Hydrology and Earth System Sciences Discussions

Hydrologic analysis for river Nyando using SWAT

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Abstract

The Nyando River is one of the major Rivers in the Lake Victoria Basin. It drains parts of Nandi, Kericho and Nyando districts. It has a catchment area of about 3600 km^{-2} of Western Kenya and an average discharge of approximately 15 m^3 s^{-1}, and has within it some of the most severe problems of environmental degradation and deepening poverty found anywhere in Kenya. The Nyando River drains into the Winam Gulf of Lake Victoria and is a major contributor of sediment.

The primary role of GIS in hydrological modeling is to integrate the ever increasing volumes of diverse spatial and non spatial data. This can be the model input or output. Recent advance in GIS (hardware and software) technology offer unprecedented capabilities for storing and manipulating large quantities of detailed, spatially-distributed watershed data (ASCE, 1999). SWAT, which is an interface of Arc View GIS, uses Arc View to prepare input data and display the model output as spatial maps, charts or time series data. This makes it easy to study and display the information for assimilation by SWAT.

SWAT is a continuous time model that operates on a daily/sub-daily time step. It is physically based and can operate on large basins for long periods of time (Arnold et al., 1998). The basic model inputs are rainfall, maximum and minimum temperature, radiation, wind speed, relative humidity, land cover, soil and elevation (DEM). The watershed is subdivided into sub-basins that are spatially related to one another. Routing in stream channel is divided in to Water, Sediment, nutrients and organic chemical routing (Neitsch et al., 2002a).

Stream flow data was available for two Stations 1GD03 and 1GD07. The stations had data ranging from 1950 to 1997, though they had missing gaps.

Rainfall data were available for twelve rainfall recording stations in and around the basin. The collected data ranges between 1960 and 2000 though there were quite a number of missing data. The other weather data used were temperature data (maximum and minimum) for Kericho and Kisumu Meteorological stations.

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During the study the available water capacity (SOL_AWC) was varied within the range of ±0.05 mm of water/mm of soil. The result showed that SOL_AWC affects the stream flow. SOL_AWC affects both the surface flow and base flow. An increase in SOL_AWC results in decrease on the stream flow because of increase in the ability of the soil to hold more water. An increase in the initial curve number (CN2) increases the stream flow, but the effect is more pronounced on the effects on surface run off. The slightly increase in total stream flow could be as a result of ration of surface run off to base flow. The amount of stream flow contributed by the base flow was more than 50% of the total stream flow as show by base flow separation. The goodness of fit between observed and simulated stream flow was assessed for the aforementioned (1GD03) station, the R^2 was found to be 0.24 while the NSE was 0.46 respectively. The low value of R^2 and NSE could be attributed to lots of data gaps in the station and also the effects of combined tributaries. The station is located about 10 km upstream of Ahero Bridge just before the flood plain. The model over estimated the low flows at this station while the high flows were well estimated.

The performance of the model varied depending on the available input data. The coefficient of determination R^2 varies for observed and simulated stream flow at River gauging Station. The relationship between land use/cover change and stream flow is very significant in Nyando basin. The observation made is that with decreased Forest Cover up to 0% there is increased stream flow mean and peak and increased forests cover i.e. 100% results in decreased mean and peak stream flow.

1 Introduction

The Nyando River is one of the major rivers in the Lake Victoria Basin. It drains parts of Nandi, Kericho and Nyando districts. It has a catchment area of about 3600 km^{-2} of Western Kenya and an average discharge of approximately 15 m^3 s^{-1}, and has within it some of the most severe problems of environmental degradation and deepening

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poverty found anywhere in Kenya. The Nyando River drains into the Winam Gulf of Lake Victoria and is a major contributor of sediment.

It has a unique physiographic characteristics, climate and elevation variation. Geologically the basin consists of extrusive igneous (volcanic) rocks mainly phonolites and metamorphic rocks.

This is a basin area of variable welfare and environmental quality, with relatively tight cause and effect relation between upstream land and water uses and downstream variation in water quality and water quantity. The historical pattern shows consistent deforestation and degradation over the last hundred years, punctuated by severe worsening of those problems during the heavy rains that accompany El Nino events. Floods in the Kano plain are becoming more severe and frequent as the river has gradually lost its ability to buffer environmental variability.

The basin drains parts of Nandi, Kericho, and Nyando districts, traversing from high to low potential areas. It is made up of six sub catchments namely Mbogo,Tugunon, Masaita, Namuting, Ainapsiwa and Nyando. The basin has a humid climate with moderate temperatures and bimodal rainfall with a mean annual rainfall of 1200 mm

1.1 Effects of land use/cover change on stream flow

The effects of land use/change on stream flows are manifested at different spatial and temporal scales. The possible changes in land use/cover include deforestation (afforestation) intensification of agriculture, drainage of wetlands and urbanization.

Deforestation which has converse effects to afforestation affects significantly the characteristics of the stream flow (Calder, 1992). Though considered a myth or folklore (McCulloch and Robbinson, 1993; Calder, 1998) forests are thought to make rain regulate low flows, reduce floods, ameliorate soil erosion and sterilize water. Intensification of agriculture affects the runoff generated through alteration of evaporation and timing of runoff. These effects are compounded by replacement of certain crops, which alters the leaf area index (Calder, 1992).

Wetlands do not or marginally affect the basin's seasonal water balance (Calder, 1998). However due to the presence of free water surface and lack of water stress, the wetlands vegetation normally has high evaporation rates as compared to other land covers. This intern affects the annual stream flow, which is likely to be less compared to other land uses (Calder, 1992).

The earth's climate is changing gradually. In East Africa for example, catchments are displaying a small increase in precipitation received and this makes them wetter. These changes definitely affect the quantity of stream flow.

1.2 Application of GIS in hydrological modeling

Geographical Information System (GIS) is an organized collection of computer hardware and software, with supporting personnel, that captures, stores, analyses and display all forms of geo-referenced information (Sabin, 1996).

The primary role of GIS in hydrological modeling is to integrate the ever increasing volumes of diverse spatial and non spatial data. This can be the model input or output. Recent advance in GIS (hardware and software) technology offer unprecedented capabilities for storing and manipulating large quantities of detailed, spatially-distributed watershed data (ASCE, 1999).

SWAT, which is an interface of Arc View GIS, uses Arc View to prepare input data and display the model output as spatial maps, charts or time series data. This makes it easy to study and display the information for assimilation by SWAT.

SWAT is a continuous time model that operates on a daily/sub-daily time step. It is physically based and can operate on large basins for long periods of time (Arnold et al., 1998). The basic model inputs are rainfall, maximum and minimum temperature, radiation, wind speed, relative humidity, land cover, soil and elevation (DEM). The watershed is subdivided into sub-basins that are spatially related to one another. The sub-basin watershed components can be categorized into the following components – hydrology, weather, erosion and sedimentation, soil temperature, plant growth, nutrients, pesticides and land management. In the land phase of the hydrologic cycle,

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runoff is predicted separately for each hydrologic response unit (HRU) and routed to obtain the total runoff for the watershed. Once the loadings (water, sediment, nutrients and pesticides) to the main channel are determined, they are routed through the stream network of the watershed.

5   The water balance equation used in SWAT for the land phase of the hydrologic cycle is given by Neitsch et al. (2002a) as:

$$SW_t = SW_0 + \sum_{i=1}^{t} (R - Q - E - W - G) \tag{1}$$

Where: SW_t is the final water content on day i (mm),
   SW_0 is initial water content on day i (mm),
   T is the time (days),
   R is the amount of precipitation on day i (mm),
   Q is the amount of surface runoff on day i (mm),
   E is the amount of Evapotranspiration on day i (mm),
   W is the amount of water entering the vadose zone from the soil profiles
      on day i (mm),
   G is the amount of return flow on day i (mm).

The hydrologic processes simulated by the sub basins as shown by the water balance equation are precipitation, surface runoff, evapotranspiration, percolation and return
10 flow.

    The daily weather data required by SWAT are precipitation, temperature (maximum and minimum), solar radiation, relative humidity and wind speed.

    After putting precipitation and temperature (maximum and minimum) data, the weather generator then generates solar radiation and relative humidity for the day.
15 Finally, wind speed is generated independently.

    Runoff is simulated separately for each of the HRU generated and combined to give the total stream flow for the sub-basin which again combines with the other sub-basin's

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to give the stream flow for the whole basin. According to Neitsch et al. (2002) SWAT predicts surface runoff using the modified SCS Curve number method or the Green and Ampt infiltration method. In this study SCS Curve number which is a function of soil permeability, land use and antecedent moisture condition was used.

The basic equation used by the SCS curve number is given by

$$Q = \frac{(R-1)2}{R-1+S} \tag{2}$$

Where: Q is the accumulated surface runoff or excess rainfall (mm),
R is the rain depth for the day,
I is the initial abstraction, which include surface storage, interception and infiltration prior to runoff (mm),
S is the retention parameter (mm).

Routing in stream channel is divided in to water, sediment, nutrients and organic chemical routing (Neitsch et al., 2002a). In routing water, SWAT accounts for any losses. These losses include those due to evaporation, transmission or any diversion. The amount of water added as a result of precipitation in the main channel and point sources discharges are also accounted for.

In the channel, manning equation is used to calculate rate and velocity of flow in the reach of each sub basin for a given time step. The manning equation is given by the Eqs. (3) and (4) below for the rate and velocity, respectively.

$$q = \frac{AR^{2/3}S^{1/2}}{n} \tag{3}$$

$$V = \frac{AR^{2/3}S^{1/2}}{n} \tag{4}$$

Where: q is the rate of flow in the main channel (m^3/s);
A is the cross sectional area of the channel (m^2);

R is the hydraulic radius for a given depth of flow (m);
S is the slope along the channel length (m/m);
n is the manning coefficient for the channel; and
V is the velocity of the flow (m/s).

The model assumes that the main channel has trapezoidal shape with a 2:1 run to rise ration. When the volume of water in the reach exceeds the maximum amount that can be contained by the main channel, the excess amount spreads across the flood plain. SWAT routes the stream flow downstream using either variable storage or Muskingum method (Neitsch et al., 2002a).

2 SWAT input data and their sources

Digital Elevation Model (DEM)

A Digital Elevation Model (DEM), gives the elevation, slope and defines the location of the streams network in a basin. A DEM with a spatial resolution of 90 M by 90 M was used in this study and it was obtained from International Centre for Research in Agroforestry (ICRAF).

Land use/cover map

The land use/cover map gives the spatial extent and classification of various land use/cover classes of the study area. The land use/cover data combined with soil cover data generates the hydrologic characteristics of the basin or the study area, which in turn determines the excess precipitation, recharge to the ground water system and storage in the soil layers.

The land use/cover data was obtained from ICRAF for the two varied years that is for 1987 and 2003.

Soil map and data

The soil data as required by SWAT to predict stream flow should have the hydraulic conductivity properties which include: soil bulk density, saturated hydraulic conductivity and the soil available water capacity (SOL_AWC). The soil data was obtained from the internet (ISREC site), the parameters of the soil such as soil bulk density (g/cc), saturated hydraulic conductivity, K_s (mm/hr) and soil available water capacity which were missing were estimated using a hydrology programme called soil water characteristics which was also downloaded from the internet.

Stream flow data

Stream flow data was available for two Stations 1GD03 and 1GD07. The stations had data ranging from 1950 to 1997, though they had missing gaps. Table 1 gives the summary of the stream flow data and the percentage of missing data for each station used for the study.

Weather data

Rainfall data were available for twelve rainfall recording stations in and around the basin. The collected data ranges between 1960 and 2000 though there were quite a number of missing data. The other weather data used were temperature data (maximum and minimum) for Kericho and Kisumu Meteorological stations.

SWAT model set up

This procedure involved integrating DEM, land use/cover map, soil map and data and weather data to create sub-basins and hydrologic response units (HRUs). This was followed by creating watersheds. The soil and land use data were characterized in the SWAT database. When defining the Hydrologic response unit (HRU), SWAT uses two options that is; the dominant land use/land cover in the sub-basins and soil or

Multiple HRU within the sub-basin (Di Luzio et al., 2002). In this study the dominant land use/land cover and soil was used to define the HRU. This means that the number of HRUs were the same as the number of sub-basins.

Parameter sensitivity analysis

5 After the model set up (simulation) using the rainfall data to compare the results of the model output vs. the actual measurements, sensitivity analysis was carried out which is an important process in guiding the subsequent calibration process. The sensitivity analysis identified the effects of changing calibration parameters as given by Neitsch et al. (2002b) on stream flow.

10 The initial parameter values (model defaults) were varied one after the other by changing within their suggested range of application as show in the table below. The results of the percentage changes in stream flow were then plotted against each parameter input to test the sensitivity of the parameters.

Soil available water capacity (SOL_AWC)

15 This is defined as the ability of the soil to hold water and depends on the soil characteristics, hence varied within the soil profile and also in the basin. During the study SOL_AWC was varied within the range of 0.05 mm of water/mm of soil. The result showed that SOL_AWC affects the stream flow as shown in Fig. 1.

SOL_AWC affects both the surface flow and base flow.An increase in SOL_AWC

20 results in decrease on the stream flow because of increase in the ability of the soil to hold more water.

Initial curve number (CN2)

CN2 is a function of soil permeability, land use/ cover and the antecedent soil moisture, it therefore affect the rate of surface runoff generation.

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From the graph it shows that an increase in CN2 increases the stream flow, but the effect is more pronounced on the effects on surface run off. The slightly increase in total stream flow could be as a result of ration of surface run off to base flow. The amount of stream flow contributed by the base flow was more than 50% of the total stream flow as show by base flow separation.

Soil evaporation compensation factor (ESCO)

ESCO is a coefficient used to modify the depth distribution used to meet soil evaporative demands (Neitsch et al., 2002b).

The default value of ESCO as used during this work was 0.95, this parameter was varied between 0.1–0.95. The result obtained from performing the variation of ESCO value showed that a decrease in ESCO value results in decrease in stream flow as well. This can be explained that the amount of water that is availed for evapotranspiration is more. ESCO affects both base flow and surface flow at the same rate.

Threshold depth of water in the shallow aquifer required for the return flow to occur (GWQMN)

The ground water flow to the main channel is allowed only when the depth of water in the shallow aquifer is equal to or greater than the threshold depth of water in the shallow aquifer required for the return flow to occur (GWQMN).

In this study the GWQMN was varied in the range of between 0% and 50%. The value of GWQMN was put at 0 mm initially; by increasing the value of GWQMN the result gave a decreasing trend in the simulated baseflow and consequently on the streamflow. The effects of GWQMN on the surfaceflow are not significant.

Groundwater "revap" coefficient (GW_REVAP)

The groundwater "revap" coefficient (GW_REVAP) has the effects on the amount of water that recharges the capillary fringe after evaporation during the dry periods. The capillary fringe is recharged by shallow aquifer during the dry periods.

By putting the initial value of the GW_REVAP at 0 mm, then varying it by between 0% to 50%, the result showed that when the groundwater "Revap" coefficient increases there is a slight decrease in the amount of simulated baseflow and total stream flow. The effects of GW_REVAP on the baseflow were not significant as it was observed to be less than 2%. Change in GW_REVAP is critical as it affects the movement of water from shallow aquifer to the root zone.

3   Model calibration and validation

Calibration involve testing model with known input and output data in order to adjust some parameters, while validation involves comparison of the model results with an independent datasets from the used during calibration without any further adjustment of the calibration parameters.

Calibration

Calibration procedures were performed while following the advice provided in some publications by the principal SWAT model developer, Dr. Jeff Anorld, and his colleagues at the USDA ARS-Blackland (Texas) Research Centre (Arnold et al., 2000; Santhi et al., 2002; Neitsch et al., 2002b).

In this study, the model calibration was done against both surface flow and base flow. The input data (stream flow and weather) used for calibration was for the period of 1970 and 1973 (based on daily values). The gauging station 1GD03 which is located within the main Nyando River was used for calibration.

The goodness of fit between observed and simulated stream flow was assessed for the aforementioned (1GD03) station, the R^2 was found to be 0.24 while the NSE was 0.46, respectively. The low value of R^2 and NSE could be attributed to lots of data gaps in the station and also the effects of combined tributaries. The station is located about 10 km upstream of Ahero Bridge just before the flood plain. The model over estimated the low flows at this station while the high flows were well estimated.

Base flow separation

The stream flow data was split into two base flow and surface flow. Table 7 gives a summary of the base flow separation results. The daily stream flow data used to perform the separation was for the gauging station 1GD03 for the period of 1974.

The alpha factor gives the base flow recession constant factor; it is an important parameter in the base flow estimation. Base flow day are the number of days for the base flow recession to decline in log cycle.

Based on the average pass 1 and 2 from Table 7, the fraction of stream flow contributed by base flow constituted between 0.49 and 0.73, the value is dependent on the location of the gauging station and the number of tributaries joining at the gauging station.

Validation

To ascertain that calibrated model could be used in Nyando basin, a model validity test was carried out. This was achieved by using a different data sets from the ones used during calibration of the model (1976–1978).

The calibration and validation of the SWAT model for Nyando basin showed that the model could be used to simulate the stream flow in the basin as it gave good results. The fair performance of the model in terms of the values obtained for R^2 can be improved later on by applying good quality datasets and representative historic data used.

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Impact of land use/cover on stream flow

A comparison on the land use/cover maps for the two years 1980's and 2003 showed that there has been a notable changes in land use/cover in the basin over the years. Accord to the land use/cover map there has been a slight decrease in forest cover by 7.6% while the area under swamp has seen quite a decline of about 34%. Agriculture (Mixed agriculture, Sugarcane, Tea, and agriculture dense) which has seen slight improvement by gaining about 2.3% more of the total land it was occupying in the year 1980's. Within the agricultural sector, Sugar cane plantation has expanded a lot by about 157% while the area under mixed forest has experience the decline in areal coverage of about 18%. The changes in land use/cover can be attributed to high population pressure which has made agricultural activities increase by encroaching into areas which were once vulnerable (steep slope, flood plains) and uncultivated lands.

The forest cover has remained almost intact with small encroachment in the South of Mau and West of Nandi for new settlements. The study therefore shows that the land use/ cover change is dynamic and therefore the rate of deforestation should be checked properly otherwise continued deforestation would lead into complete depletion of the forest hence alteration into the stream flow.

The land use/cover (map) data for the two cases were loaded in the SWAT interface small tenuously. After each loading the interface including the land use/cover report, this gives the percentage and areal coverage of each land use/cover. The changes in land use as quantified from the two maps were used to develop the land use scenarios for this research work. The base scenario is taken as the simulation values from the model without any modification of the data used.

The land use/cover map was then loaded in the SWAT interface using the varied scenarios while keeping the other parameters constant, then stream flow was simulated for each scenario to establish the impact of land use/cover change on the stream flow.

The results from the land use/cover changes scenario showed that different land use/cover categories have different stream flow characteristics. The peak, mean and

frequency characteristics of the simulated stream flow vary depending on the land use/cover type and scenario. In this study mean stream flow ranged between 19.48 m^3 to 32.14 m^3. For scenario A: Scenario with low forest cover (0%) gave the highest mean stream flow (32.14 m^3) while the scenario with 50% forest cover gave the lowest mean stream flow (19.48 m^3). Whereas 100% forest cover gave a mean stream flow of 26.33 m^3. The result can be explained in terms of the effects of forest in arresting the run off. Forests have the effect of reducing runoff, thus the smaller the area under the forest the more the runoff hence the high increase in the stream flow.

Scenario B: Where agricultural dense was the dominant land use/cover, the stream flow registered the highest value both mean and peak (32.14 m^3 and 121.13 m^3), respectively, this can be said to be as a result of crops which demand less soil moisture than forests thus rainfall satisfies the soil moisture deficit in agricultural lands more quickly than in forests thereby generating more runoff hence increased stream flow.

4   Conclusion and recommendation

Conclusion

SWAT model can simulate stream flow in Nyando Basin. The performance of the model varied depending on the available input data. The coefficient of determination R2 varies for observed and simulated stream flow at river gauging station.

The relationship between land use/ cover change and stream flow is very significant in Nyando Basin. The observation made is that with decreased Forest Cover up to 0% there is increased stream flow mean and peak and increased forests cover i.e. 100% results in decreased mean and peak stream flow. It therefore worth noting that conversion of forest and swamp areas to agricultural land can be attributed the increased annual flooding in the basin hence the need to control forest exercising.

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Recommendations

The potentials of SWAT in channel routing such as sediment transport, agricultural chemical and crop yields should be explored as a way of making SWAT be a tool for watershed management to be used by the managers for decision making.

Land use/cover change in Nyando Basin should be monitored thoroughly and reduction in deforestation encouraged so as to control the frequent flooding in the basin.

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Table 1. Summary of available streamflow data for Nyando Basin.

Gauging station	River	Daily Mean flow (M3/s)	Period recorded	Percentage missing
1GD03	Sondu	17.14	1956–1997	7
1GD07	Sondu	12.54	1963–1963	25

Source: MWI.

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Table 2. Summary of available rainfall data for Nyando catchment.

Rainfall station ID	Name	Period recorded	Percentage missing
9035020	Lumbwa Soil Cionservation Service	1960–2000	11
9035148	Koru mission	1962–2000	6
8935148	Kipkurere forest station	1960–2000	7
9034086	Ahero, Kano Irrigation Scheme	1962–2000	4
8935001	Songhor, Kaabirir	1960–1993	9
9035075	Kericho Kaisugu house	1960–2000	5
8935159	Ainabkoi, Corengoni forest station	1964–1998	4
9035279	Kericho Meteorological Station	1977–1993	34
9034009	Miwani, European quarters	1960–1998	7
9034025	Kisumu Meteorological Station	1960–1998	34
8935033	Nandi hills, Savani estate	1960–1998	17
8935161	Nandi hills, Kibwari tea estate	1964–2000	4

Source: KMD.

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Table 3. Summary of available weather data for Nyando catchment.

Meteorological station	Weather parameter	Period recorded	Percentage missing
Kericho	Maximum Temperature	1977–2000	39
	Minimum Temperature	1977–2000	38
Kisumu	Maximum Temperature	1977–2000	5
	Minimum Temperature	1977–2000	5

Source: KMD.

Table 4. Summary of available weather data for Nyando catchment.

	Parameter	Default value	Range of variation
1.	Available water capacity of the soil layer (SOL_AWC)	Var*	±0.05 mm water/mm of soil
2.	Soil evaporation compensation factor (ESCO)	0.95	0–1
3.	Threshold depth of water in the shallow aquifer required for return flow to occur (GWQMN)	0	0–5000 mm
4.	Threshold depth for water in the shallow aquifer for "revap" or percolation to the deep aquifer to occur (REVAPMN)	0	0–500 mm
5.	Initial soil curve number for moisture condition II (CN2)	Var*	±8
6.	Ground water "revap" coefficient (GWREVAP)	0.02	0.02–0.2 mm

Var* the default parameter value varied per sub-basin.

Table 5. Soil and shallow aquifer water balance for each sub basin used by SWAT.

Sub basin	GWQMN (mm)	GW_REVAP (mm)	REVAPMN (mm)	ESCO	CN2	SOL_AWC (mm of water/mm of soil)
1	100	0.12	85	0.95	36	0.15
2	100	0.12	85	0.95	59	0.14
3	185	0.17	140	0.80	90	0.13
4	185	0.17	140	0.80	86	0.13
5	185	0.17	140	0.80	78	0.14
6	185	0.17	140	0.80	80	0.13
7	185	0.17	140	0.80	78	0.12
8	185	0.17	140	0.80	78	0.10
9	116	0.17	135	0.70	71	0.13
10	116	0.17	135	0.70	71	0.13
11	105	0.12	135	0.70	68	0.16
12	105	0.12	135	0.70	75	0.13
13	105	0.12	135	0.70	75	0.15
14	105	0.12	135	0.70	42	0.14
15	105	0.12	135	0.70	75	0.14
16	105	0.12	135	0.70	75	0.14
17	105	0.12	135	0.70	85	0.16
18	105	0.12	135	0.70	75	0.13
19	105	0.12	135	0.70	75	0.14
20	105	0.12	135	0.70	85	0.16
21	100	0.12	75	0.95	87	0.13
22	100	0.12	75	0.95	87	0.14
23	100	0.12	75	0.95	83	0.11
24	100	0.12	75	0.95	84	0.14
25	100	0.12	75	0.95	84	0.14
26	100	0.12	75	0.95	87	0.13
27	100	0.12	75	0.95	84	0.13
28	100	0.12	75	0.95	77	0.16
29	100	0.12	75	0.95	84	0.14
30	116	0.17	135	0.70	71	0.13
31	116	0.17	135	0.70	77	0.11
32	185	0.17	140	0.80	78	0.10
33	100	0.12	85	0.95	59	0.13
34	185	0.17	140	0.80	78	0.13
35	105	0.12	135	0.70	75	0.14

Note: The value given for SOL_AWC are for the soil first layer.

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Interactive Discussion

**Hydrologic analysis for river Nyando using SWAT**

A. O. Opere and
B. N. Okello

Table 6. Results obtained after calibrating SWAT using observed stream flow data for the period 1970–1973.

		Stream flow (m^3/s)	Surface flow (m^3/s)	Base flow (m^3/s)
1GD03	Observed	20.42	5.72	14.7
	Simulated	20.81	4.66	16.15
	R^2	0.24	0.08	0.27
	NSE	0.46	0.23	0.46

Table 7. Summary of Base flow separation results.

Gauging station	Base flow (pass1)	Base flow (pass2)	Base flow (pass3)	Alpha factor	Base flow days
1GD03	0.64	0.57	0.50	0.0104	96
1GD07	0.57	0.50	0.41	0.0160	62

A. O. Opere and
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Table 8. Quantified land use/cover change in the Nyando Basin.

Land use/ cover	1980's Area (km^2)	%	2003 Area (km^2)	%	Change Area (km^2)	%
Forest	503	14.5	465	13.4	−38	−7.5
Swamp	88	2.5	58	1.7	−30	−34.0
Agriculture	2880	83	2948	84.9	67	2.3
Mixed agriculture	390	11.2	320	9.2	−70	−18.0
Tea	48	1.4	52	1.5	4	8.7
Sugarcane	58	1.7	148	4.3	91	157.4
Agricultural dense	2385	68.7	2428	69.9	43	1.8
Total	3471	100	3471	100	0	0.0

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Table 9. Land use/cover scenario as used to study the impact of land use/cover on stream flow.

	Forest (%)	Agriculture dense (%)	Mixed agriculture (%)	Plantation (%)	Others (%)
Base	14	69	11	3	3
2	100	0	0	0	0
3	50	30	13	5	2
4	0	80	13	5	2

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Table 10. Mean and peak of simulated stream flow for the land use/cover scenario at gauging station 1GD03.

Scenario	Forest (%)	Mean (m^3/s)	Peak (m^3/s)
A	100	26.33	69.49
B	0	32.14	121.13
C	50	19.48	109.36
D (Base)	14	20.42	111.97
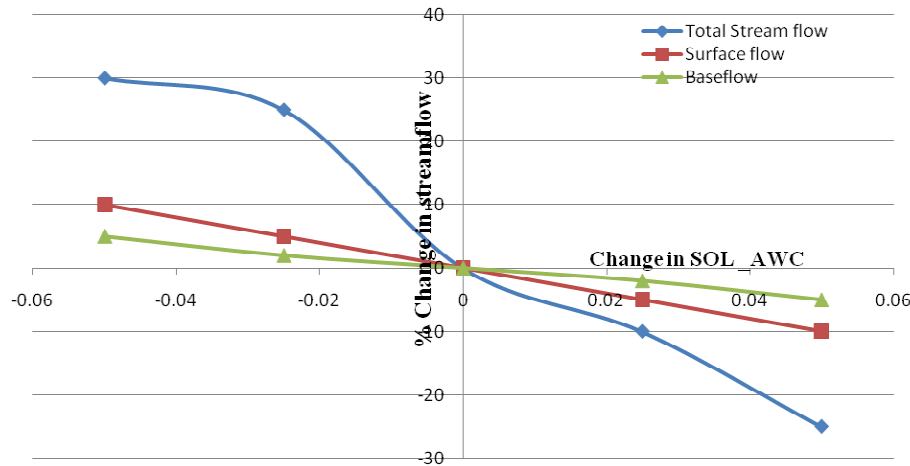
Fig. 1. The effects of varying SOL_AWC on simulated stream flow.

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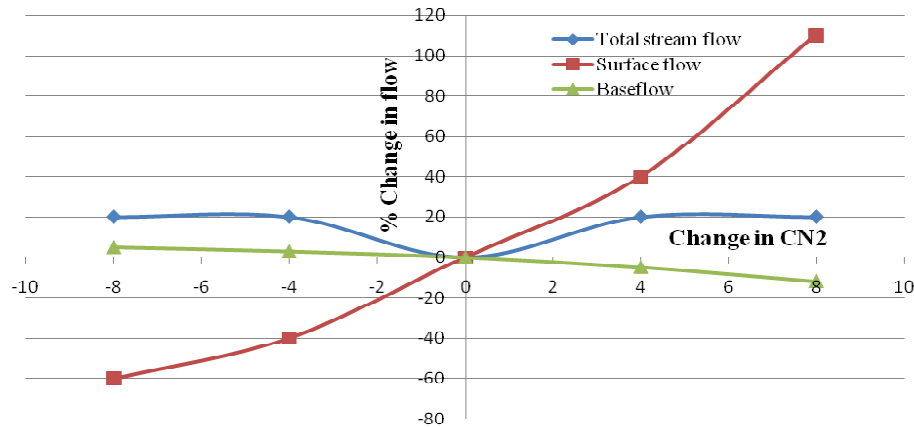
Fig. 2. The effect of changing CN2 on simulated stream flow.
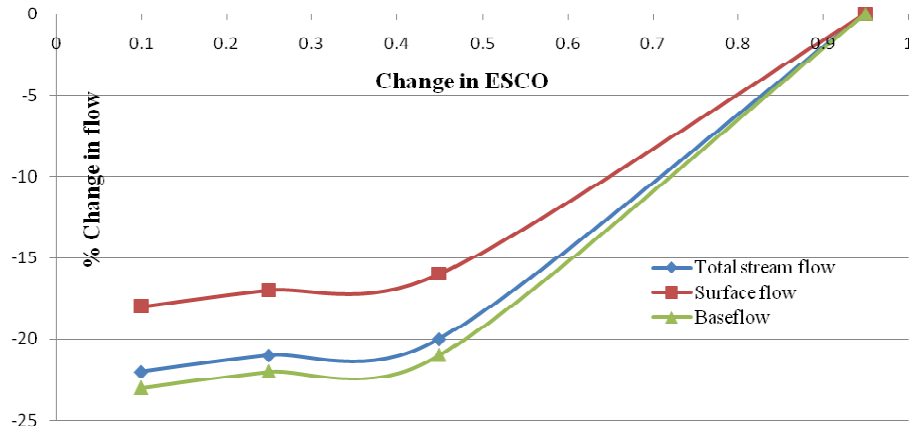
Fig. 3. The effects of varying ESCO on simulated stream flow.
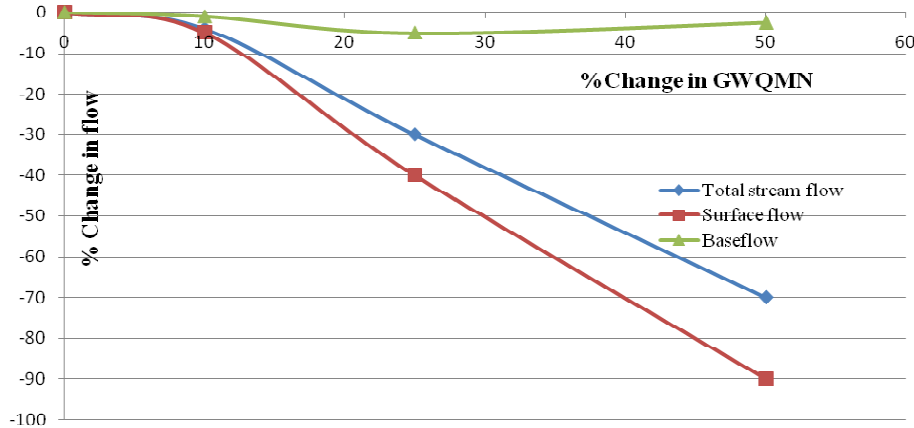
Fig. 4. Effects of changing GWQMN on simulated stream flow.
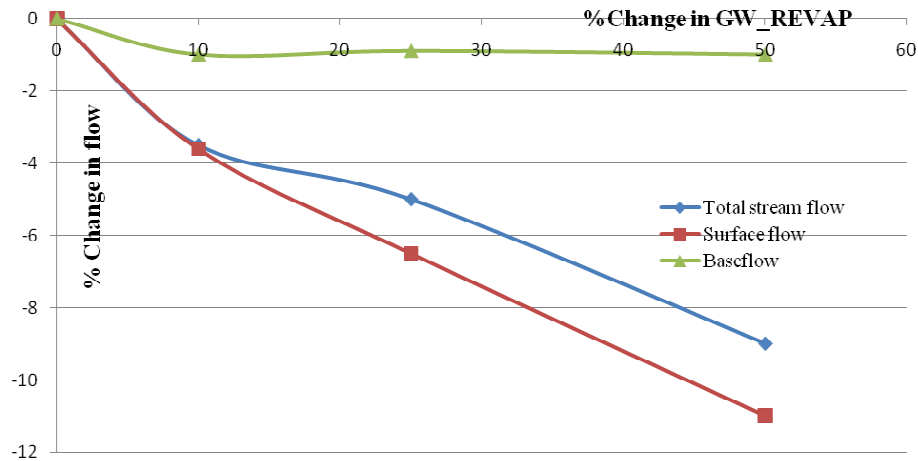
Fig. 5. Effects of changing GW_REVAP on simulated stream flow.
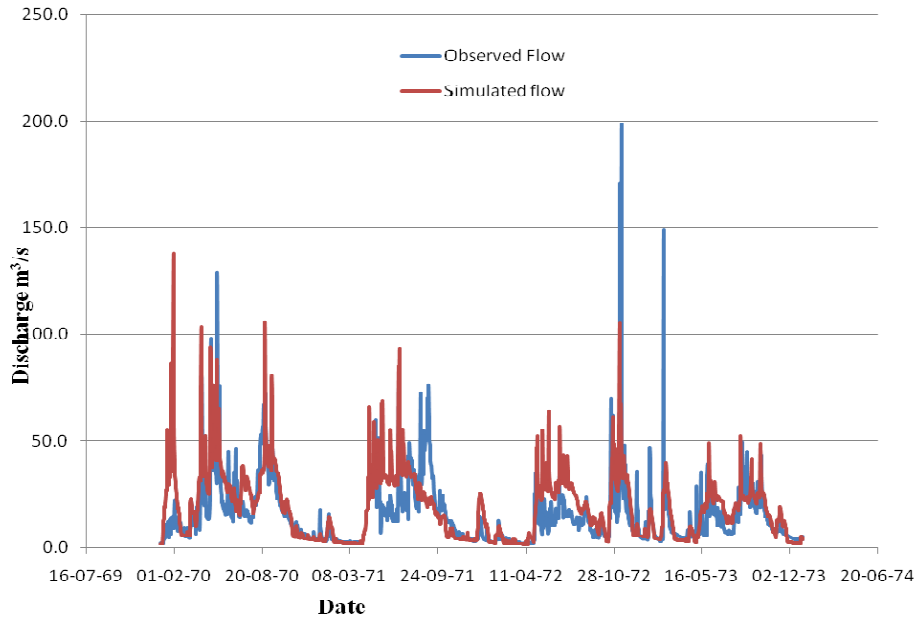
Fig. 6. Calibrated hydrograph for 1GD03 for the period (1970–1973).