to identify the parameters that have the greatest influence on model results .Table (5), shows the rank of the most sensitive parameters. The range of the final values of the parameters was selected, to reduce the time needed for the iterations of the calibration process. The most sensitive parameters for the stream flow and water balance are the effective hydraulic conductivity in main channel and initial SCS runoff curve number for moisture condition II respectively.

Table (4): Lower, upper and default of Parameters used during calibration of the ArcSWAT2009 model in the Greater-Zab basin.

Parameter	Description	Lower Bound	Upper Bound	Default Value
Stream flow parameters				
CH-K2	Effective hydraulic conductivity in main channel alluvium,(mm/hr)	0.0	150.0	0.3
ALPHA_BF	Base flow alpha factor (days)	0.0	1.0	0.048
SMFMX	Maximum melt rate for snow during year (mm H_2O /c^o-day)	0.0	10.0	4.5
SMFMN	Minimum melt rate for snow during year (mm H_2O /c^o-day)	0.0	10.0	4.5
TLAPS	Temperature laps rate (^{o}C/km)	0.0	50.0	6.0
Water balance parameters				
CN2	Initial SCS runoff curve number for moisture condition II	30.0 -25%	98.0 25%	Varies
SOL_AWC	Available water capacity of soil layer(mm/mm)	0.0	1.0	0.24
ESCO	Soil evaporation compensation factor	0.01	1.0	0.45
GW_REVAP	Groundwater “revap” coefficient	0.02	0.20	0.02
REVAPMN	Threshold depth of water in the shallow aquifer for “revap” to occur (mm H_2O)	0.0	500.0	5.0
GWQMIN	Threshold depth of water in the shallow aquifer for return flow to occur (mm H_2O)	0.0	5000.0	6.0

Table (5): The rank of the most sensitive parameters

Parameter	Rank	Range of Final values
Stream flow parameters		
CH-K2	4	129.2-135.29
ALPHA_BF	6	0.84-0.85
SMFMX	10	1.71-6.82
SMFMN	9	5.79-8.51
TLAPS	11	36.14-43.49
Water balance parameters		
CN2	1	50-90
SOL_AWC	5	0.11-0.17
ESCO	2	0.13-0.49
GW_REVAP	8	0.017-0.052
REVAPMN	7	0.0014-8.62
GWQMIN	3	8.09-31.7

Results and Discussion:

- Water Balance

The important components of the average annual water balance are shown in Table (6). ArcSWAT2009 predicted an average annual stream flow of 657 mm for the total period 1994-2013 as compared with the measured stream flow of 652 mm. The measured and simulated monthly flow values matched well and showed a strong coefficient of determination R^2 (0.99), Nash-Sutcliffe model efficiency coefficient $E_{N.S.}$ (0.99) and a percent difference statistic d% (0.90) of the overall period .The hydrologic calibration yielded average annual values of 193 mm of surface runoff , 86 mm of lateral flow (inter flow) through surficial layers of soil and 131 mm groundwater return flow. The average simulated stream flow was (363) m^3/s and the base flow was 72 m^3/s. The ratios of the base flow and the flow of the hydrograph shape (surface runoff flow plus lateral flow) to the total flow are 20 % (base flow index) and 42 % respectively. Reference [32] shows that mean annual base flow indices (ratio between base flows to stream flow) vary from 0.25 to 0.76 estimated using different methods. The lateral flow, computed as a percentage of average annual rainfall varies greatly from 4.8% to 38% .The yearly average actual evapotranspiration for the study area was 364 mm and the precipitation was 690 mm per year (the ratio between them was 53 %). The average potential evapotranspiration was as high as 1540 mm. From the ArcSWAT2009 simulation it is clear that actual evapotranspiration is much lower than potential evapotranspiration, since irrigation of the agricultural land use and the canal seepage were not considered in the simulations. The actual evapotranspiration depends on many factors such as the moisture content of soil (availability of water), atmospheric and land cover. The ratio between the average yearly precipitation and potential evapotranspiration was 45 %.The climate of the study area classified as a semiarid region according to [33].

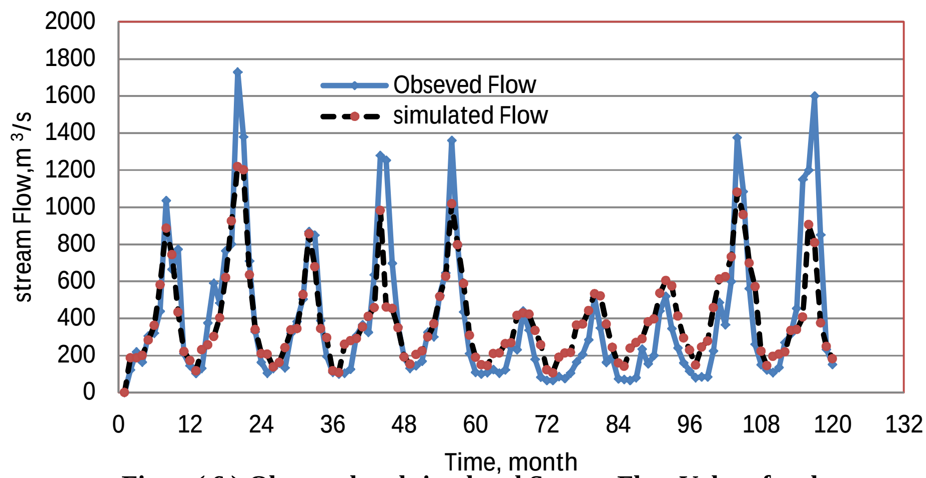
-Stream Flows

The calibrated flows which were monthly basis, match observed flows well (Figure 6). The coefficient of determination (R^2), the Nash-Sutcliffe model efficiency coefficient ($E_{N.S.}$) and a percent difference statistic (d%) computed values are 0.99, 0.99 and 2.76 respectively for the calibration period (1994-2003). In this study the magnitude of the simulated peaks is low as compared to observed peak flow. Generally, the calibrated flow values matched well the low flows as compared to peak flows. There are some difficulties in simulating high flow using ArcSWAT2009 especially for the wet years. In snow melt months, the peaks are too high so the values for maximum and minimum melts rates for snow (SMFMX and SMFMN), temperature lapse rate (TLAPS) and the base flow alpha (ALPHA_BF) factors must be modified.

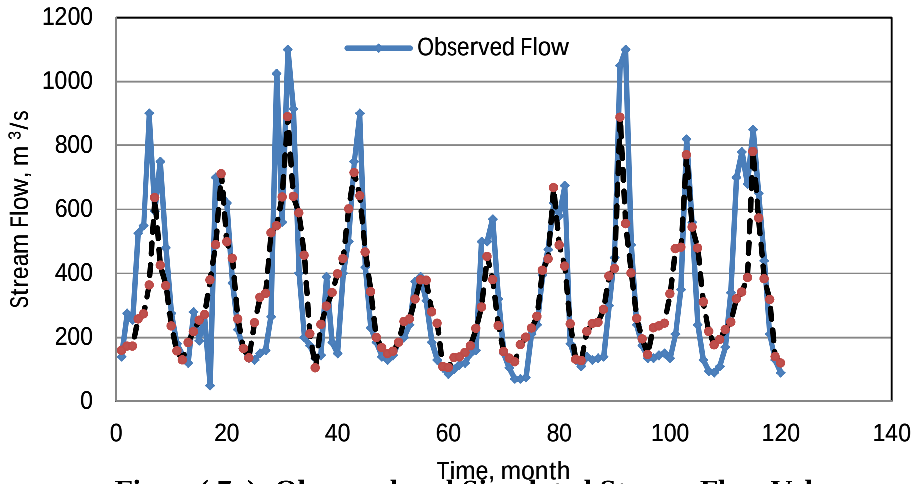
ArcSWAT2009 verification was performed for the years 2004-2013. The calibrated model was used to simulate the monthly stream flows for validation. The simulation results were compared with the corresponding observed stream flow values. The simulation during validation matches well with the observed data in each year, Figure (7). Generally, the model simulates well low flows and peak flows as compared to the calibration period (1994-2003). The model evaluation performance reveals that the model is able to explain most of the variability in the measured stream flow with a coefficient of determination (R^2), Nash-Sutcliffe model efficiency coefficient ($E_{N.S.}$) and a percent difference statistic (d%) values of 0.87, 0.86 and 1.22, respectively. These values are less than of the calibration values because of the fluctuation in the observed stream flow values during the period (2004-2007).It is important to consider measured data uncertainty when using the statistical evaluation to evaluate watershed models. The average monthly inlet flow to the catchment area of the Greater Zab at Cukurca was assumed constant along the whole period of study because of no data available.

Table (6): Annual Water Balance Terms (mm) for Greater-Zab River Basin as Simulated by ARCSWAT.

Parameters	PET	ET	Precipitation	Groundwater Flow	Lateral Flow	Percolation	Surface Runoff
1994	1566	356	697	170	83	70	195
1995	1523	451	866	214	131	100	285
1996	1487	347	660	106	80	45	193
1997	1600	401	784	130	90	54	213
1998	1490	420	824	227	104	93	233
1999	1619	295	533	70	56	24	163
2000	1427	320	618	65	77	30	174
2001	1544	364	713	143	87	56	191
2002	1492	467	939	327	135	135	257
2003	1580	354	687	119	85	51	202
2004	1508	316	549	119	80	50	113
2005	1582	334	628	138	79	57	176
2006	1544	436	862	205	115	91	225
2007	1525	413	806	100	100	53	218
2008	1580	295	490	16	52	6.5	143
2009	1555	291	475	31	44	13	144
2010	1597	328	621	122	70	39	181
2011	1541	354	678	119	82	50	195
2012	1522	369	736	113	89	45	207
2013	1521	332	642	135	77	54	182
Average	1540	364	690	131	86	56	193

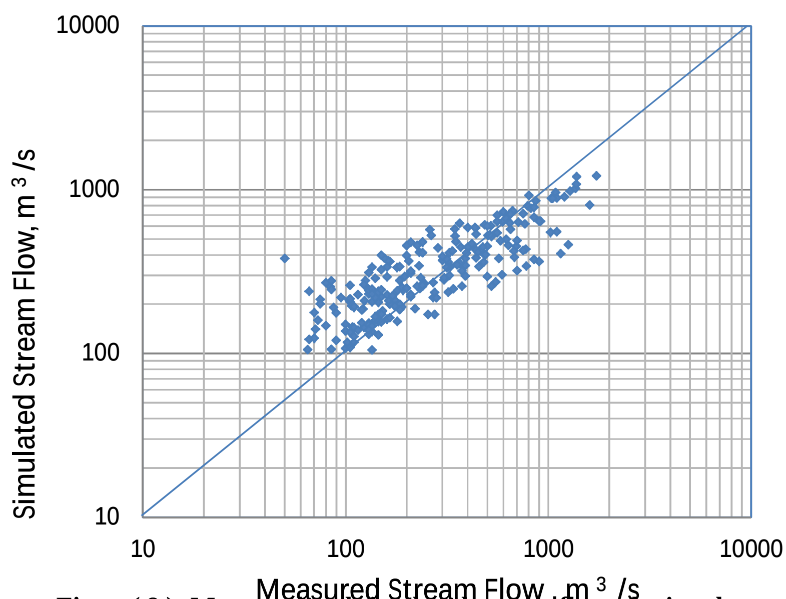


Figure(6):Observed and simulated Stream Flow Values for the greater Zab Basin for period (1994-2003).



Figure(7): Observed and Simulated Stream Flow Values for the Greater-Zab Basin for Period(2004-2013).

The log-log scatter plots of measured and simulated stream flows during the calibration and validation periods (all data) are shown in Figure (8). There are some differences between the points in the Figure(8) and the line which is drawn with angle of 45 ^{o} (tan θ =1.0).The value of R^2 ranges from 0 to 1, with higher values indicating better agreement between predicted and observed stream flow .The values of $E_{N.S.}$ range from −∞ to 1, with $E_{N.S.}$ values greater than 0.50 indicating that the model is a good predictor. R^2 evaluates only linear relationships between variables; thus, it is insensitive to additive and proportional differences between model simulations and observations [34]. $E_{N.S.}$ is sensitive to differences in the means and variances of observed and simulated data and hence is a better measure to evaluate model simulations [35].



Figure(8): Measured and simulated stream flows during the calibration and validation periods.

Conclusions and Recommendations:

The conclusion of this study is that ArcSWAT2009 can be used for modeling stream flow and hydrologic budget. The model can be used efficiently in semi-arid regions to support water management policies in Iraq. It is important to note that in the model set-up, attention should be on the classification of land use and soil type to match the model classification and type respectively. During model set-up, the soil type of Iraq which was classified as in [26], was used by making a shape file because of no soil type data. The soil type and the land use classification were sensitive issues for the stream flow estimation.

Consideration should be given to the change in the land use of the Greater Zab basin also for all river basins in Iraq in future research of the strategy for water and land resources. The study results show that the simulated average stream flow for the total period (1993-2013) was 363m^3/sec while the average value for the stream flow for the period (1930-1993) was 417m^3/sec. These differences are due to global warming, GAP project in Turkey and no data available for the stream flow hydrograph at Cukurca (boundary between Iraq and Turkey) for the total period of study(only the average values of the flow rates) and rivers entering Iraq from the co-riparian countries .It is useful to import predefined watershed boundaries in the model. Two types of drainage inlets must be taken into account, the point source discharge (outlet of drainage watershed) and a portion of the watershed area is not directly modeled with the ArcSWAT2009 .Discharge data records at the watershed boundaries(Iran and Turkey boundaries) must be provided. A long term planning, regional cooperation will be needed in the future to solve these problems. However, in a future study, it is recommended to use land cover and Climate change scenarios, their projected impacts and adaptation. The study results are helpful for the management and planner of water resources in Iraq which relate to the sustainability and water quantity.

The results show a better performance in the hydrologic simulations, during the calibration period than the validation period. This indicates that the physical processes in Greater-Zab river basin are well represented by the model. But the process indicated a model tendency to under predict the magnitude of peak stream flow values. However, the ArcSWAT2009 can be evaluated to suit the Greater-Zab river basin hydrologic simulations taking into account data availability .The best results were obtained for the set with the largest number of parameters and the widest ranges of variation which help the other researcher in the same basin area and to reduce the time of calibration process.

The results of water balance for annual time scale show that the actual evapotranspiration was much lower than the potential evapotranspiration. The agriculture of the total area of the Greater-Zab basin was depended on rainfall. No details about water pumping from wells for irrigation, springs, irrigation projects and domestic water supply were available for each sub-basin and these data have not been accounted in the water balance.

If the water balance results including groundwater in the Greater-Zab river basin are to be estimated by the others, the groundwater inflow and outflow from the aquifer boundaries must be included to the model. The estimation of groundwater recharge is important to yield the optimal safe discharge of groundwater that should not exceed the recharge.

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