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# Evaluation of Land Development Impact on a tropical Watershed Hydrology Using Remote Sensing and GIS

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**Abstract**

Understanding how the land use change influence the river basin hydrology will enable planners to formulate policies to minimize the undesirable effects of future land use changes. Land cover changes increase impervious ground surfaces, decrease infiltration rate and increase runoff rate, hence causing low base flow during the dry seasons. Efficient tools such as satellite remote sensing and Geographic Information System (GIS) are currently being used to manage the limited water resources. The need for spatial and temporal land-cover change detection at a larger scale makes satellite imagery the most cost effective, efficient and reliable source of data. The ability of GIS makes it an important and efficient tool for spatial hydrologic modeling. In this study, Satellite data and GIS were integrated with a spatial hydrological model to evaluate the impacts of land development in the Upper Bernam River Basin of Malaysia. HEC-1 (Hydrologic Engineering Center) model was calibrated and validated using actual flow data from the outlet of the watershed. The model performance was checked by means of four criteria viz., mean absolute error (MAE), root mean square error (RMSE), Theil's coefficient (U) and coefficient of determination ($R^2$) obtaining values of 0.14, 0.18, 0.097, and 0.86, respectively. From the hydrographs, it was found that the change in peak flow between the years 1989 and 1993 was 28% while it was 11% between the years 1993 -1995. The reduction of the time to peak was 7% for the same years. The model can be run for any future land development plans to investigate the hydrological impacts in order to avoid the shortage of irrigation water and mitigate the risk of floods occurrence.

Keywords: Land Development, runoff, HEC, Water Resources, GIS, Remote Sensing.

## 1. Introduction

Land use change is an important characteristic in the runoff process that affects infiltration, erosion, and evapotranspiration. Due to rapid development, land cover is subjected to changes causing many soils to become impervious surfaces. This lead to decrease in the soil infiltration rate and consequently increase the amount and rate of runoff. Deforestation, urbanization, and other land-use activities can significantly alter the seasonal and annual distribution of stream flow (Dunne 1978). Understanding how these activities influence stream flow will enable planners to formulate policies towards minimizing the undesirable effects of future land-use changes on

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stream flow pattern. This is critical even in high rainfall areas like Malaysia, especially if there is no reservoir for irrigation water supply during the dry season such as in the Tanjong karang Rice Irrigation Scheme. Although rainfall is sufficient to meet the water demand of crops, its spatial and temporal distribution makes rainfed farming a risky proposition. Excess water available during part of the growing season may be unavailable at critical crop growth stage. Hence, there is a need to investigate the relationship between the landuse change and the stream flow regime.

With rapid developments, water resources become an important commodity that every sector is competing for. However, being an agricultural based nation, the government has set a 65% self sufficiency in rice production. The required quality and quantity of irrigation water for double cropping of rice must be made available at all time.  The problem of dry season flow reduction can only be approached from a whole-watershed perspective with improved water management tools based on sound scientific principles and efficient technologies.

Hydrological modeling is a powerful technique of hydrological system investigation for both the research hydrologist and practicing water resources engineers involved in the planning and development of integrated approach for the management of water resources (Seth et al., 1999). With advances in computational power and the growing availability of spatial data, it is possible to accurately describe watershed characteristics when determining runoff response to rainfall input (Arwa, 2001). With the development of geographic information system (GIS) and remote sensing techniques, the hydrological catchments models have been more physically based and distributed to enumerate various interactive hydrological processes considering spatial heterogeneity (Mohan and Shrestha 2000).

Hydrological models, distributed models in particular, need specific data on land use and soil types and their locations within the basin. The conventional methods of detecting land use changes are costly and low in accuracy. Remote sensing technique, because of its capability of synoptic viewing and repetitive coverage provides useful information on land use dynamics. It can provide a measurement of many hydrological variables used in hydrological and environmental model applications comparable to traditional forms of land use data collection. GIS as a computer-based tool that displays, stores, analyzes, retrieves and generates spatial and non-spatial (attribute) data provides suitable alternatives for efficient management of large and complex databases. It can be used in the hydrologic modeling to facilitate the processing, managing and interpretation of hydrological data.

Remote sensing data and geographic information system is increasingly becoming an important tool in hydrology and water resources development. This is due to the fact that most of the data required for hydrological analysis can easily be obtained from remotely sensed images. The greatest advantage of using remotely sensed data for hydrological modeling is its ability to generate information in spatial and temporal domain which is very crucial for successful model analysis, prediction and validation (Jagadeesha 1999). The changes in land use due to natural and human activities can be observed using current and archived remotely sensed data.

The HEC-1 model was used to simulate the surface runoff response of a river basin to precipitation by representing the basin as an interconnected system of hydrologic and hydraulic components. Each component models an aspect of the precipitation-runoff process within a portion of the basin, commonly referred to as a sub-basin. A component may represent a surface runoff entity, a stream channel, or a reservoir. Representation of a component requires a set of parameters which specify the particular characteristics of the component and mathematical relations which describe the physical processes. The result of the modeling process is the computation of stream flow hydrographs at desired locations in the river basin. A river basin is represented as an interconnected group of sub basins. The assumption is made that the hydrologic processes can be represented by model parameters which reflect average conditions within a sub area. If such averages are inappropriate for a sub area then it would be necessary to consider smaller sub areas within which the average parameters do apply. Model parameters represent temporal as well as spatial averages. Thus the time interval to be used should be small enough such that averages over the computation interval are applicable (HEC-1 1998).

The model component functions are based on simple mathematical relationships which are intended to represent individual meteorological, hydrologic and hydraulic processes. These processes are separated into precipitation, interception/infiltration, transformation of precipitation excess to sub basin outflow, addition of base flow and flood hydrograph routing.

Land surface interception, depression storage and infiltration are referred as precipitation losses in the HEC-1 model. Interception and depression storage are intended to represent the surface storage of water by trees or grass, local depressions in the ground surface, in cracks and crevices in parking lots or roofs, or in a surface area where water is not free to move as overland flow. Infiltration represents the movement of water to areas beneath the land surface.

Although originally Soil Conservation Service –Curve Number (SCS-CN) method (USDA 1985) was developed for agricultural purpose, the method has been expanded for use in urban and suburban areas. The method is attractive as the major input parameters are defined in terms of land use and soil type. The advantage of this method is that the user can experiment with changes in land use and assess their impacts. The objective of this work is to develop a methodology to evaluate the impacts of land use change on a tropical watershed using remote sensing and GIS as tools to perform the evaluation.

## 2. Methodology

The method to evaluate the hydrological impacts due to land use modifications can be achieved through integrating remote sensing, GIS and HEC-1 Model. This study was conducted in a 200 $km^2$ tropical watershed located in northern east part of Selangor state, Malaysia, between $3^0$ 36' 23'' to $3^0$ 47' 55'' North and $101^0$ 30' 53'' to $101^0$ 39' 33'' East. The area is characterized by high temperature and high humidity with relatively small seasonal variation. The mean relative humidity is 77%, while the minimum and maximum temperatures are $26^0$C and $32^0$C respectively. The average rainfall ranges from 2000 mm to 3500 mm. The mean annual evaporation ranges from 1200 mm to 1650 mm, and the average daily sunshine hour is 6.2 hours. The wind is calm for most of the year; the average daily wind speed is 1.03 m/s. Six soil series are found within the study area. The dominant vegetation cover in the river basin consists of tropical hill rainforests, oil palm and rubber. Other land covers that can be found are few small or medium sized urbanized built up areas especially the along river banks and roadsides. The main tributaries of the river are Bernam and Inki Rivers.

A contour map of scale 1:25000 for the year 1995 obtained from Department of Surveying and Mapping Malaysia was used to perform the Digital Elevation Model (DEM). Topographic ParameteriZation (TOPAZ) (Martz and Garbrecht, 1992) computer program was run to create the flow directions and flow accumulation files which were used later to delineate the basin and sub basins boundary and the stream networks. The river basin was divided into 10 sub basins. DEM was also used to compute the geometric values of the basin such as areas, slopes, stream lengths, etc.

Earth Resources Data Analysis System (ERDAS IMAGINE 4.8) (ERDAS 1999) software was used to process the LANDSAT satellite images path/row 127/57 of 30 meter resolution for the years 1989, 1993 and 1995. The images were enhanced, registered, and classified into different land use types using supervised classification. The false color composite was used for the visual examination and interpretation. The training signatures to perform this classification were selected from hard copy maps. In areas where there was no distinct spectral signature within the land cover types as a result of mixed pixels the ground truth data was used and on screen digitizing technique applied to clearly demarcate the classes.

The State based soil map of scale 1:25000 was converted to digital format using on screen digitizing approach, the map registered to a real world location and projection using control points. The soil series were classified to hydrological soil groups (A, B, C and D) based on the physical soil characteristics following the USDA (1985) method. The USDA (1985) method classifies the soils into four hydrological groups based on the physical properties of the soils. These groups can be defined as: Group (A) is characterized by lowest runoff potential. This group includes the deep sands with very little silt and clays and the deep rapidly permeable soil. The final infiltration rate for this group ranges from 8 to12 mm/hr. Group (B) is characterized by moderately low runoff potential, mostly sandy soils less deep than A, and less deep or less aggregated than A, but the group as a whole has above average infiltration through wetting. The final infiltration ranges from 4 to 8 mm/hr. Group (C) is characterized by moderately high runoff potential, comprises shallow soils and soils containing considerable clay and colloids, though less than those of group D. The group has below average Infiltration after pre-saturation, the final infiltration rate ranges from 1 to 4 mm/hr. Group (D) has the highest runoff potential, includes mostly clays of high swelling percent, but the group also includes some shallow soils with nearly impermeable sub-horizons near the surface. The final infiltration rates range from 0 to 1 mm/hr.

Daily and hourly rainfall data from ten rain gages were analyzed for the years 1960 to 2002 in addition to hourly and daily runoff data from the outlet point for the same years. The average rainfall depths were computed for each sub basin by applying the Thiessen polygon technique. In this method the total storm precipitation for a sub basin was computed as the weighted average. The daily and hourly flow data from the outlet point were used to create the runoff hydrographs for the calibration and validation purposes.

HEC-1 model (HEC-1, 1998) was used to simulate the rainfall-runoff process. The model components function based on simple mathematical relationships, which comprise the precipitation-runoff process. To estimate the losses in the rainfall runoff process the Soil Conservation Services Curve Number (SCS-CN) method was selected (HEC, 1981). This method relates soil group type to the CN as a function of soil cover and antecedent moisture conditions of the basin (AMC) (Table 1).

**Table 1: Classification of antecedent moisture conditions**

| AMC Total 5-days antecedent rainfall (mm), SCS, 1986 | | |
|---|---|---|
| AMC | Dormant season | Growing season |
| I | <12.7 | <35.6 |
| II | 12.7-27.9 | 35.6-53.3 |
| III | >27.9 | >53.3 |

Precipitation loss was calculated based on CN and initial surface moisture storage capacity as shown in Equations 1. The standard SCS-CN method is based on the relationship between rainfall depth, *P* in millimetres, and runoff depth, *Q* in millimetres.

$$Q = \frac{(P - 0.2S)^2}{(P + 0.8S)} \quad \text{.......................................} (1)$$

The potential maximum retention, *S* in millimetres, represents an upper limit of the amount of water that can be abstracted by the watershed through surface storage, infiltration, and other hydrologic abstractions. For convenience, *S* is expressed in terms of a curve number (Equation 2).

$$S = \frac{25400}{CN} - 254 \quad \text{..........................................} (2)$$

HEC-1 generates runoff hydrograph which composed of direct runoff and base flow resulting from releases of water from sub surface storage. In order to calibrate the Rainfall-Runoff model of the study area, the base flow was added to the simulated hydrograph. These results were used in the model calibration by fitting the simulated hydrograph to the measured flow's hydrograph at station No. 3615412 which represents the outlet of the watershed.

The model was run using total rainfall event of 66.7 mm for 3 June 1989. The flow from sub basin outlets was routed to the watershed outlet using Maskingum method (Corps of Engineers, 1960) which computes the outflow from a reach using Equations 3, 4 and 5. For the purpose of calibration and validation the hourly means discharge ($m^3$/s) from station No. 3615412 was used to calibrate the model and routing parameters to fit the simulated hydrograph to the observed one.

$$Q_{OUT(2)} = (CA - CB) * Q_{IN(1)} + (1 - CA) * Q_{OUT(1)} + CB * Q_{IN(2)} \quad \text{.................. (3)}$$

$$CA = \frac{2 * \Delta t}{2 * AMSKK * (1 - X) + \Delta t} \quad \text{........... (4)}$$

$$CB = \frac{\Delta t - 2 * AMSKK * X}{2 * AMSKK * (1 - X) + \Delta t} \quad \text{................... (5)}$$

where $Q_{IN}$ is the inflow to the routing reach in $m^3$/sec, $Q_{OUT}$ is the outflow from the routing reach in $m^3$/sec, *AMSKK* is the travel time through the reach in hours, *X* is the Muskingum weighting factor ($0 \le X \le 0.5$).

To quantify the change in runoff due to land use modification, the rainfall which occurred before land use modification was assumed to occur after the land use modification. The changes in peak flow and time to peak which can be determined from the hydrographs generated by the model were used as indicators to estimate the hydrological effects due to land use change.

## 3. Results and discussion

In this study the precipitation loss was computed by using the unit hydrograph method, in which the precipitation loss is considered to be a sub basin average (uniformly distributed over an entire sub basin). There are many methods to calculate the rainfall losses, among these the Soil Conservation Services Curve Number (SCS-CN) method was selected for this study because it relates the precipitation losses to the land use and soil type. Hence the impact of land use change can be reflected on the amount and distribution of the predicted runoff which can be observed from the hydrograph shape.

### 3.1 Land-cover and Hydrologic soil group (HSG) classification

Determination of CN requires land use, soil type and AMC information. The potential of deriving land use maps from satellite images is one of the main features of this study. Land use from large areas can be detected easily in a short time with low cost compared to the traditional methods. Five types of land use were identified in the study area, namely forest, rubber, oil palm, built-up areas and tin-mining areas with average classification accuracy of 90%. The classified thematic raster maps were vectorized and converted to land use shape file maps using ARCVIEW 8.3 (Figures 1a and 1b). Figure 2 shows the classification of the soils into different HSG found in the study area.

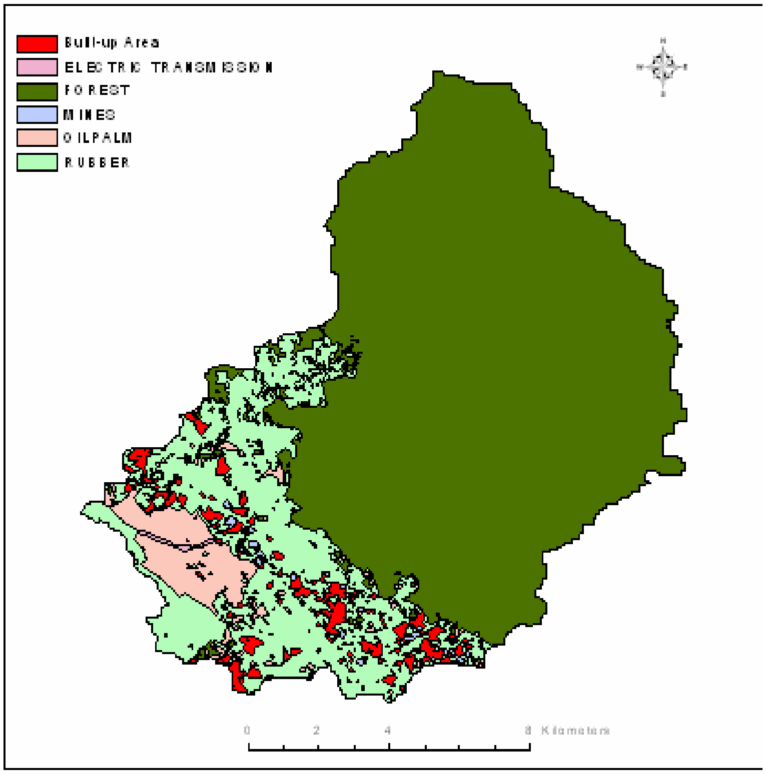


**Figure 1a: Landuse map for the year 1989**

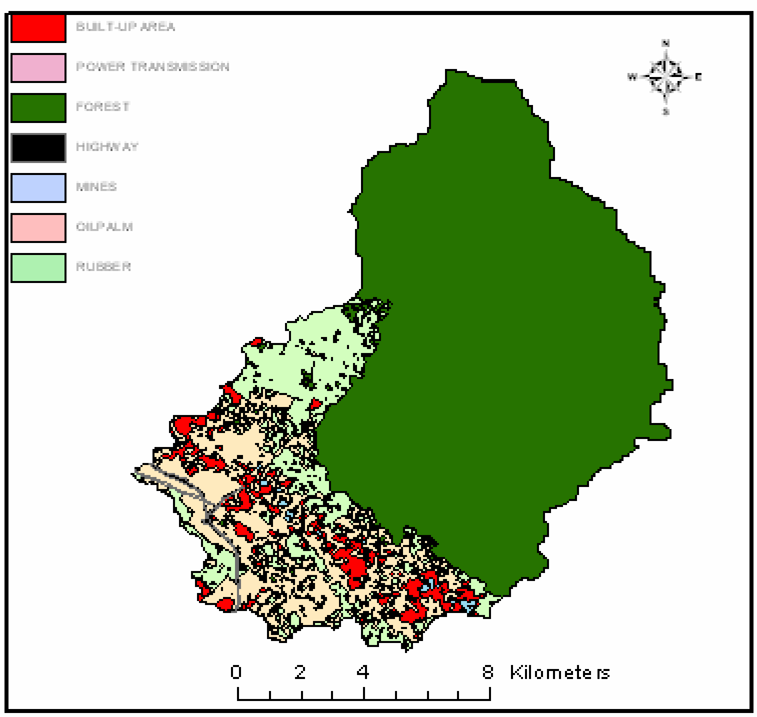


**Figure1b: Landuse map for the year 2001**

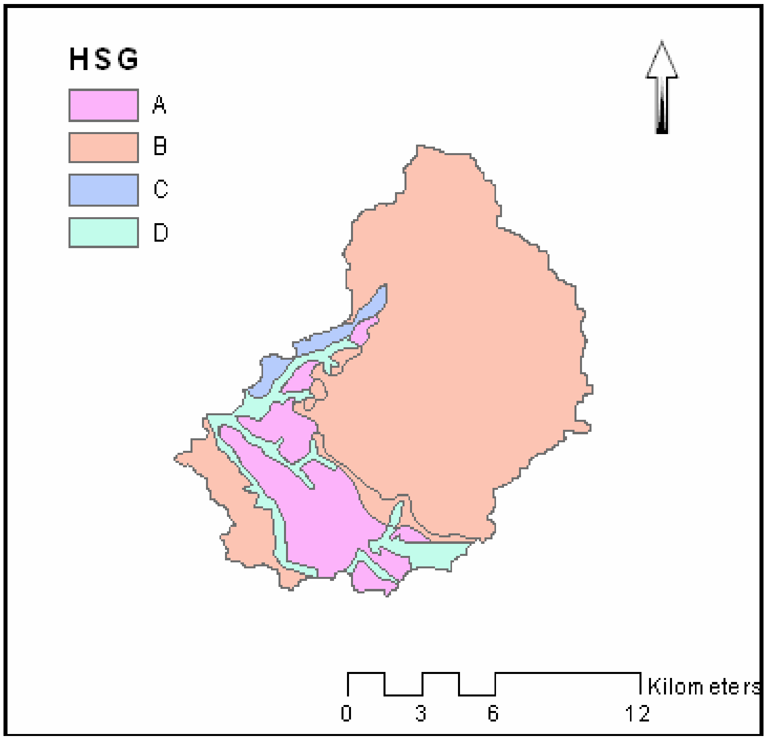


**Figure 2: Hydrological soil groups (HSG)**

### 3.3 Geographic Information System (GIS) Applications

Overlaying layers of information is one of the most basic and powerful GIS operations for manipulating spatial data and for hydrologic modeling. Overlaying produce specific hydrologic parameters like curve number which is derived by overlaying a landuse and soil coverage with the drainage coverage. Using Overlaying process the landuse was overlaid with the drainage map. The percentage of the landuse type covering the basins was obtained and hence the change in the landuse for each basin can be detected (Table 2).

**Table 2: Percentage of landuse areas**

| Landuse | 1989 | 1993 | 1995 |
|---|---|---|---|
| Built-up area | 3.3 | 3.9 | 4.8 |
| Oil palm trees | 4.9 | 8.6 | 9.7 |
| Rubber trees | 21.5 | 18.9 | 16.9 |
| Forest | 69.9 | 68.2 | 68.2 |
| Tin mining area | 0.4 | 0.4 | 0.4 |

To assess the hydrologic response of the sub-basins as a result of land-use change using the Curve Number technique, soils GIS layer showing hydrologic soil groups (HSG) were prepared through scanning, geo-referencing and digitizing the hard copy maps. Four HSG found in the study area covers 15%, 75%, 2% and 8% for the groups A, B, C and D, respectively (Figure 2). Vector layer of the HSG was mapped for spatial overlay of the data with that of the land-cover information. GIS was used to combine the data from remote sensing with other spatial data forms such as topography, soils maps and hydrologic variables such as rainfall distribution and soil moisture. The landuse maps and HSG map were overlaid. The composite CNs for each basin was computed by taking an area-weighted average of the different curve numbers for the different regions (soil type and land use combinations) within a basin. The CNs were determined for each sub basin and adjusted according to the AMC levels. The AMC was determined by taking the total rainfall amount for the 5 previous days of certain event as shown in Table 1. The values for the weighted CN as per AMCs were 40, 59.5 and 78 for the AMC I, II, and III, respectively for the year 1989.

### 3.4 Watershed delineation

Delineation of watersheds from Digital Elevation model (DEM) data has become standardized on the eight-direction pour point model. Each cell is connected to one of its eight neighboring cells according to the direction of steepest descent. Given an elevation grid, a grid of flow direction is constructed and from this is derived a grid of flow accumulation, counting the number of cells upstream of a given cell. Streams are identified as lines of cells whose flow accumulation exceeds a specified number of cells and thus a specified upstream drainage area (Maidment, 1996).

The digital contour map for the study area was processed through the Watershed Modeling System (WMS 7.0) software, developed by Brigham Young University USA, (2004). The Triangulated Irregular Networks (TIN) was derived from the contour map. DEM was derived from the TIN with a 30m×30m cell size. DEM was used to determine the hydrological parameters of the watershed such as slope, flow accumulation, flow direction, drainage area delineation and stream network. To generate flow direction, flow accumulation and stream network, a custom version of the TOPAZ model distributed with WMS was used. With the aid of the flow accumulations, the location of the watershed outlet was determined and an outlet feature point was created. To delineate the sub-basins, 9 outlet points were created based on the uniformity of the sub-basins in the land use type, soil type and slope ranges. Basins and sub basins were defined and converted to feature polygons. The largest sub- basin area is 74.48 $km^2$ while the smallest sub-basin area is 5.99 $km^2$. These parameters were later used to develop spatially distributed direct runoff hydrographs.

### 3.5 HEC-1 model results

Lag time is a variable often used when computing surface runoff using unit hydrograph method. This variable indicates the response time at the outlet of a watershed for a rainfall event, and is primarily a function of the geometry of the basin. The most commonly used method for lag time determination, the SCS method was used to estimate the lag time for the different sub basins based on the basin geometry. Lag time of 1.17 and 0.78 hours were obtained for the largest and smallest sub- basin, respectively.

Flood routing was used to simulate flood wave movement through river reaches and reservoirs. Most of the flood routing methods available in HEC-1 are based on the continuity equation and some relationship between flow and storage or stage. Based on Equations 3, 4 and 5, the

Muskingum routing method was used to compute outflows from the river reaches. Using the basin data computed by WMS when DEM was used to delineate the watershed, Muskingum method parameters such as Muskingum K coefficient in hours for the entire reach (AMSKK) and the number of integer steps for the Muskingum routing (NSTPS) can be estimated. AMSKK is essentially the travel time for the reach, which can be estimated by dividing the length of the stream segment by the assumed channel velocity. The NSTPS value can be determined by dividing AMSKK by the computational time step, taking the time units consistency into consideration.

The HEC-1 model was run after preparing and supplying the required inputs to the model with selected rainfall events for different seasons and different land use in order to simulate the runoff amount and distribution in different basins through generating runoff hydrographs. The simulated hydrographs were compared to the observed hydrographs at the river basin outlet point. The model was calibrated and validated and the model performance was checked by four means of evaluation criteria namely, Mean Absolute Error (MAE), Root Mean Square Error (RMSE), Theil's coefficient (U) and the coefficient of determination ($R^2$) as shown in equations 6 to 8 .

$$MAE = \frac{1}{n}\sum_{i=1}^{n}\left|P_i - A_i\right| \quad \text{.................................... (6)}$$

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(P_i - A_i)^2} \quad \text{... ................................... (7)}$$

$$U = \frac{\sqrt{\frac{1}{n}\sum_{i=1}^{n}(P_i - A_i)^2}}{\sqrt{\frac{1}{n}\sum_{i=1}^{n}(P_i)^2} + \sqrt{\frac{1}{n}\sum_{i=1}^{n}(A_i)^2}} \quad \text{......................... (8)}$$

Where $P_i$ = the predicted data from the model, $A_i$ = the experimental data and $n$ = the number of records, (Naylor 1970 and Hossein and Velu, 2004). The MAE, MSE statistics have as the lower limit, the value of zero, which is the optimum value for them as it is for U.

Figure 3 shows the predicted hydrographs versus the actual one using the landuse maps for different three years and different rainfall events. The model performance results are shown in Table 3.

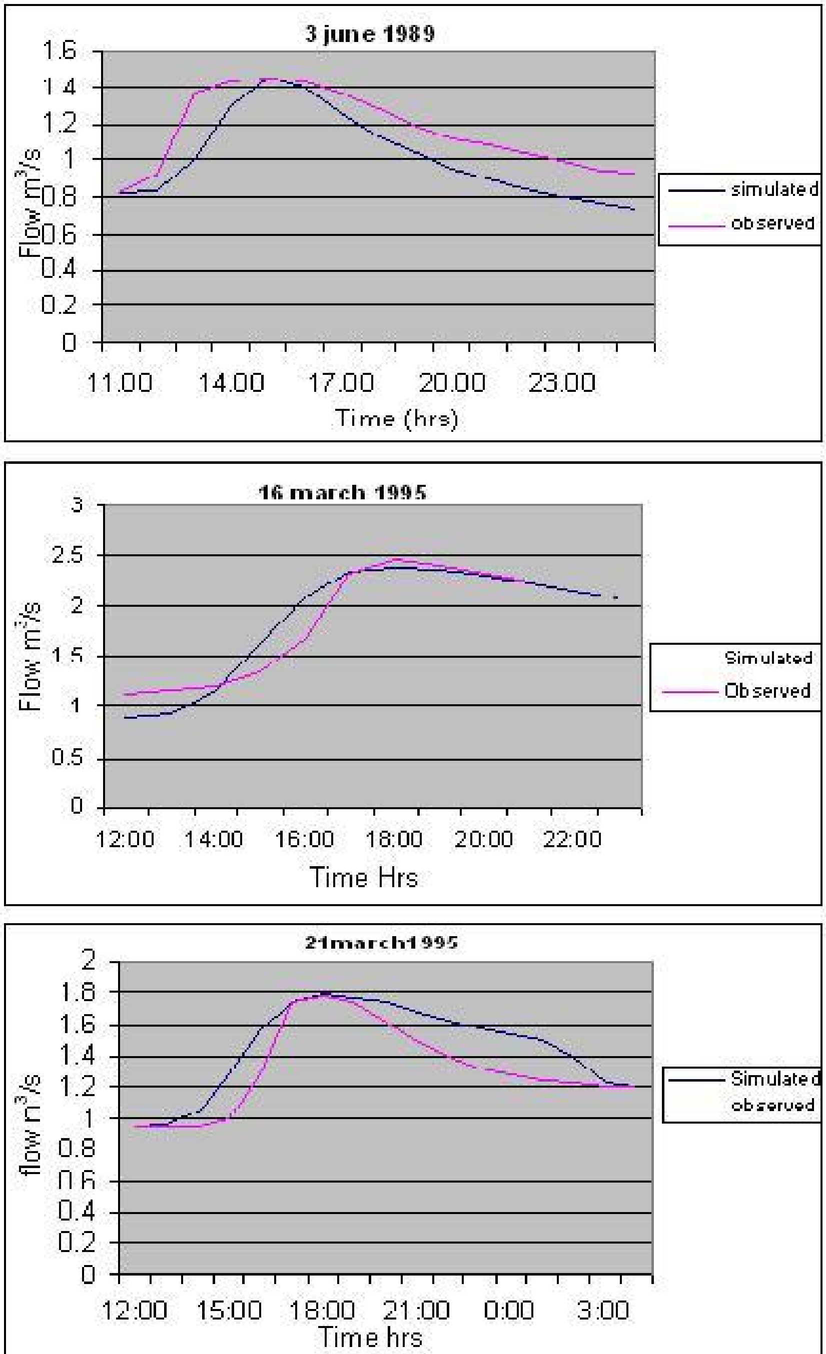


**Fig. 3 : Simulated flow versus observed flow**

**Table 3: Model performance**

| Rainfall Events | Performance Criteria | | | | |
|---|---|---|---|---|---|
| | $R^2$ | MAE | RMSE | U | E |
| 10-Jan-1989 | 0.84 | 0.93 | 1.22 | 0.32 | 0.43 |
| 7-Feb-1993 | 0.89 | 0.57 | 1.08 | 0.19 | 0.85 |
| 30- Mac-1993 | 0.95 | 0.75 | 1.45 | 0.24 | 0.13 |
| 3-Jun-1989 | 0.87 | 1.38 | 1.92 | 0.39 | 0.25 |
| 6-Jul-1993 | 0.87 | 0.09 | 0.76 | 0.12 | 0.86 |
| 26-Aug-1993 | 0.83 | 1.03 | 1.19 | 0.26 | 0.30 |
| 8-Dec-1989 | 0.89 | 0.49 | 1.52 | 0.14 | 0.66 |

The runoff hydrograph was used as an indicator to evaluate the changes in the watershed hydrology due to the spatial change in the landuse within the watershed. To perform this evaluation the selected rainfall event was supplied to the model using land use for different years to observe the change in the peak runoff and time to peak due to the landuse change. The rainfall event of 110.9 mm for 10th January 1989 was used to run the model for the years 1989, 1993 and 1995. The results were compared by plotting the hydrographs for the three years as shown in Figure 4, it can be observed that the impacts of changes in CN is reflected more clearly in the rising limb than the falling limb.

From the hydrograph comparison, it can be observed that the peak runoff increased by 28% and 11% between the years 1989-1993 and 1993-1995, respectively. On the other hand, the time to peak decreased from 37.5 hrs in year 1989 to 35 hours in year 1993, and remaining at 35 hrs for the year 1995 because the change in these years was relatively very little. However the reduction by 7% in the time to peak means that the time needed to reach the peak flow is reduced. Consequently the flow recession will appear earlier as long as the runoff volume remaining the same. Hence the low flow appearance is expected to be earlier. It can be stated that the time needed to reach the peak flow as a response from all watershed was 37.5 hrs in the first set of simulated years. From Table 3 it is clear that the forest and rubber areas decreased by 3% and 11% respectively between the years 1989 and 1993, while the built up and the oil palm areas have increased by 1% and 86%, respectively for the same years. The built up areas increased by almost three times between the years 1993 and 1995.  It is observed here that the spatial change in land use has led to change in the river flow pattern inspite the little land modification.

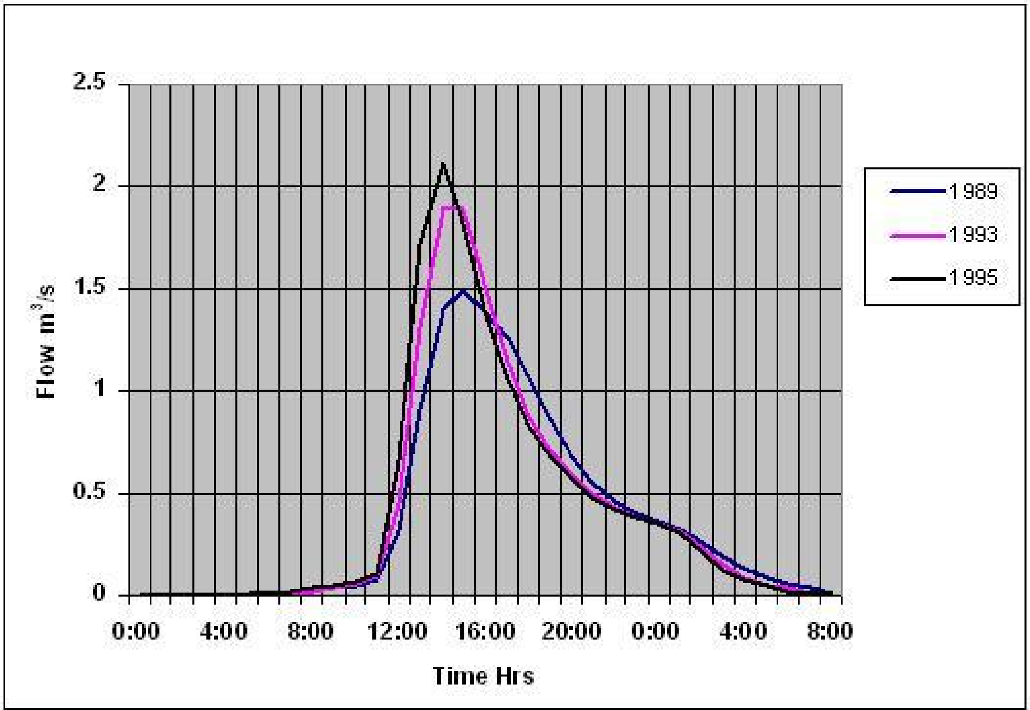


Figure 4. Change in the hydrograph shape due to the land use change

The change in composite CN for the whole basin is shown in figure 5.

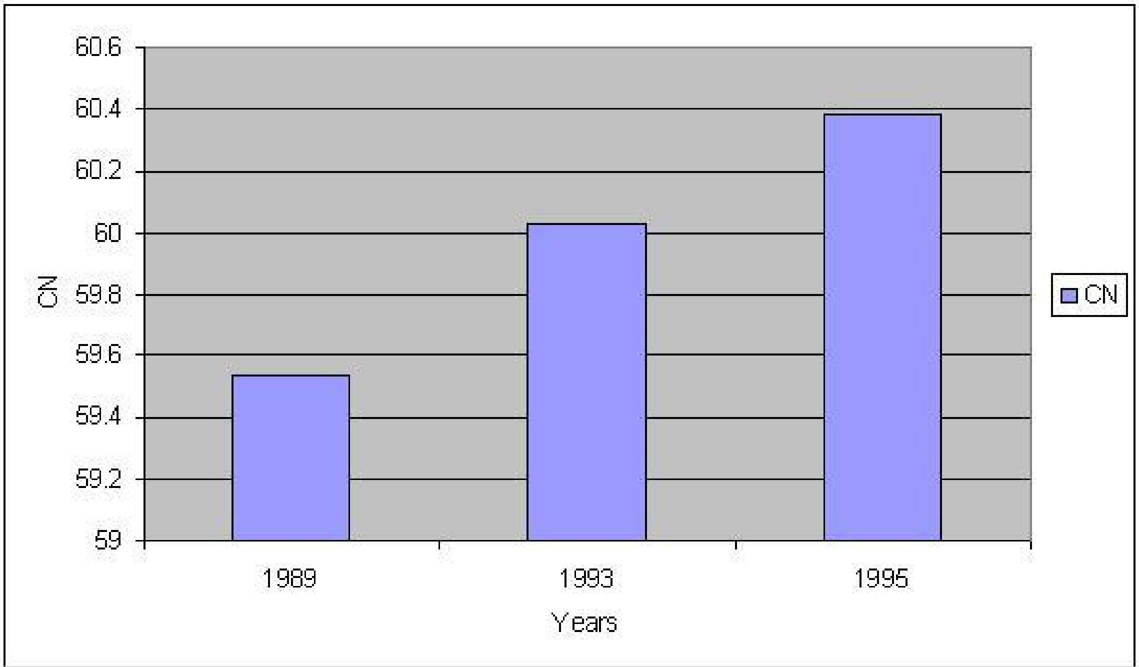


Figure 5 : Changes in the wieghted curve number due to the changes in the landuse

The model can be used for future landuse scenarios to predict the expected changes in the river flow regime. This will help in avoiding the shortage in irrigation water in the dry seasons due to the base flow reduction or even plans to mitigate the floods that may be caused by the higher peak flows. In addition to that, dam and reservoir engineers and designers should take into account the long term changes that may happen to the river flow pattern due to changes in the impervious ground surfaces within the river basin when determining the capacity and dimensions of the dams. This can be achieved through implementing the above-mentioned methodology to simulate the various landcover change scenarios.

## 4. Conclusion

In the study area, due to the landuse changes the peak flow increased by 28% and 11% between the years 1989-1993 and 1993-1995, respectively. On the other hand the time to peak decreased from 37.5 hrs in year 1989 to 35 hours in year 1993, and in 1995. These changes in the peak flow and time to peak were caused by the change in the forest and rubber areas which decreased by 3% and 11%, respectively between the years 1989 and 1993, while the built- up and the oil palm areas have increased by 1% and 86%, respectively for the same years. The built-up areas increased by almost three times between the years 1993 and 1995.

This method of evaluating of the impacts of land development on water availability can be used when planning for the agricultural seasons particularly for the time of higher demands of the irrigation water supply. In addition, this method can be implemented for future land use scenarios to predict the changes that may happen to the river flow regimes. The integration of remote sensing, GIS, and HEC-1 model provides a powerful tool for assessing the impacts of land development on the river flow pattern and irrigation water availability. Remote sensing, because of its capability of viewing and repetitive coverage, provides useful information on land use dynamics. GIS is an efficient tool for presentation of input data as required by the hydrological models. Using remotely sensed data and GIS to simulate the runoff process is more advantageous when the study area is large.

## Acknowledgments

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