Report for 2004TX155B: A Near Real-Time Flood Prediction Using Hourly NEXRAD Rainfall Data for the State of Texas

- Other Publications:
  - Palanisamy, Bakkiyalakshmi. 2004. Second Place, Oral Presentation in Student Research Week. Competition held at Texas A&M University, College Station, TX.

Report Follows

A Near Real-time Flood Prediction using Hourly NEXRAD Rainfall for the State of Texas

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Introduction

Radar derived precipitation data is becoming the driving force for hydrological modeling. Being rainfall the key input for modeling natural resources such as water, accurate measurement of rainfall in terms of spatial and temporal is very important. The potential of radar rainfall is obvious in such a way that in recent years, hydrological modeling of all spatial scales started using it for simulation of runoff. It has been very well recognized that errors in rainfall input increases error in the estimation of stream flow (Sun et al., 2000). Thus, radar estimates supersede the raingage measured rainfall in terms of its large spatial coverage, such that it can capture any small amount of rainfall where raingage usually tends to miss some of these small events. Not only the low intensity rainfall, because the raingage network is very scarce around the area being studied, there is a very high possibility that it will fail to capture some of the high intensity, short duration rainfall too.

Hence, using radar estimates for producing accurate amount of runoff is promising in the field of hydrological modeling. Even though, radar estimates are capable enough to characterize the spatial variability of rainfall in terms of space and time, there are lot of uncertainties aroused in the estimation methods of the precipitation from the reflectivity values. Rainfall-runoff modeling is very sensitive to uncertainty in radar derived rainfall values (Borga Marco, 2002). Issues related to radar rainfall uncertainties are being studied for many years and researches are being carried out to separate effect of radar rainfall errors from the modeling errors.

Hence, take into account the spatial and temporal resolution in runoff estimation and eventually in hydrological simulation, can improve the prediction very well. It has been said in the literature that runoff simulation is very sensitive to spatial and temporal scale of the input (Winchell et al., 1998). These past studies suggest that using radar estimates with the variability being represented at very large scales of measurements can improve the prediction of runoff. Thus, this study is focused on using radar derived

rainfall estimates at 4 x 4 km spatial and 60 minutes temporal resolution. Soil wand Water Assessment Tool (SWAT) model (Arnold et al., 1998) is used for runoff estimation. SWAT is semi-distributed hydrological, watershed scale model and calculates runoff based on water budget method. SWAT can simulate runoff at various temporal scales which include hourly, daily, monthly and yearly basis. Daily runoff estimation is using SCS Curve Number method and hourly runoff estimation uses Green-Ampt Mein-Larson excess rainfall method (GAML) [King et al., 1999] . In this method of calculating runoff, the amount of water that does not infiltrate into the soil becomes runoff.

The objective of this study is that to examine the performance of SWAT model to simulate runoff on hourly basis. Past study by Di Luzio and Arnold, 2004 on simulating hourly runoff shows that the model performed well and was able to generate the stream flow when compared with observed hydrograph with radar derived rainfall input. This study is focusing on generating stream flow with both raingage and radar rainfall data for the watersheds in Upper Trinity River Basin of Texas. The study area selected for this study is Eagle Mountain. Although, the study was intended to predict the flow for the entire state of Texas, this watershed is selected as test study area and trying to examine the performance of the model.

Description of the study area

Big sandy creek watershed is located in the Northwest part of the upper Trinity River basin with the drainage area of 312 square miles (Fig 1). The study area is of smooth to rolling topography. It is sloping gradually from 1,200 ft above sea level at the headwaters and decreasing as it goes down. The climate of the watershed is temperate with warm summers. The variation in climate across the study area is decreasing land elevation from west to east. Annual average precipitation is 32 inches and with uniformly distributed , average temperature of less than 65° F. Though the rainfall is of greater amount , 32 inches, the average runoff is less than 4 inches. This is primarily due to the variation of climate across the study area. The watershed experiences little water surplus in any season (Ulery and Brown, 1994). Summer experiences high intensity, short duration rainfall bursts resulting in thunderstorms. This eventually, leads to flash flood in the area.

Soil and Land Use

Thin mantle of soil is covered in the northwestern part of area with increasing depth towards downstream part of the watershed. Across the watershed, very deep to moderate deep clay, sandy loam is present. The soil data was obtained from SSURGO dataset, which is available for most of the state. Range and pasture are prevalent in the watershed

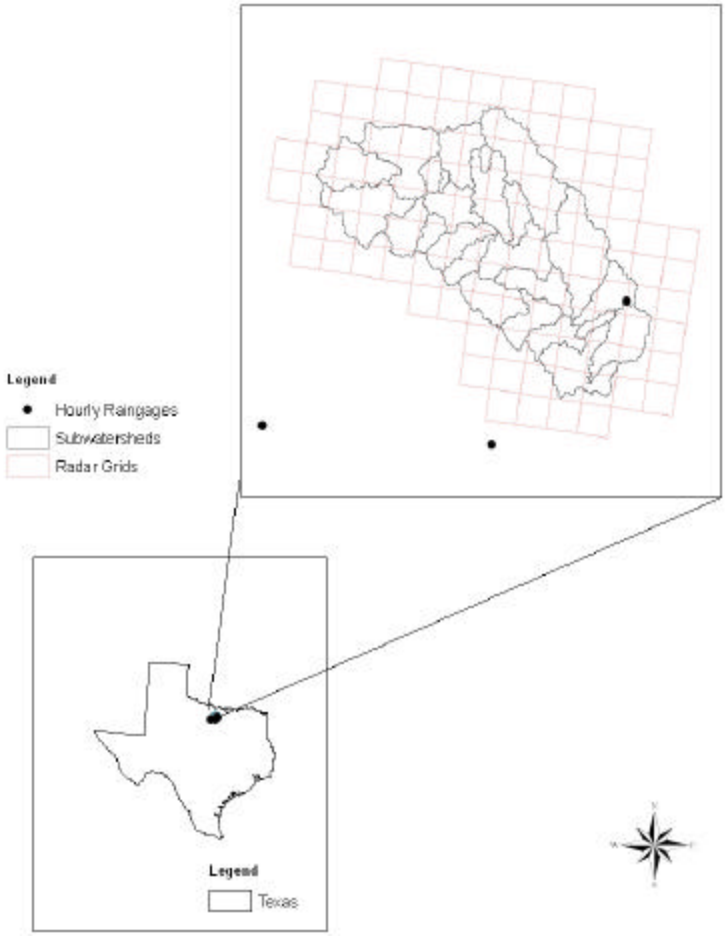

Fig 1 Study area , raingages and Radar grids

The land use dataset was collected from National Land use Land cover Data (NLCD) for the year 2000 and used in the study. The resolution of both soil and land use data is 30m. The elevation dataset needed for the model was obtained from National Elevation Dataset (NED) at 30m resolution.

Climate Data processing

Hourly precipitation was collected from National Climatic Data Center (NCDC) for the five years of simulation period, from 1999 to 2003. Corresponding observed stream flow was obtained from United States Geological Survey (USGS). Temperature data used in this study was in daily basis since; the main objective of this study was to examine the effect of spatial variability of different rainfall inputs. Radar data for the study area was collected from West Gulf River Forecasting Center (WGRFC) and Stage III data is used in this study. Since, raingage measurements are collected from 12 AM to 12 AM for a day, radar data were also extracted from 12 to 12AM for a day.

All the input files required for simulation were prepared using ArcView GIS interface of SWAT model.

Precipitation comparison

Precipitation estimates for gage and radar were compared to use with the model. The rainfall events were selected for convective storm, i.e. the events in summer as it produces more runoff than any other events occur during any other season. The selected events were for the years 2002 and 2003. Since, 2002 had some higher amount of runoff (greater than 500 cubic feet per second), in the late spring, two events were selected for that season. The comparison statistics used are defined as follows:

Total difference (mm) = Radar total – Raingage total

Positive total difference represents overestimation of precipitation by radar whereas the negative difference indicates the underestimation.

Radar Bias (%) = 100*(Radar total – Raingage total) / Raingage Total

Similar to total difference, positive radar bias represents overestimation of radar and negative radar bias represents the underestimation by radar.

Table 1 presents the comparison statistics for both gage and radar rainfall for the selected events in the year 2002. As can be seen from the statistics, radar is overestimating for all the events.

	Event_1	Event_2	Event_3	Event_4
Total Difference	**35.8**	**31.20**	**123.80**	**71.20**
Radar Bias	**60.76**	**26.78**	**78.95**	**201.70**

Table 1 Comparison statistics for the selected events in the year 2002

Where,

Event_1 is from 144 to 146th days of 2002

Event_2 is from 155 to 159th days of 2002

Event_3 is from 77 to 80th days of 2002, which is in spring season

Event_4 is from 89 to 91st days.

Table 2 presents the comparison statistics for gage and radar rainfall events for the year 2003.

	Event_1	Event_2	Event_3
Total Difference	**-3.4**	**22.50**	**65.90**
Radar Bias	**-3.73**	**42.13**	**41.95**

Table 2 Comparison statistics between gage and radar for selected events in 2003

Where,

Event_1 is from 156 and 157th days

Event_2 is from 145 and 146th days

Event_3 is from 162 to 165th days

For the selected events in the year 2003, from table 2, it can be explained that radar is underestimating the rainfall for event 1 and for the other two events, radar is overestimating.

These comparisons on hourly basis, shows that when the temporal and spatial resolution is increased to capture the precipitation, the better estimates can be obtained. This is obvious from the radar derived rainfall values. Also, it clearly shows that the larger events, such convective storms, which are very typical of the study area, can be represented well with the radar data than the point measured rainfall data. Another important point to be noted in regard to the overestimation of radar in all the events is that radar captured not only the high intensity rainfall but also, the low intensity rainfall too; when raingage failed to measure these events. But for event 1 in 2003, even though the statistics show that radar is underestimating, the percentage of underestimation is negligible as it is just 3%.

Model Simulations

The simulation was performed on hourly basis for the watershed for five years using both gage and radar data. All the model parameters are kept the same except the rainfall inputs for the uncalibrated run with Priestly-Taylor method for calculating

Evapotranspiration. USGS stream gage was located at the downstream of the delineated watershed. Warm up period of first two years were allowed to account for unknown initial conditions of the watershed and the simulation results from these years were not included in the analysis. Calibration was performed for both simulations using gage and radar rainfall input. To compare the simulated flow values with the observed stream flow, various statistics ranging from correlation, coefficient of determination (r^2), and Nash-Sutcliffe coefficient of efficiency, E (Nash and Sutcliffe, 1970) and to Index of Agreement (d) were used. But for presentation purpose, only efficiency and index of agreement are used.

Nash-Sutcliffe is defined as.

$$E = \frac{\sum_{i=1}^{n}(O_i - O_m)^2}{\sum_{i=1}^{n}(O_i - O_m)^2}$$

Where, n = Number of observed flow = Number of simulated flow

O_i = Observed stream flow (I = 1to n)

O_m = Mean of the observed stream flow

S_i = Simulated stream flow (I = 1 to n)

Value of e can vary from minus infinity to 1; higher the value of E, better the efficiency of the simulated values

Index of Agreement is defined as,

$$d = \frac{\sum_{i=1}^{n}(O_i - O_m)^2}{\sum_{i=1}^{n}(|S_i - O_m| + |O_i - O_m|)^2}$$

Values of d can vary from 0 to 1and the value closer to 1 represents the better agreement of simulated results.

Results and Discussion

Simulation results for the selected events for 2002 and 2003 are presented in Table 3 and 4 respectively with the Efficiency and Index of agreement for calibrated and uncalibrated simulated stream flows.

	Efficiency		Index of Agreement	
	Uncalibrated	**Calibrated**	**Uncalibrated**	**Calibrated**
Event 1	-0.12	-0.1	0.32	0.25
Event 2	-0.68	-0.74	0.46	0.46
Event 3	-63.72	-53.40	0.13	0.28
Event 4	-0.41	-0.33	0.37	0.36

Table 3a. Simulation statistics for all the events in 2002 with gage rainfall

	Efficiency		Index of Agreement	
	Uncalibrated	**Calibrated**	**Uncalibrated**	**Calibrated**
Event 1	-20	-4.91	0.36	0.66
Event 2	-0.93	0.02	0.64	0.86
Event 3	-15.33	-53.37	0.42	0.31
Event 4	-2.36	-0.77	0.78	0.67

Table 3b. Simulation statistics for all the events in 2002 with radar rainfall

	Efficiency		Index of Agreement	
	Uncalibrated	**Calibrated**	**Uncalibrated**	**Calibrated**
Event 1	-0.96	-0.94	0.34	0.79
Event 2	-138.00	-289.00	0.15	0.013
Event 3	-133.00	-690.00	0.17	0.06

Table 4a Simulation statistics for the events in 2003 with gage rainfall data

	Efficiency		Index of Agreement	
	Uncalibrated	**Calibrated**	**Uncalibrated**	**Calibrated**
Event 1	-0.02	0.57	0.75	0.92
Event 2	-28.60	-52.00	0.36	0.28
Event 3	-31.86	-54.90	0.3	0.28

Table 4b Simulation statistics for the events in 2003 with radar rainfall values

Overall, for the years 2002 and 2003, simulated flow is always overestimated when compared with observed streamflow values (Fig 2a to 2g). The water was routed using Muskingum routing method incorporated in SWAT. The annual water balance for this watershed also overestimated the surface runoff and ground water flow. While the observed annual water yield for the watershed was 33mm out of which 22 mm was surface runoff and 10 mm was ground water flow, remaining being the lateral flow; the simulated values where 80mm of total yield out of which 45mm was surface runoff, 35mm was ground water flow and remaining lateral flow.

Calibration was performed with the parameters being tuned in for increasing the width of the hydrograph and for reducing the amount of surface runoff. The main contribution of the calibration to this watershed runoff simulation was that the lag to peak was drastically decreased from 12-24 hours to 3 to 6 hours. As said in the proposal, the

primary objective of this research is to calibrate the model for decreasing the lag to peak. This task was able to be achieved in very good agreement with observed values.

The volume of the hydrograph is the main concern as can be seen from the simulated values. One of the primary reasons for increased runoff volume is type of rainfall input into the model. Due to the scarcity of raingage network around the watershed (two hourly gages for 321 square miles area of the watershed), the rainfall assigned to each delineated sub watersheds are nearly uniform; which is not of the typical climatic condition of the watershed. Especially, in the upper Trinity River basin, where the topography makes the variation of climate very sensitive to elevation, assigning uniform rainfall to such a big area is not feasible. Hence, the volume produced by raingage rainfall values, after performing calibration, is very large.

Considering the simulated values using radar rainfall, since each sub watershed will be using the rainfall occurred at that particular space, the prediction was in very well agreement with the observed streamflow; including width and timing of the graph. Yet, the volume of flow was always double, in some case, triple the amount of observed flow. The solution to this problem, is to adjust or calibrate the radar rainfall in accordance with the measured raingage values. This can be done by multiply the radar values by the bias between gage and radar total at the pixel. For this purpose, the gage data has to be interpolated using different interpolation techniques such as Inverse Distance Weighted (IDW), spline.

The next step in this study is to use adjusted radar data to improve the volume prediction of hydrograph by the model. Also, this study proposed to use radar data at the resolution of 4Km^2 and after doing the simulation using adjusted radar data, this task will be performed.

Conclusion

The results from the simulations performed for the selected convective storms show that radar data can predict the flow better than the raingage rainfall values. This is mainly due to its ability to capture spatial variability of rainfall across the space; in this case, at every 4 km^2 of the study area. Problem concerning the lag to peak; which was addressed in the proposal, was solved after performing calibration for both gage and radar rainfall values. The parameters that are calibrated were flood attenuation coefficient in

Muskingum routing method, Manning's roughness coefficient, saturated hydraulic conductivity and ground water evaporation coefficient.

This research is extended to study the effect of very high spatial resolution of radar data, at every $4km^2$ of study area and test the model's ability to produce runoff at this grid scale.

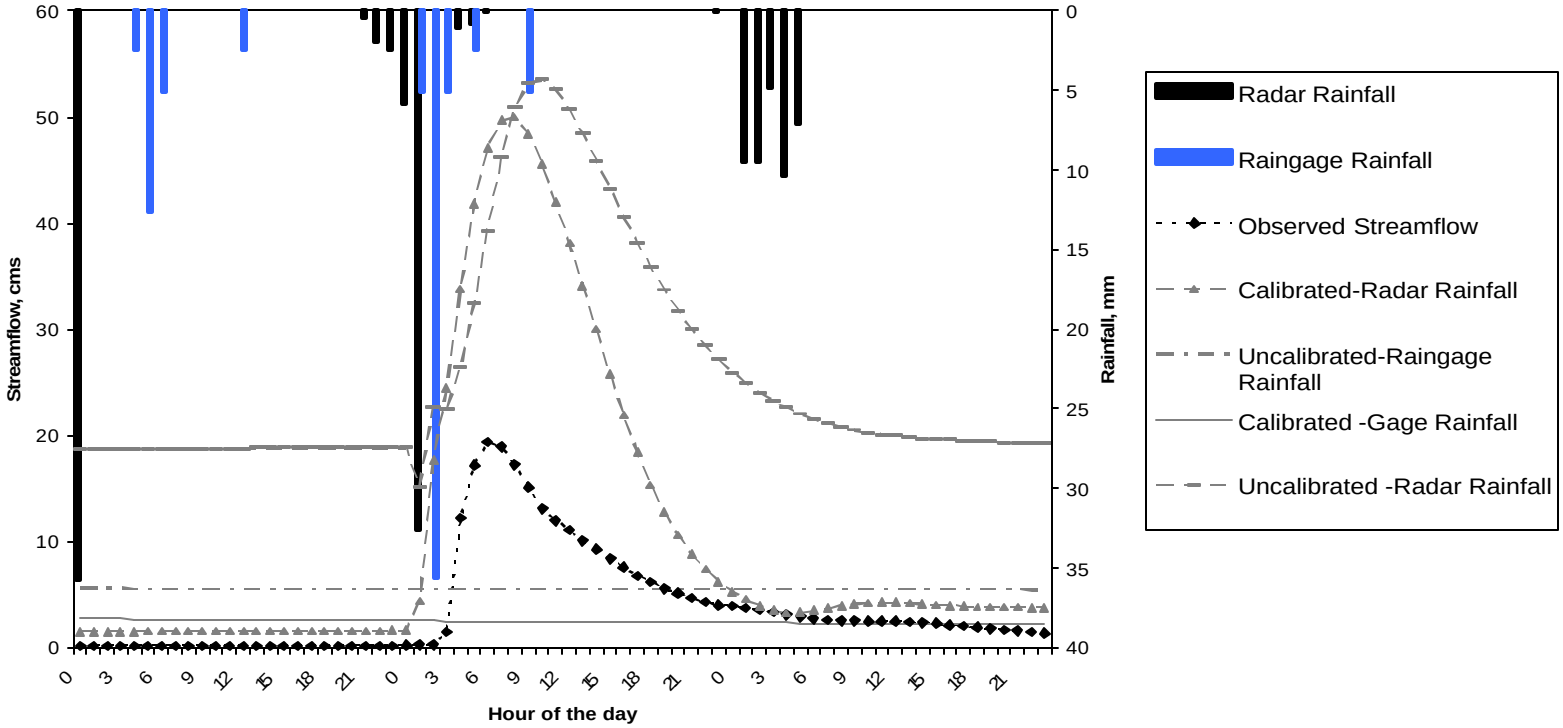

Fig 2a Hourly streamflow comparison for Big sandy creek watershed using for Julian days 144 to 146 of 2002.

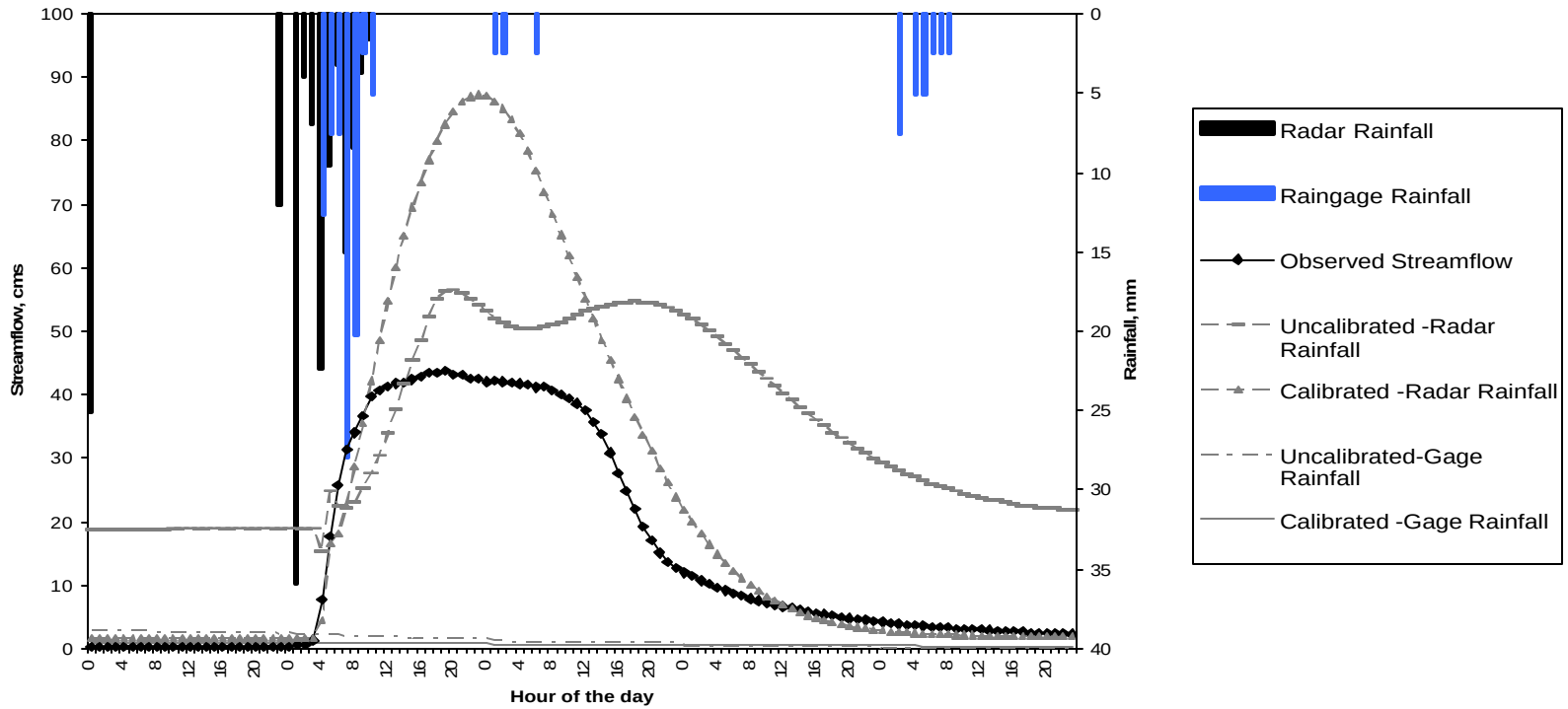

Fig 2b Hourly streamflow comparison for Big sandy creek watershed using for Julian days 155 to 159 of 2002.

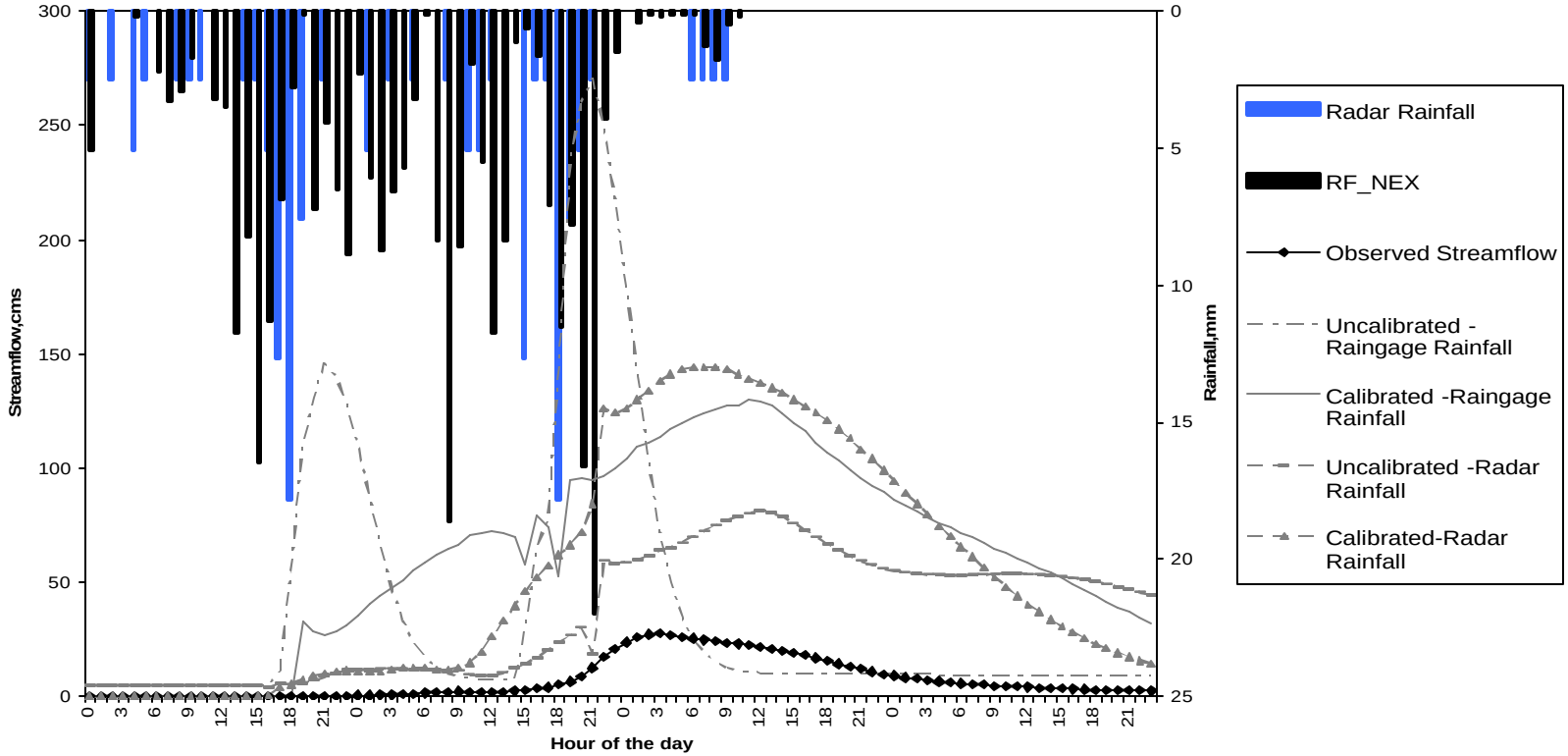

Fig 2c Hourly flow comparison for Big sandy creek watershed in Julian days 77 to 80 of 2002.

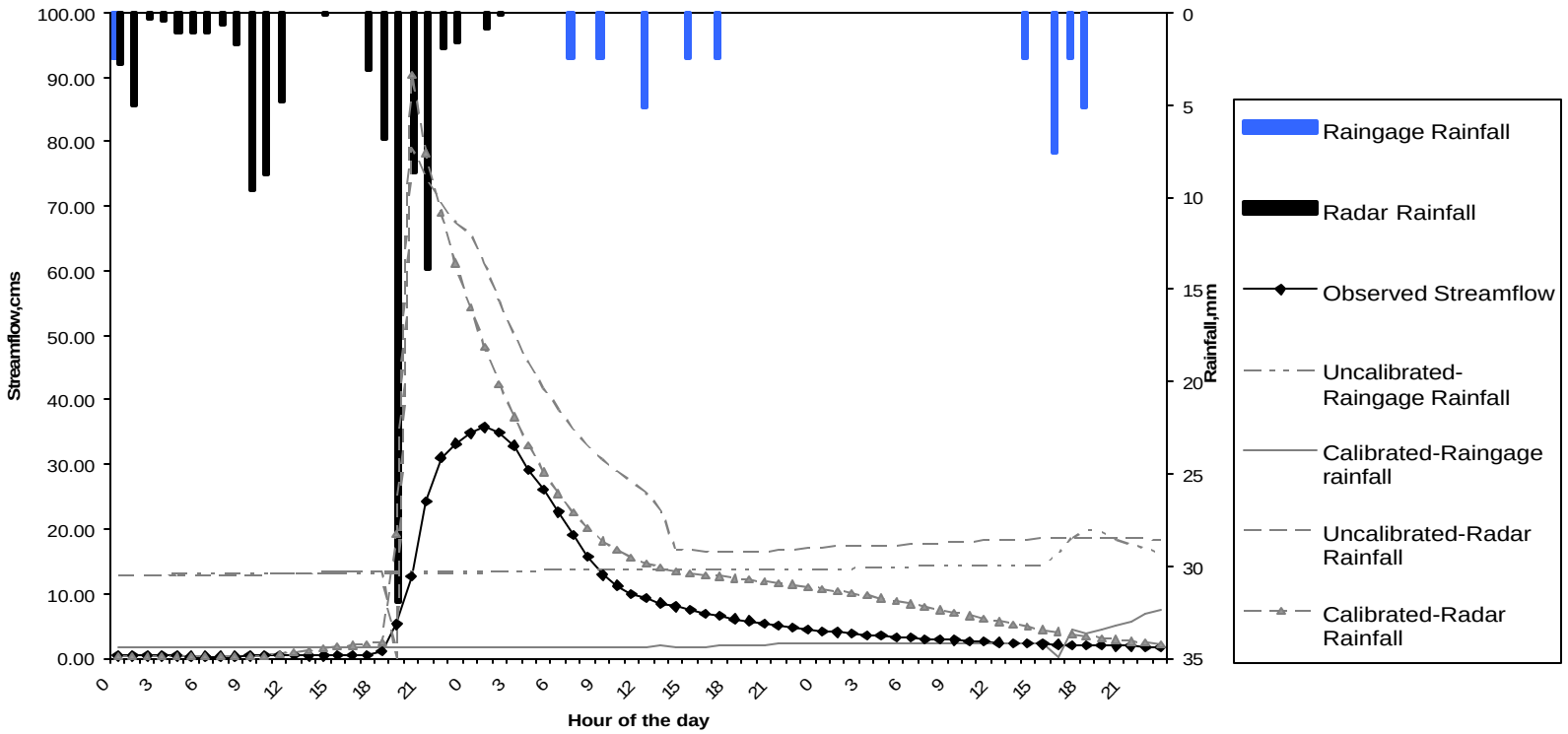

Fig 2d Hourly flow comparison for Big sandy creek watershed in Julian days 89 to 91 of 2002.

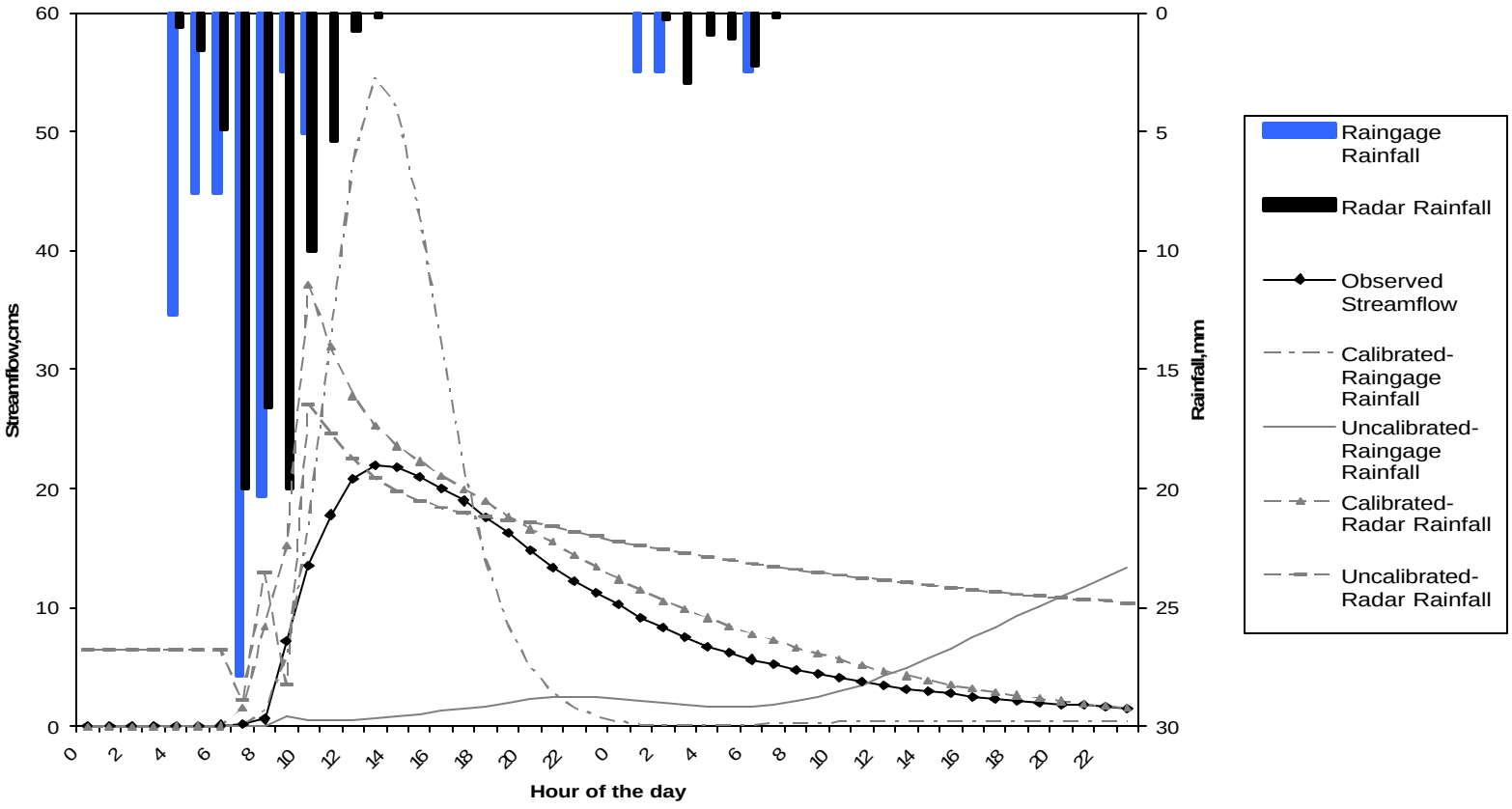

Fig 2e Hourly flow comparison for Big sandy creek watershed in Julian days 156 and 157 of 2003.

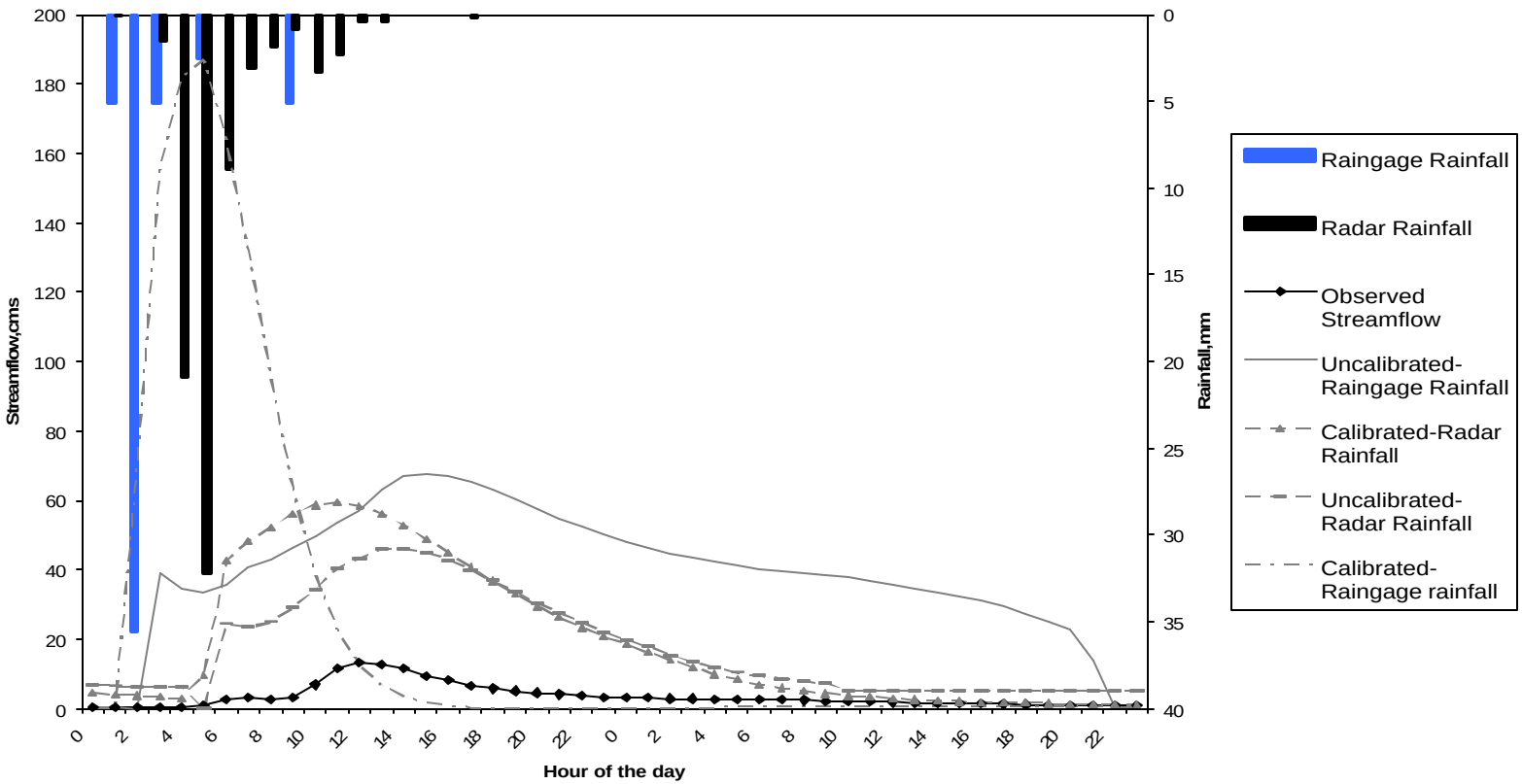

Fig 2f Hourly flow comparison for Big sandy creek watershed in Julian days 145 and 146 of 2003.

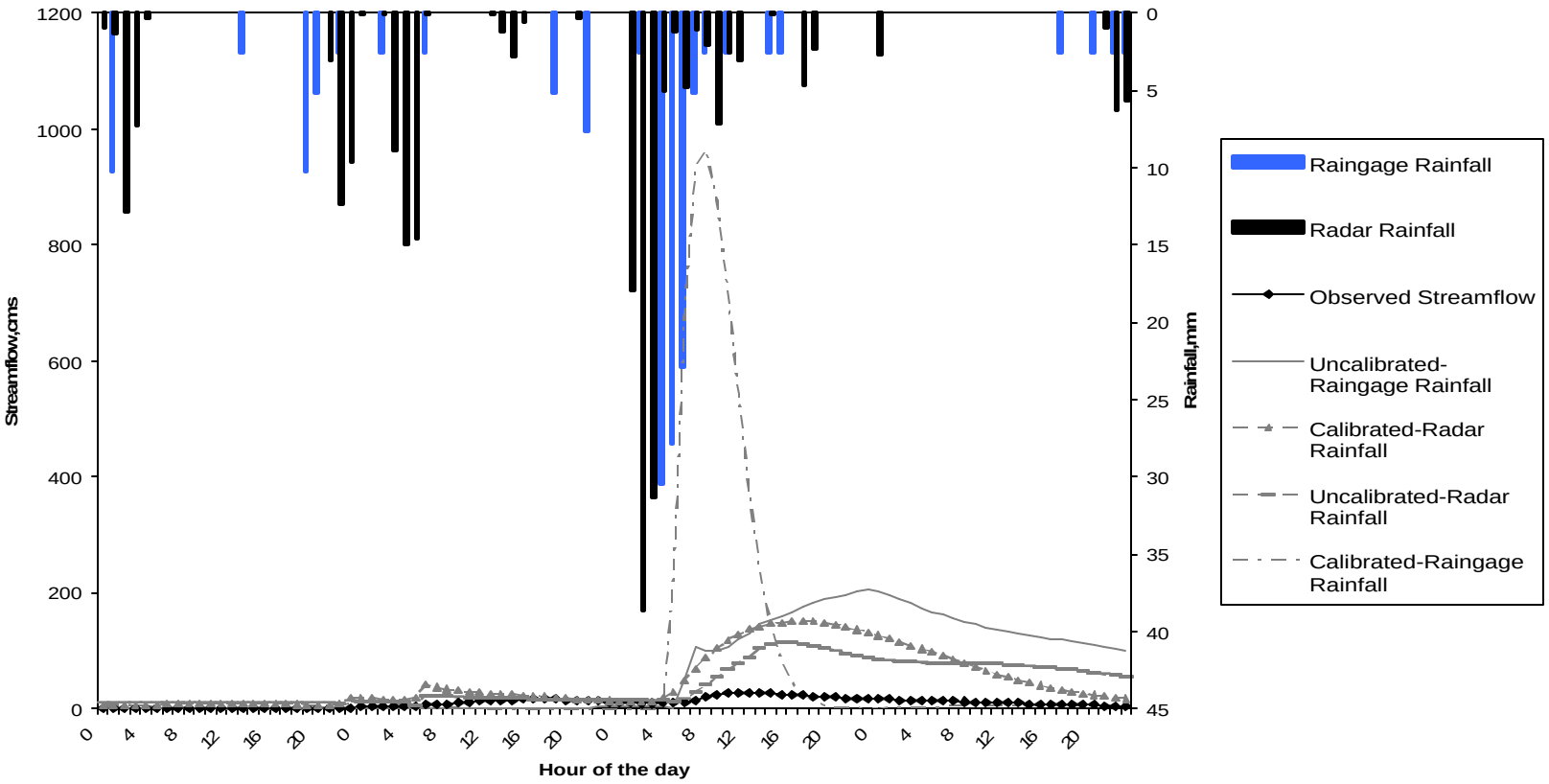

Fig 2g Hourly flow comparison for Big sandy creek watershed in Julian days 162 to 169 of 2003.

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This section explains additional details regarding the project:

The results from the study suggest that the model has to be evaluated for simulation on hourly basis. Mainly, the overland flow routing method for hourly rainfall input should be evaluated carefully to take into account the volume of water routed through the main channel. Also, this study clearly explains the effect of spatial variability of rainfall in runoff estimation. As the spatial and temporal resolution increases, increase in runoff simulation can be achieved. The study is being continued to use bias adjusted radar values and also to evaluate overland flow routing component of the model.