*Research article*

# Impacts of Land Use-Land Cover Changes on Streamflow and Water Balance of Stung Sangkae Catchment Using SWAT

**NARETH NUT***
*Faculty of Agricultural Engineering, Royal University of Agriculture, Phnom Penh, Cambodia*
*Email: nnareth@rua.edu.kh*

**MACHITO MIHARA**
*Faculty of Regional Environment Science, Tokyo University of Agriculture, Tokyo, Japan*

**JAEHAK JEONG**
*Blackland Research & Extension Center, Texas, USA*

**BUNTHAN NGO**
*Royal University of Agriculture, Phnom Penh, Cambodia*

**SAKDANUPHOL CHAN**
*Faculty of Agricultural Engineering, Royal University of Agriculture, Phnom Penh, Cambodia*

**GILBERT SIGUA**
*United States Department of Agriculture, Agriculture Research Service,*
*Coastal Plains Research Center, South Carolina, USA*

**MANUEL R. REYES**
*Sustainable Intensification Innovation Lab., Kansas State University, Kansas, USA*

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**Abstract** Land use-land cover changes (LULCC) brought by increasing population and food demand could affect not only the fluxes of water, sediment, contaminants and energy, but also ecological, physical and socioeconomic aspects in the environment. In this study, the Soil and Water Assessment Tool (SWAT) model was used to examine the effects of LULCC on hydrological processes of Stung Sangkae catchment in Tonle Sap Basin, Cambodia. The performance of the model was evaluated through uncertainty sensitivity analysis, calibration, and validation. The time series of LULCC were used to estimate the streamflow and the water balance in the catchment based on five interval years (1998, 2003, 2008, 2013, and 2018). From 1998 to 2018, the coverages of forest land, wetland, and the paddy rice decreased by 5.1%, 1.4%, and 1.2%, respectively. The forest land and wetland were converted into cultivated land with an increase of about 7.6% over the study periods. These changes resulted in significant variations of water balance (2000-2018) namely: i) an increase of average annual surface runoff (SURFQ) by 10 mm; ii) 3 mm reduction of the average annual lateral flow (LATQ); iii) 6.2 mm reduction of the average annual groundwater (GW); iv) reduction of the average annual evapotranspiration (ET) by 0.97 mm; and v) an increase of average annual water yield by 0.9 mm. On a monthly basis, the model results had shown a reasonable agreement with the observed values as shown by the coefficient of determination ($R^2$) = 0.41, Nash Sutcliff efficiency (NSE) = 0.40, and percent of bias (PBIAS) = 0.34. Based on the validated water discharge and water balance results in 2018, LULCC have impacted the environmental sustainability, especially the streamflow that caused flooding at the downstream watershed due to decline in forest cover at the watershed.

**Keywords** land use-land cover, Stung Sangkae Catchment, streamflow, SWAT model, water balance

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## INTRODUCTION

In Cambodia, the annual increase of population is always followed by the increasing demand for land, food, housing, and other social needs of the people. In Battambang, Cambodia in 2005, the total population of the province was 952,306 (185,868 families) and increased to 1,066,928 (205,351 families) in 2018 (NCDD, 2010). Several studies have shown that the land changes caused by the increase of urbanization, agricultural activities, and devastation of forest area have caused wide changes of streamflow and water balance in the watershed. As expected, there will be shortage of water due to the increase in water demand for all types of land use activities. However, the knowledge of the effects of LULCC on various hydrological processes of Stung Sangkae catchment in Tonle Sap Basin is not well understood. Additionally, the impact of LULCC on the streamflow and the water balance in the catchment, where the research is targeted to create accessibility of important information of water resources for sustainable resources management is not yet fully identified. Since 2005, people have cleared forested areas to cultivate maize and/or cassava. Most of these products are being exported to Thailand. Over time, newly cleared land would require more and more fertilizer to improve land productivity and this activity may contribute to degradation of water resources due to eutrophication if no countermeasures are taken properly. Currently, an estimated 191,492 ha of forest cover is left, of which 150,992 ha is under the forestry administration’s management and 40,000 ha is under the provincial department of the environment. However, protected areas are increasingly under threat from land encroachment for large-scale agricultural land development (Sotheary, 2015).

As described above, the streamflow and water balance such as the surface runoff and groundwater are being affected by LULCC. Despite progress in assessing and projecting LULCC impacts, vulnerability and adaptation studies in Cambodia is still failing to provide sufficient understanding of existing vulnerabilities, thereby constraining mitigation responses, current and projected risks in constantly changing contexts. Building resilience to LULCC variability, understanding the hydrology-sensitive linkages between sectors and promoting sustainable development and integrated hydrological cycle risk management require policies and plans that are informed by scientific evidence.

To address the potential impacts of LULCC on hydrology and water balance, the Soil and Water Assessment Tool (SWAT) model was used in Stung Sangkae catchment. Although, nowadays, there are many hydrological models to help calculate the water discharge more accurately, easily and quickly than the traditional measurement method, SWAT was proven to be quite effective. Soil and Water Assessment Tool model, is a basin-scale model integrated with ArcGIS to help improve the accuracy of the simulated result of streamflow from rainfall and physical properties of the basin. As mentioned earlier, SWAT model has a good reputation for best use in agricultural watersheds and its uses have been successfully calibrated and validated in many areas around the world (Ang and Oeurng, 2018; Gassman et al., 2007). It has the most comprehensive literature database of 4200 articles compiled by the Center for Agriculture and Rural Development, Iowa State University (CARD-ISU, 2020).

## OBJECTIVES

The objective of this research was to evaluate the impacts of LULCC on streamflow, surface runoff (SURFQ), lateral flow (LATQ), ground water (GW), evaporation and transpiration (ET) and water yield in Stung Sangkae catchment in Tonle Sap Basin, Cambodia (Fig. 1).

## METHODOLOGY

### Site Description

This study was carried out in Stung Sangkae catchment containing the Tonle Sap Lake. This lake is the greatest lake in South East Asia and one of the world richest biodiversity located in the North-

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western part of Cambodia (Fig. 1). Stung Sangkae catchment is the third largest of Tonle Sap Basin river system with an area of 6,051 km$^2$. Stung Sangkae River is one of the key sources of water in Battambang, Cambodia. The natural habitats of this region form a complex network of interconnected landscapes and watersheds that provides important ecosystem services to the region (Killeen, 2012). The majority of the catchment area is mostly lowlands with elevations of less than 100 m above the mean sea level, and with gentle slopes. There are six (6) main soil types within the catchment area and 13 land uses. Of the 13 land uses, 25% are planted with annual crops such as cassava (*Manihot esculenta* L.), corn (*Zea mays* L.), sugarcane (*Saccharum officinarum* L.) etc. and 24% is under rice production. Battambang Province receives most of its rainfall during the southwest monsoon from May to November, as most of the regions in Cambodia. According to the Mekong River Commission in 2008, long-term rainfall between 1920 and 2004, with 60 years of complete data, averaged 1,318 mm/year. Typically, there is very little rainfall from December to March (on average 5.6% of the annual total), and because of high temperatures and evaporation rates through May, there is usually little standing water in most paddy fields until June.

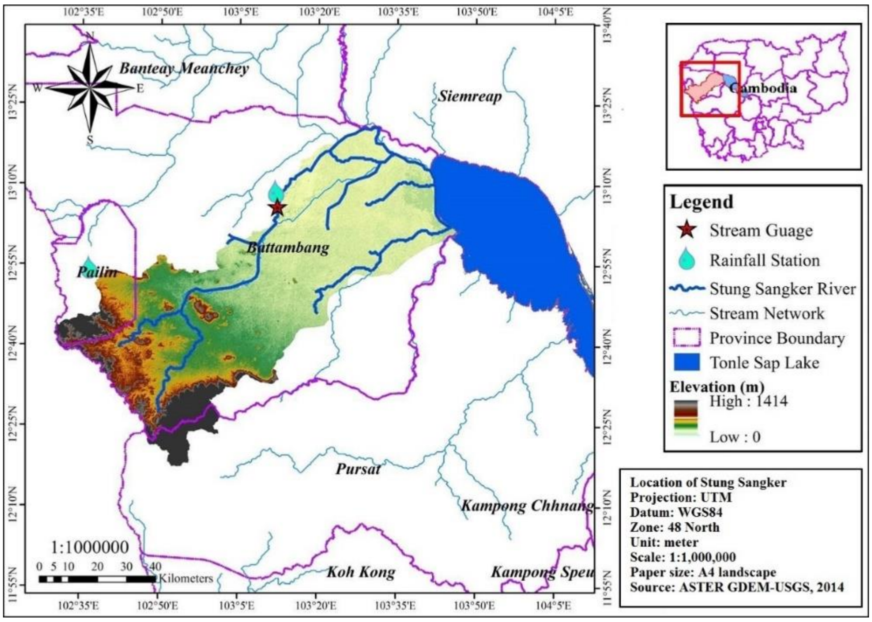


**Fig. 1 A map of Stung Sangkae catchment showing the Great Lake, stream gauge and rainfall stations with a background of 30 m resolution DEM**

## SWAT Modeling

Soil and Water Assessment Tool is a physically based semi-distributed continuous time model developed by United States Department of Agriculture-Agricultural Research Service (USDA-ARS) (Arnold et al., 1998). Soil and Water Assessment Tool can be operated to estimate, predict, and assess the effects of soil characteristics, land management, and climate change on water resource, sediment, nutrient cycling and crop growth in the enormous complicated watersheds (Neitsch et al., 2002). Soil and Water Assessment Tool model simulates various hydrologic processes, including surface runoff calculation, using either Natural Resources Conservation Service curve number method or the Green and Ampt infiltration equation. For the quantification of evapotranspiration, SWAT model offers several approaches such as, Pristley-Taylor, Hargreaves, or Penman-Monteith methods. Groundwater flow, lateral flow and percolation are assessed through mass balance of the underlying system (Anand et al., 2018).

In this research, the required input data of SWAT model in Stung Sangkae catchment were collected from different sources both locally and globally. A digital elevation model (DEM) with a 30 m resolution was retrieved from the Shuttle Radar Topography Mission (SRTM). Stream/river in 2010 and administrative province/district in 2014 data obtained from the open source site at www.opendevelopmentcambodia.net. A land use-land cover map was developed by the SERVIR Mekong from 1998 to 2018 based on satellite imagery. A soils map of 16 soil types developed by Crocker in 1962 and was classified based on the FAO/UNESCO in 1984 with the classification up to two levels (0-30 cm and 30-100 cm) were utilized during the simulation process. Rainfall data (1995–2018) were obtained from Department of Meteorology (DoM) of Ministry of Water Resources and Meteorology (MoWRAM) and satellite image from bias correction. Daily and monthly streamflow data (2000–2018) were obtained from Department of Hydrology and River Work (DHRW) of Ministry of Water Resources and Meteorology (MoWRAW).

For a better estimation of model parameters in order to simulate the streamflow to match the observed value, the model was calibrated manually by adjusting several default parameters. We calibrated daily streamflow from 2000 to 2010 with a basis of LULCC from SERVIR-Mekong in 2003, where the simulation period between 1995 and 1999 serving as the warm-up period. Then the model with modified parameters is validated by running different time period to ascertain model consistency between the observed and simulated values. In the study, we validated daily streamflow from 2011 to 2018 with a basis of LULC from SERVIR-Mekong in 2003. After the evaluation of SWAT model rating, we modified different LULCC layers (1998, 2008, 2013, and 2018) as an input parameter. All simulated results from calibration and validation were evaluated by three quantitative statistics: i) Coefficient of determination ($R^2$); ii) Nash-Sutcliffe efficiency (NSE); and iii) Percent Bias (PBIAS).

## RESULTS AND DISCUSSION

### LULC Change Analysis

Table 1 summarized the relative areas of each land use class for the years 1998, 2003, 2008, 2013 and 2018. The result has shown that during the study period (1998-2018), the forest land, wetland, and paddy rice has decreased by 5.10%, 1.44%, and 1.20%, respectively. These land uses were converted into cultivated land with an increase of the agricultural land by 7.60%. The changes in various land uses was due to increasing human influence through the development of urban area and the process of industrialization and modernization.

**Table 1 Summary of LULC change in Stung Sangkae catchment from 1998 to 2018 (%)**

| LULC | 1998 | 2003 | 2008 | 2013 | 2018 | Change |
|---|---|---|---|---|---|---|
| Agricultural land (AGRR,ORCD) | 45.60 | 47.62 | 47.29 | 48.07 | 53.20 | 7.60 |
| Forest (FRSD,FRSE,FRST) | 23.83 | 20.74 | 20.62 | 20.43 | 18.74 | -5.10 |
| Wetland Forest (WETF,WETL,WETN) | 25.33 | 24.44 | 24.22 | 23.99 | 23.89 | -1.44 |
| Rice (RICE) | 5.02 | 6.97 | 7.63 | 7.25 | 3.82 | -1.20 |

### Model Sensitivity Analysis

In the study, we analyzed the five most sensitive parameters which influenced water quantity in Stung Sangkae catchment namely: 1) Manning's "n" (CH_N2); 2) Effective hydraulic conductivity (CH_K2); 3) Groundwater delay (GW_DELAY); 4) Threshold water depth in the shallow aquifer for return flow (GWQMN); and 5) Threshold water depth in the shallow aquifer for "revap" (REVAPMN). The fitted value of model parameters was illustrated in Table 2. Sensitivity analysis of different parameters was performed for streamflow.

### Impact of LULCC on Streamflow

The model was calibrated for the 2000–2010 period, while the validation period was done from 2011 to 2018. The model performance was reasonably good with limited rainfall data as shown in Table 3. Fig. 2 presented the simulation results of LULCC in 1998, 2003, 2008, 2013 and 2018 about streamflow.

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Results of the simulation LULCC were not significantly different. However, the result of streamflow has increased with the range from 1.6 $m^3/s$ to 781 $m^3/s$ due to the loss of forestland converted into the agricultural land. Several simulation studies revealed that LULCC due to deforestation have increased the mean annual streamflow (Anand et al., 2018; Oeurng et al., 2019; Quyen et al., 2014).

**Table 2 Parameters use for calibration and validation**

| Parameter | Definition | Default range | Fitted value |
|---|---|---|---|
| CH_N2 | Manning's "n" value for the main channel | -0.01–0.3 | 0.22 |
| CH_K2 | Effective hydraulic conductivity in the main channel alluvium (mm/h) | 0–500 | 5 |
| GW_DELAY | Groundwater delay (days) | 0–500 | 40 |
| GWQMN | Threshold depth of water in the shallow aquifer required for return flow to occur (mm $H_2O$) | 0–5000 | 1500 |
| REVAPMN | Threshold water depth in the shallow aquifer for "revap" ( mm ) | 0–500 | 500 |

**Table 3 Summary result of model performance efficiency evaluation of the monthly stream flow for Stung Sangkae catchment**

| | Calibration (2000-2010) | | | | | Validation (2011-2018) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | A basis of LULC from SERVIR-Mekong | | | | | | | | | |
| | 1998 | 2003 | 2008 | 2013 | 2018 | 1998 | 2003 | 2008 | 2013 | 2018 |
| $R^2$ | 0.40 | 0.41 | 0.41 | 0.41 | 0.41 | 0.28 | 0.28 | 0.28 | 0.28 | 0.28 |
| NSE | 0.40 | 0.40 | 0.40 | 0.41 | 0.40 | 0.21 | 0.22 | 0.22 | 0.22 | 0.21 |
| PBIAS | 1.06 | 0.34 | -0.19 | -0.60 | 0.88 | 31.24 | 30.52 | 30.05 | 29.73 | 31.10 |

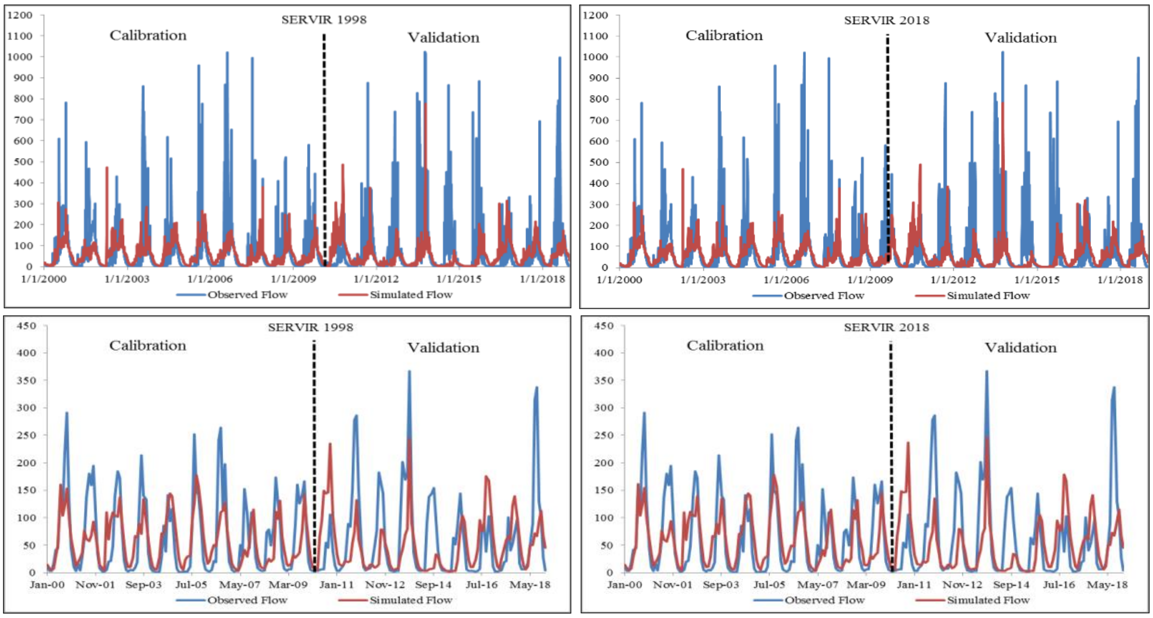


**Fig. 2 Daily and monthly streamflow (cm) in calibration and validation periods**

## Impact of LULCC on Water Balance

Due to LULCC from 1998 to 2018, the average annual change in SURFQ, LATQ, GW, ET and water yield was approximately 277 mm, 77 mm, 297 mm, 764 mm, and 668 mm, respectively. Fig. 3 presented the spatial distribution of water balance in Stung Sangkae catchment under the gauging station. The water yield and the surface runoff came to catchment has increased by 0.9 mm and 10

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mm, respectively; the lateral flow, the ground water and the evapotranspiration has declined by 3 mm, 6.2 mm, and 0.97 mm, respectively. Moreover, the changes shown in Fig. 3, in terms of the different hydrologic components such as surface runoff, water yield, and ET were in agreement with the results reported by other researchers (Anand et al., 2018; Dey and Mishra, 2017; Kundu et al., 2017; Remondi et al., 2016; Wagner et al., 2017). However, we noted that the impacts of LULCC on the water balance varied significantly for each sub-basin due to urbanization. Our results were similar to several studies that investigated the correlation between urbanization and the water balance in tropical regions (Anand et al., 2018; Gumindoga et al., 2014; Remondi et al., 2016; Wagner et al., 2013).

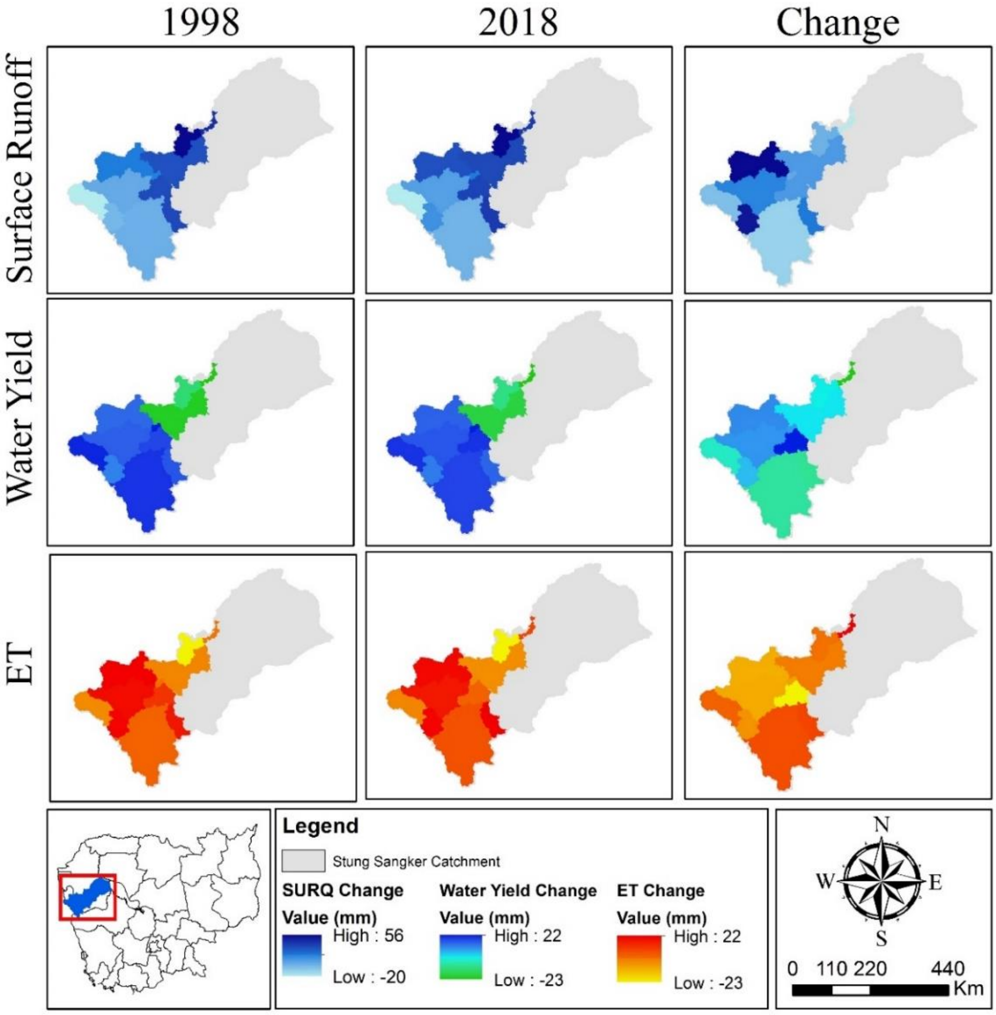


**Fig. 3 Change in water balance from 1998 to 2018 for Stung Sangkae catchment**

## CONCLUSION

Based on the LULCC data provided by SERVIR Mekong, results showed that from 1998 to 2018, the forest land, wetland, and paddy rice had decreased by 5.10%, 1.44%, and 1.20%, respectively. These led to the increase of agricultural land by 7.6%. This increase in agricultural land resulted in the increase of average annual surface runoff (SURFQ) by 10 mm, reduction of 3 mm in the average annual lateral flow (LATQ), reduction of the average annual ground water (GW) by 6.2 mm, decrease of 0.97 mm in average annual evapotranspiration (ET), and an increase of average annual water yield by 0.9 mm. Moreover, the model captured a reasonable agreement with the observed values in monthly basis. Based on the validated water discharge and water balance results in 2018, LULCC have impacted the environmental sustainability, especially the streamflow that caused flooding at the downstream watershed due to declined forest cover at the watershed.

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