Setting up of an Experimental Basin and Development of a Cell-Based Model to Derive Direct Runoff Hydrographs for Ungauged Basins

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Summary

Proper qualitative and quantitative management of water resources is necessary due to ever increasing demand of water for growing foods, for household water uses, including drinking, cooking and sanitation, and as a critical input for the industry. It is important to estimate the amount of water availability and the extreme events of a basin in the planning as well as in the operational stages of any sustainable water resources development project. To do this, long-term stream flow records at the particular basin outlet is extremely important. However in many cases, hydrological information such as runoff is not available for sufficient periods and required resolutions. Therefore, mathematical models have been developed to predict the actual behavior to attain reasonable levels of accuracy, after being calibrated with the existing stream flow records. But in most cases it is not possible to find such existing data for model calibration, as most of the basins in the world are ungauged. Situation worsens specially in developing countries because most of their river basins continue to remain totally ungauged. It is a serious challenge for sustainable development and poverty reduction in these countries and methodologies for Prediction in Ungauged Basin (PUB) is indeed a dire need. With that consideration in mind, this study was focused on research pertaining to stream flow prediction in ungauged basins.

The central hills of Sri Lanka constitute the sources of all major rivers of the country. It receives an annual average rainfall of about 3000mm and this area is very sensitive for the water resources of the country. Therefore, an experimental basin was set up in the central hills selecting the Upper Kotmale basin, which is a tropical mountainous sub-basin of the Mahaweli River in Sri Lanka. The basin is 304 km^2 in size and the elevation varies from 1200 m to 2500 m above mean sea level. The average annual rainfall varies from 2200 mm to 2600 mm. and the basin is under varying land use and land cover types comprising of tea (44%), forest (36%), built-up land (7%), grass (5%), water bodies (1%) and other crops. Soil, Land use, topographical and other GIS data were collected from various organizations. Also, the rainfall data over past thirty years period at ten stations in the region was analyzed to investigate their reliability, and the daily rainfall data at five stations were found to be inconsistent. A field survey was conducted at those stations and found that the data at one station (Holmwood Estate) is highly unreliable and data at other stations could be corrected. Almost all rain gauges in this area are manually operated and data is available only at the level of daily time resolution. This is one of the major disadvantages for detail hydro-meteorological research. Considering these circumstances, six automatic high-resolution (0.1mm tipping bucket) rain gauges and three-stream flow measuring stations were installed in the basin under this study and data collection has been carried out since November 2002.

Three hydrological models, HEC-HMS model, Tank model and SHER (Similar Hydrological Element Response Model) model were calibrated for the experimental basin using past hydro-

meteorological data. All three models are capable of predicting the stream flow of the basin at reasonable levels of accuracy while the Tank model forecasts the stream flow to the best level with the highest value of Nash coefficient of 0.8 for the verification period. However, in SHER model, the number of parameters that should be calibrated is smaller than other models due to its physically based model structure. Hence, the SHER model is possible to calibrate with short period of stream flow records. Furthermore, it is capable of predicting the soil moisture storage changes in each of the soil moisture blocks. This is useful in understanding the actual basin hydrological process. Moreover, the model is possible to be used for studying the effects of urbanization, future land use changes etc. on the water availability of the basin. However, all these models demands observed stream flow data for model calibration.

A new cell based model, "*CellBasin*", which is applicable to derive direct runoff hydrograph for ungauged basins using spatial physical properties of the basin derived from GIS and rainfall data, was developed in this study. In the model, the basin is divided in to several grid cells and the physical properties are derived for each cell using GIS data. Flow paths to the basin outlet and the stream network are derived from the digital elevation model of the basin. Overland flow is generated from each grid cell of the basin by the application of continuous effective rainfall of 1mm/hr over the basin. The flow velocity through each grid cell is calculated using the kinematic wave approach, and travel time of flow through each cell was obtained considering travel distance through the cell. The collated overland flow at a cell with a flow accumulation number above a specified value is considered as a canal flow. The travel time for direct runoff from each grid cell to the basin outlet is calculated by using the flow direction grid and the flow travel time through each cell. The S-curve for the basin so obtained is then used to derive the unit hydrograph of a given duration for the basin. Direct runoff hydrograph for a given rainfall hyetograph is obtained by using the basin unit hydrograph with a flow travel time-based constant rate loss model.

The model is tested using data collected from the experimental basin, the Upper Kotmale basin, which was observed under this study. The unit hydrograph obtained from the model was compared with the unit hydrograph derived from the observed data. Both unit hydrographs were found to be similar in shape. However, it was found that the *CellBasin* model unit hydrograph gives lower peak flows than the derived unit hydrograph from the observed data. The direct runoff hydrographs for rainfall events obtained by the application of the model agree reasonably well with the observed hydrographs. The *CellBasin* model predictions for the Upper Kotmale basin were then compared with the predictions obtained from the Snyder's synthetic unit hydrograph of the basin developed using regionalized parameters. The *CellBasin* model predictions showed better agreement with the observed data than the Snyder's unit hydrograph predictions. The Snyder's unit hydrograph predictions have not matched properly with the observed stream flow data of the Upper Kotmale basin. Therefore, the Snyder's regional coefficients suggested by past studies for ungauged mountainous basins of Sri Lanka are not suitable for the Upper Kotmale basin. It is found that the new model predictions are more accurate than the Snyder's unit hydrograph predictions and thus, the developed model is clearly a useful tool to derive the direct runoff hydrograph for ungauged basins.