DISTRIBUTED MODEL FOR CHANGES IN RIVER PEAK FLOW DUE TO LAND DEVELOPMENT

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ABSTRACT

Land development for new townships, agriculture or recreational areas is almost always accompanied by environmental problems. Some of these are soil erosion, soil fertility degradation, river sedimentation and sometimes flash floods. Exposed soil is subjected to the impact of raindrops, sealing the soil surface, reducing infiltration and causing high surface runoff. A question that always comes to mind is, with land development, can the river still carry the runoff rate from a certain rainfall event or is flooding imminent? Increased runoff results in higher flows during rainfall events, which in turn increases the number of times that a river floods the adjacent land areas. Likewise, this increase in runoff and channel flows can drastically increase the erosion of river channel beds and banks, potentially destabilising bridges or local structures. There is a need then for a tool to correlate the land development with the river peak flow. For this purpose a Landuse- peak flow model (LPM) was developed, the model was based on curve number (CN) method, which was derived from landuse and hydrological soil groups in each sub basin for the watershed. The model was developed for Upper Bernam River basin, Malaysia for both wet and dry seasons. Using the measured peak flow data the models were verified and tested. To evaluate the model performance in simulating the peak flow changes the correlation coefficient (R^2), mean absolute error (MAE), root mean square error (RMSE), Theil's coefficient (U) and model efficiency (E) were used as statistical tests. The models obtained 0.99, 0.004, 0.84, 0.04 and 0.98 for the rainy season and 0.93, 0.11, 0.61, 0.07 and 0.92, respectively. It was found that increases in CN by 0.3, 0.5, 0.7 and 1.2 % cause increases in peak flow values by 2, 3, 4 and 7 %, respectively. The changes in peak flow are constant regardless of the changes in rainfall pattern. The models were applied to investigate the changes in peak flow from the proposed land development for the study area in the year 2020. Due to the implementation of this plan, peak flow would be expected to increase by 80 % and 76 % for the wet and dry seasons, respectively. The models can be used to simulate the changes in peak flow from future landuse scenarios.

Keywords : *Distributed Model, GIS, Land Development, Peak Flow and Remote Sensing*

1. INTRODUCTION

Water has a major effect on the landform, shaping the land through erosion and deposition. Likewise, landuse has a significant influence on water balance, affecting infiltration and runoff, peak and base flows. Although any land disturbance will change the water balance, land development and urbanisation and their associated impervious surfaces inhibit infiltration and speed up runoff. These effects combine to cause higher peak discharges and greater storm water and flooding problems during major storm events and reduced base flows and low flows between storms and during drought [10]. Deforestation, urbanization, and other landuse activities can significantly alter the seasonal and annual distribution of stream flow [3]. Understanding how the land development influences the stream flow will enable planners to formulate policies towards minimising the undesirable effects of future landuse changes on stream peak flow.

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 [11]. 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 [1]. Many computer programs for hydrologic and hydraulic modeling are available to the engineering community. Over the past decade, numerous interfaces have been developed for various hydrological models such as Simulator for Water Resources in Rural Basins (SWRRB), Environmental Policy Integrated Climate (EPIC), Groundwater Loading Effects of Agricultural Management Systems (GLEAMS), TR20, HEC-1, and HEC-2. In each case, GIS is used for pre-processing and post-processing of data.

Hydrological models, distributed models in particular, need specific data on landuse and soil types and their locations within the basin. The changes in landuse due to natural and human activities can be observed using current and archived remotely sensed data. The conventional methods of detecting landuse changes are costly and low in accuracy. The remote sensing technique, because of its capability of synoptic viewing and repetitive coverage, provides useful information on landuse dynamics. It can provide measurement of many hydrological variables used in hydrological and environmental model applications comparable to traditional forms of landuse data collection. GIS as a computer-based tool that displays, stores, analyzes, retrieves and generates spatial and non-spatial (attribute) data provides suitable environment 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.

With the development of GIS and remote sensing techniques, the hydrological catchment models have been more physically based and distributed to enumerate various interactive hydrological processes considering spatial heterogeneity [8]. Coupling GIS and with the deterministic or stochastic process models will accelerate the field of research and development in spatial science. The application of GIS will facilitates new avenues of exploratory spatial data analysis that were previously not feasible and also enables the integration of data collected by different media thereby substantially increasing the communications capabilities of those involved in urban management [7]. Distributed-parameter models may be more accurate since they offer the possibility of modeling the spatial variability of hydrologic parameters. These parameters can be derived from remote sensing of various platforms [2].

Remote sensing data and geographic information system is increasingly becoming an important tool in hydrology. 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 [4].

Although originally developed for agricultural purpose, the Soil Conservation Service (SCS-CN) method [12] has been expanded for use in urban and suburban areas. The method is attractive as the major input parameters are defined in terms of landuse and soil type. The advantage of this method is that the user can experiment with changes in landuse and assess their impacts.

A lumped model using basin average input data and producing total basin stream flow may be used to model river basins. Such models may produce reasonable result, but because of the distributed nature of hydrological properties like landuse, soil type and slope, the model cannot be expected to accurately represent the watershed conditions, they are often inappropriate for studying the effects of climate change, landuse and vegetation change on watershed hydrology [6]. Distributed models attempt to remove this averaging as a source of error in hydrologic simulation.

The main objective of this study was to develop a distributed hydrological model integrating with remote sensing and GIS, to estimate the changes in the river peak flow arising from land development.

2. METHODOLOGY

This study was conducted in a 200 km^2 tropical watershed located in North eastern part of Selangor state, Malaysia, between 3˚ 36' to 3˚ 47' North and 101˚ 30' to 101˚ 39' East. The area is characterised 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˚C and 32˚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 89 km/day. Six soil series are found within the study area. The dominant vegetation cover in the river basin consists of tropical hill rainforests, oil palm trees and rubber trees. Other land covers 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. (Figure1).

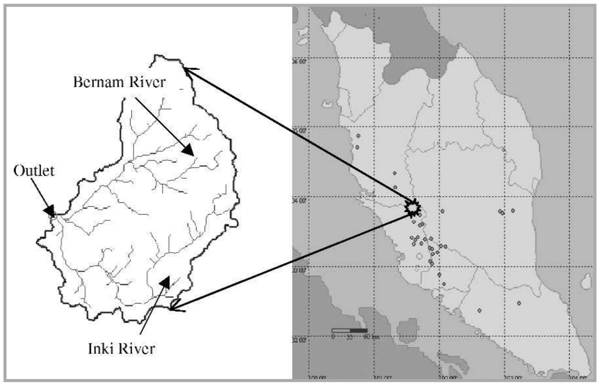

Figure 1: Location of the study area

A contour map of scale 1:25000 for the year 1995 obtained from Department of Surveying and Mapping Malaysia was used to derive the Digital Elevation Model (DEM). DEM was used to compute the geometric values of the basin. Topographic ParameteriZation (TOPAZ) computer program was run to create the flow directions and flow accumulation files, which were used later to delineate the basin and sub basin boundaries and the stream networks. The river basin was divided into 10 sub basins to cover the spatial variation of landuse and soils within the watershed.

ERDAS IMAGINE 4.8 (ERDAS 1999) software [5] was used to process the LANDSAT satellite images path/row 127/57 of 30-meter resolution for the years 1989, 1993, 1995, 1998 and 2001 to generate the landuse maps for those years. The images were enhanced, registered, and classified into different landuse types using supervised classification. The false colour 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 digitising technique was applied to clearly demarcate the classes.

The State based soil map of scale 1:25000 was converted to digital format using on screen digitising 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. Daily and hourly rainfall data from eight rain gages around the basin 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 by applying the Thiessen polygon technique.

Linear regression was used to model the value of a dependent variable based on its linear relationship to one or more predictors. The relationship between the change in curve number (CN) and the change in the river peak flow due to the change in the landuse for the ten sub basins was simulated by creating a linear regression model. The goal of this model was to determine the dependency of the change in the peak flow as affected by the changes in the landuse within the river basin.

Landuse-peak flow Model (LPM) inputs are the changes in the CN for the different sub basins and the output is the change in the river peak flow at the outlet point of the watershed. The model was developed for both rainy and dry seasons.

Model verification is an approach to determine weather the developed model describes the behaviour of the real system for events not used in the model building process. The verification process involves comparison between the simulated output from the model and the actual data. For verification purposes, both graphical and statistical tests were conducted. The statistical criteria used were namely, correlation coefficient (R^2), mean absolute error (MAE), root mean square error (RMSE), Theil's coefficient (U) and model efficiency (E). The model was applied to predict the changes in peak flow due to development plans of the year 2020 proposed by the Department of Town and Country Planning. Changes in CN in each sub basins due to the proposed plan were supplied to the model. The change in peak flow due to the change in the landuse was estimated.

3. RESULTS AND DISCUSSIONS

Determination of CN requires landuse, soil type and antecedent soil moisture (AMC) information. The potential of deriving landuse maps from satellite images is one of the main features of this study. Recent landuse changes from large areas can be detected easily by satellite images in a short time with low cost compared to the traditional methods. The average classification accuracy was 90%. The classified thematic raster maps were vectorized and converted to landuse maps using ARCVIEW 8.3. The major types of landuse found in the study area are forest, rubber trees, oil palm trees and builtup areas. The percentage of the landuse types covering the basin is shown in Table (1). Figure (2) presents the landuse map for the year 2001.

Table 1: Break down of landuse areas in percentage

Landuse	1989	1993	1995	1998	2001
Built-up area	3.5	4.3	5.1	5.9	5.9
Oil palm	4.6	8.5	9.1	10.2	15.1
Rubber	21.2	18.9	16.5	14.3	11.9
Forest	69.6	68.2	68.2	68.7	67.0

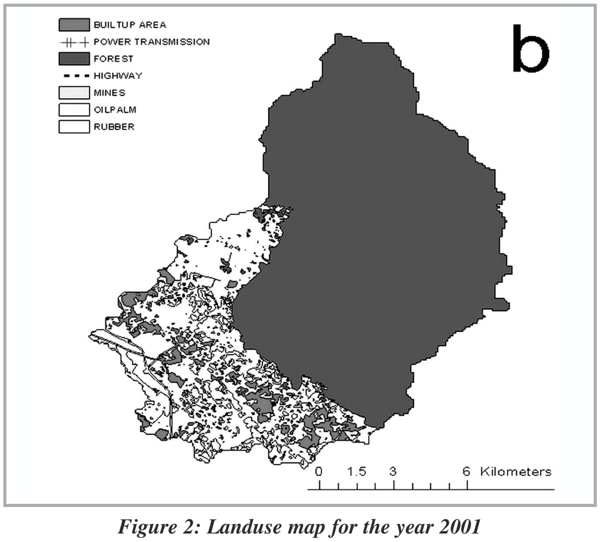

Figure 2: Landuse map for the year 2001

The USDA (1985) method classifies the soils into four hydrological soil groups (HSG) based on the physical properties of the soils. These groups can be defined as: Group A is characterised 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. Figure 3 shows four different HSG found in the study area covering 15%, 75%, 2% and 8% for the groups A, B, C and D, respectively.

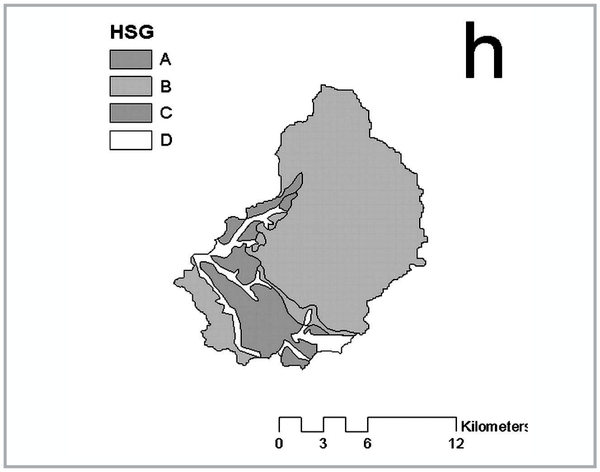

Figure 3: Hydrological soil groups

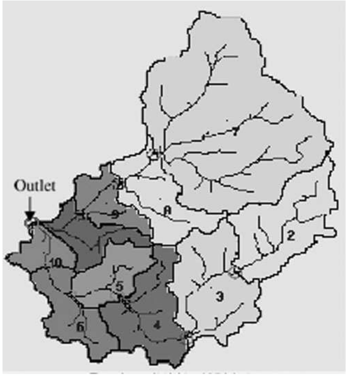

Figure 4: Sub-basins of the watershed

The digital contour map for the study area was processed. The Triangulated Irregular Networks (TIN) was derived from the contour map. Digital Elevation model (DEM) was derived from the TIN with a 30mx30m 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 networks. The location of the watershed outlet was determined to delineate the subbasins. Ten outlet points were created based on the uniformity of the subbasins in the landuse type, soil type and slope ranges. Watershed and its subbasins were delineated. The largest subbasin area is 74.48 km^2, while the smallest sub basin area is 5.99 km^2 (Figure 4).

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 that is derived by overlaying landuse and soil coverage. The composite CNs for each sub basin was determined and adjusted according to the antecedent moisture content (AMC) levels. The composite CN for different sub basins for normal moisture condition is shown in Table 2.

Table 2: Weighted CN for the sub basins

Basin No.	CN 1989	CN 1993	CN 1995	CN 1998	CN 2001
1	58.4	59.3	60.1	62	61
2	60	60	60	60	60
3	62.6	62.6	62.9	63	63
4	49.9	51.7	54.2	54.9	55.1
5	53.1	53.9	55.6	57.9	55.9
6	64.6	65.4	64.3	65.5	67.5
7	60.1	60.1	60.1	60.1	60.1
8	61.7	61.8	61.8	61.8	61.7
9	61.6	62.2	62.6	63.3	62.7
10	62.1	67.8	68.1	70.1	68.5
Average	59.5	60.0	60.4	60.8	60.7

The Land-use Peak Flow Model (LPM) inputs are the changes in the CN for the river's sub basins. The simulated output is the change in the river peak flow at the outlet point of the river basin. Two models were developed for wet and dry seasons separately. The model structures that gave best results for wet and dry season are shown in Equations 1 and 2, respectively.

$$\Delta\ PF_W = \mathit{0.263} - (1.570{*}\Delta CN_1) - (1.492\ {*}\Delta CN_2) - (3.118{*}\Delta CN_3) + (0.842{*}\Delta CN_4) + (1.703{*}\Delta CN_5) + (0.108{*}\Delta CN_6) + (7.460{*}\Delta CN_8) - (3.547{*}\Delta CN_9) - (0.130\Delta CN_{10}) \quad [1]$$

$$\Delta\ PF_D = \mathit{0.243} + (0.272{*}\Delta CN_1) + (0.678{*}\Delta CN_2) - (2.740{*}\Delta CN_3) + (0.373{*}\Delta CN_4) + (0.139{*}\Delta CN_5) - (0.005{*}\Delta CN_6) + (2.844{*}\Delta CN_8) - (1.357{*}\Delta CN_9) - (0.147{*}\Delta CN_{10}) \quad [2]$$

Where: Δ PFW is the change in the peak flow in m^3/s during the wet season. Δ PFD is the change in the peak flow in m^3/s during the dry season. 0.263 and 0.243 are constants. ΔCN1- 10 is the change in curve number for the subbasins 1 to 10.

Model verification is to determine whether the developed models continue to describe the behaviour of the real system for events not used in the model building process. The verification process involves compression between the simulated output from the models and the actual data. To achieve this purpose the graphical and statistical tests were conducted. Changes in peak flow were estimated for both seasons and compared to the observed data; the results are shown in Figures 5 and 6 for wet and dry seasons, respectively.

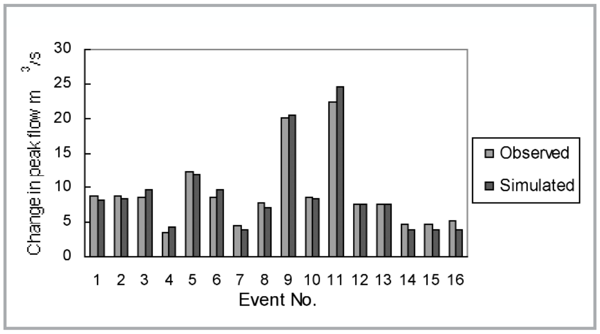

Figure 5: Observed and simulated results from the wet season model

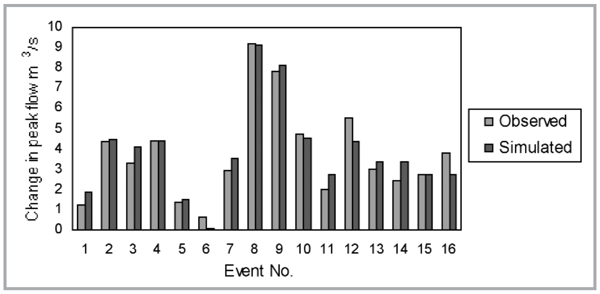

Figure 6: Observed and simulated results from the dry season model

From Figures 4 and 5, it can be stated that the simulated results are very close to the observed data in both models. To analyse these results statistically, R^2, MAE, RMSE, U and E tests were performed and the analysis results are shown in Table 3. The models show high efficiency in simulating the changes in peak flow due to the changes in CN especially during the rainy season.

Table 3: Results of the Statistical analysis of LPM

Statistical test	LPM for rainy season	LPM for dry season
RMSE	0.84	0.61
MAE	0.0037	0.11
U	0.04	0.07
R^2	0.99	0.93
E	0.98	0.92

LPM models were used to simulate the changes in the peak flow due to the changes in CN between the years 1989, 1993, 1995, 1998 and 2001. The results of these calculations are shown in Table 4 and Figure 6. From Table 4 it can be observed that the changes in CN by 0.3 %, 0.5 %, 0.7 % and 1.2 % cause change in peak flow by 2 %, 3 %, 4 % and 7 %, respectively. On the other hand, form Table 4 and Figure 7 the changes in peak flow is almost constant for a certain change in CN in spite

Table 4: Changes in peak flow from different rainfall patterns

		change in peak flow			
Years	change in CN	Apr-89	May-89	Sep-89	Oct-89
1993-1989	0.5%	3%	4%	3%	3%
1995-1989	0.8%	5%	5%	5%	5%
1998-1989	1.2%	7%	8%	7%	7%
2001-1989	1.1%	7%	7%	6%	7%
1995-1993	0.3%	2%	1%	2%	2%
1998-1993	0.7%	4%	4%	4%	4%
2001-1993	0.6%	4%	3%	3%	3%
1998-1995	0.4%	2%	2%	2%	2%
2001-1995	0.3%	2%	2%	2%	2%

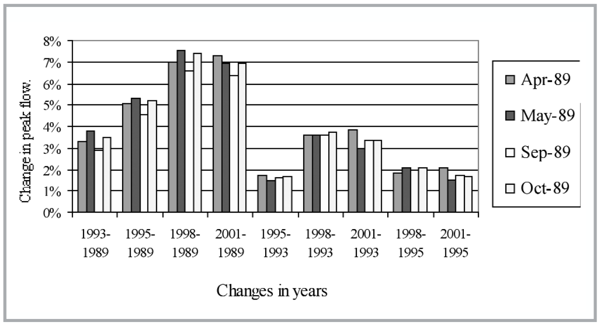

Figure 7: Changes in peak flow from different rainfall patterns

of different rainfall patterns. This leads to the fact that changes in peak flow is constant regardless of the changes in rainfall pattern, a fact previously mentioned [9].

Since LPM generated results agreeable with pervious works, it can be used as a tool to estimate the impacts of land development on the river's peak flow. This will help planners and decision makers to consider the impacts of future land development to avoid any disastrous consequences as a result of improper land development, such as frequent flash floods and increased erosion of river channel beds and banks, potentially destabilising bridges or local structures.

To show the applicability of LPM, the model was applied to simulate the change in peak flow due to the change in CN from the land development plan for the year 2020 proposed by the Department of Town and Country Planning (Figure 8). Due to implementation of this plan the composite CN will be increased by 10 % compared to the current status. Consequently as shown in Figure 9 the peak flow will be increased by 80 % and 76 % for the wet and dry seasons, respectively.

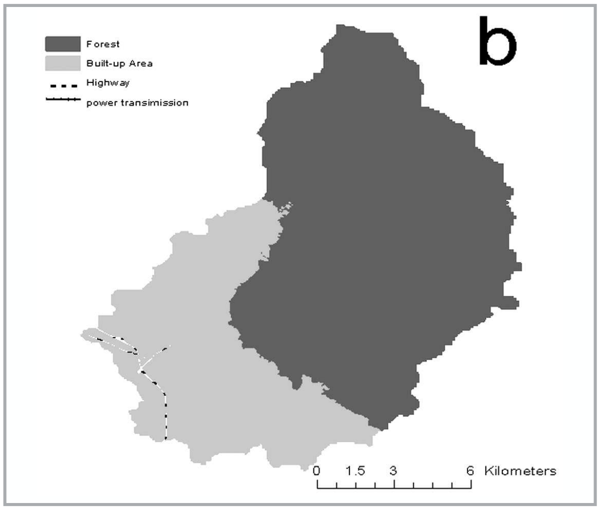

Figure 8: Landuse map for the year 2020

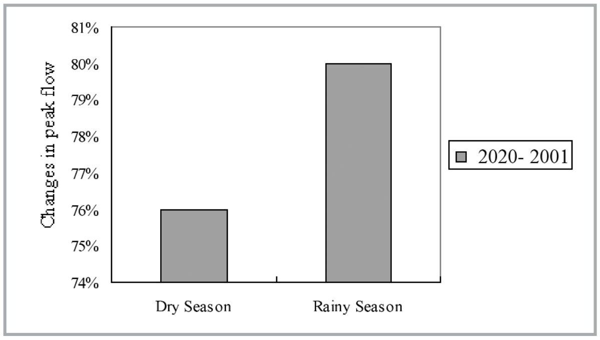

Figure 9: Changes in peak flow due to future land development

4. CONCLUSION

There is a need for a tool to correlate the land development with the river peak flow for the Upper Bernam River basin. For this purpose a Land-use peak flow model (LPM) was developed. The model was based on the Soil Conservation Service – Curve Number method, and was derived based on the landuse and hydrological soil groups in each sub basin for the watershed. The following conclusions can be drawn from the study:

- Coupling of GIS and Hydrologic models is a logical direction in rainfall-runoff modeling.
- Integration of distributed hydrologic model, GIS and remote sensing is a powerful tool to estimate the impacts of land development on the river peak flow.
- In this study increase in weighted CN of 0.3 %, 0.5 %, 0.7 % and 1.2 % resulted in increases of peak flows by 2 %, 3 %, 4 % and 7 %, respectively.
- Percentage change in peak flow due to land development is constant irrespective of rainfall pattern and time of occurrence whether in rainy season or dry season.
- If the digital data is available, the models can be used to simulate the changes in peak flow from future plans scenarios. This will help planners and decision makers to take the hydrological impacts into account when formulating the future plans for land development.

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