



### 3 Methodology

Hydrological models are always simplified representations of real systems. Within this study, radar observations adjusted to raingauge measurements are assumed to represent true rainfall. The radar images have been corrected accounting for ground clutter contamination and mountain screening effects, Berenguer et al. (2005). The adjustment to ground measurements is realised with regard to the areal mean of radar images and raingauge observations. Together with actual streamflow measurements this rainfall data is used to determine ‘true’ parameter values. The model provided with ‘true’ parameters and ‘true’ rainfall is assumed to be completely deterministic, i.e. truly representing the dynamics of the real system. Within this framework, error free reference hydrographs are generated for a set of rainfall events. For the intended purpose this proceeding is adequate in order to cut off disturbances due to model structure and errors in observed streamflow data.

In a next step, simulation runs are conducted for all events now using input data obtained from different methods to determine areal rainfall. Thus, different degrees of uncertainty of the input variable are introduced to the system. The computed hydrographs are compared to the reference hydrographs and the magnitude and behaviour of the produced residuals as defined in (1) are analysed.

$$\varepsilon_i = Q_{i,ref} - Q_{i,sim} \quad (1)$$

where

$\varepsilon_i$  : error in timestep  $i$

$Q_{i,ref}$  : reference discharge  $i_{th}$  timestep

$Q_{i,sim}$  : simulated discharge  $i_{th}$  timestep

According to the definition of errors in (1) positive and negative residuals correspond to under and overprediction of streamflow respectively. For further analysis of the errors time sequence plots (residuals against time) and residuals against predictions as proposed by Kuczera (1983) are prepared for all sites examined within the basin and at the outlet.

### 4 Case study

The study is carried out in the Besòs river basin (1024 km<sup>2</sup>) situated in the North of Barcelona, Spain. The basin is characterised by its pronounced topographic relief and Mediterranean climate. It is a heterogeneous basin varying from forested mountains in altitudes up to 1000 m asl. to rural planes which undergo a continuous urbanisation process, Corral et al. (2002). Fig. 1 shows the digital elevation model of the study area in the used grid resolution of 1 km<sup>2</sup>. Flow directions are also included as well as the location of evaluation sites marked by the dots labelled in small letters.

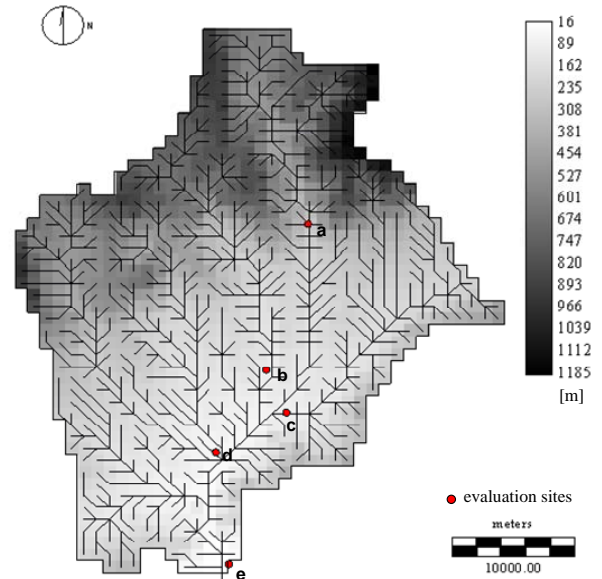


Fig. 1 Study basin, topographic relief, flow paths and evaluation sites

#### 4.1 Hydrological model

For the study the distributed Water Balance raster Model (WBrM), Klawitter (2006); Lempert (2000) is used. WBrM discretises the catchment in square grids which are the minimum units to represent spatial heterogeneity. For each grid cell vertical (infiltration, percolation, evapotranspiration) and lateral (direct runoff, interflow, base flow) process rates are determined depending on actual soil moisture conditions. The model concept consists of a piecewise linear approximation of the basic physical mass balance equations based on conceptual approaches, Ostrowski (1991).

#### 4.2 Precipitation Data

Radar images of the Spanish Weather Service (INM) in a spatial resolution of 1 km<sup>2</sup> and 10 minute intervals are available. In addition, there are 41 telemetered raingauges within the region reporting in 10 minute intervals, Corral et al. (2002).

#### 4.3 Areal rainfall

In contrast to the detailed information on spatial distribution of rainfall provided by radar images often only point observations of rainfall are available in practice. In the context of this work, four methods to represent areal rainfall based on spatial interpolation of raingauge measurements are examined. The first method is based on arithmetic averaging which determines a uniform areal rainfall (UNIF). The second approach is the widely applied Thiessen Polygon Method (TPM). Third, a statistical method, Kriging with External Drift as proposed by Velasco-Forero et al. (2005) is used (EDK). The fourth method is a mathematical interpolation approach based on a spline approximation of the different observations (SPLINE).

## 5 Results

A total of five rainfall events simulated in 10 minute time steps are examined. The application of interpolation methods introduces uncertainty to the input data with regard to the total precipitation depth and its spatial variation. The comparison of the mean accumulated areal rainfall obtained from different interpolation methods shows that UNIF yields a (about 7%) lower areal mean and TPM, EDK and SPLINE exceed the reference value of true rainfall by 2, 7 and 1 %, respectively. The mean squared error of true and interpolated rainfall summed over all grid cells indicates the degree of deviation from the true spatial rainfall distribution. EDK achieves the lowest value. In contrast to its important deviation of mean areal rainfall this method seems to represent the spatial structure best. TPM and SPLINE yield similar but larger values and UNIF produces the largest error.

Taking a hydrological perspective, the simulated hydrographs obtained with different input data are compared. A deviation of simulated runoff volume at the outlet is expected already from the differences of mean accumulated rainfall. However, there is no consistent relation between over and underestimation of precipitation depth and simulated runoff volume. Similar to UNIF, the other methods yield lower runoff volumes. It is noteworthy that the simulation based on EDK results in the best representation of runoff volume although the input data is affected by a clear deviation of mean accumulated areal rainfall. The methods TPM and UNIF perform poorly in this respect as the present error in rainfall depth is inflated to a runoff volume error of 10% and 30% respectively. Apparently, the realistic representation of spatial distribution of rainfall depth and intensity is of great significance for the hydrological processes of runoff generation.

Next, the error structures of the simulated hydrographs are examined with regard to the underlying assumptions of LS parameter estimation. To this end, time sequence plots of the calculated residuals are prepared. In Fig. 2 the temporal evolution of the residuals at the basin outlet (evaluation site e, see Fig. 1) are exemplary shown for one event.

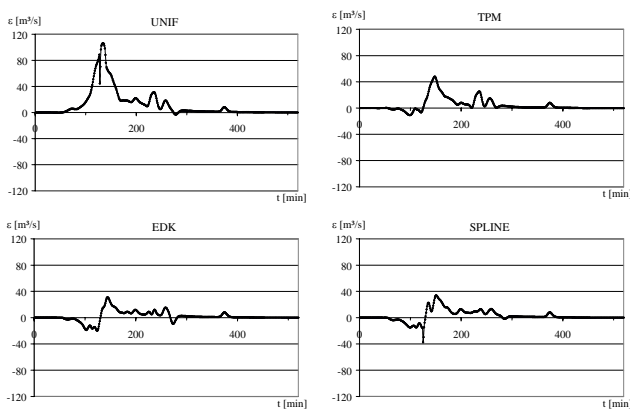


Fig. 2 Time sequence plots of residuals at evaluation site e

It is apparent that the expectation value of the residuals is unequal zero; thus violating assumption II. The positive bias is present for all interpolation methods and is in line with the underestimation of runoff volume discussed before. Besides, a strong autocorrelation of the residuals can be observed challenging assumption IV.

Assumptions II and III are checked by means of a plot of errors as a function of the predictions. In Fig. 3 the sample of errors determined from all events are shown exemplary for evaluation site (a).

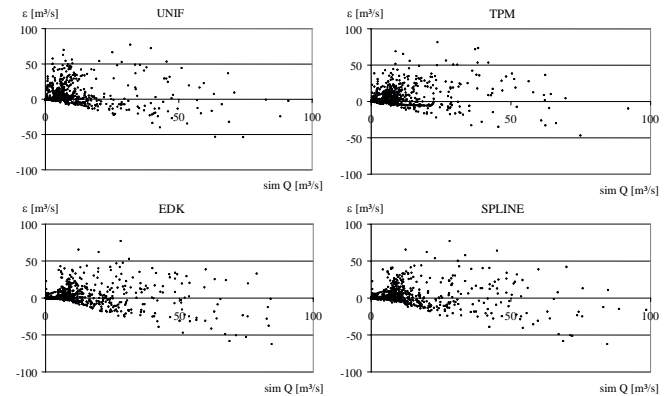


Fig. 3. Plots of errors versus predictions, evaluation site a

Two common features of the error samples can be derived from these plots. First, there seems to exist a negative trend within the error samples. This trend consists in an increasing overprediction of larger discharge values. The observed trend reveals a dependence of the errors on the predictions suggesting a systematic error in the input data. Second, the range of scatter becomes broader for larger discharge streamflow values. This increase of error variability indicates that the variance of the errors is not constant as presumed in assumption II.

It is interesting to check these outcomes at different sites within the basin in order to learn about the spatial variation of the errors associated with different interpolation methods. This is realised for the evaluation sites a to d which coincide with tributaries of different sub basins. Essentially, the examination of the error plots reflects the findings as discussed above: negative trend and increasing variability of errors. However, the slope of the trend varies for the different sites examined. This suggests a spatial variation of the extent of systematic error present in the input data, i.e. the goodness of approximation of the precipitation field varies within the basin.

A distinction has to be made with regard to site c. The prediction errors for this sub basin are comparatively small and the errors do not exhibit the general trend identified, but show a peculiar dependence on predictions for each event examined. In contrast to the other sub basins the runoff volume at site c is overpredicted for all interpolation methods. This quality can be attributed to the fact that the precipitation in that area tends to be overpredicted by areal

rainfall interpolation. As a consequence the errors of the remaining tributaries are partially compensated.

## 6 Conclusions

The impact of uncertainties in input data as a result of simplified representation of areal rainfall on the errors of simulated streamflow has been analysed. The features of the produced errors do not comply with the basic assumption of LS parameter estimation. Particularly, the errors are not independent of each other and depend on the predictions. They are systematically biased and the error variance is not constant. In addition, the errors show a clear spatial variation. From the hydrological evaluation it becomes apparent that an accurate representation of spatial rainfall distribution is of great importance for the reproduction of runoff generation processes and, in turn, for the quality of modelling results.

The error features identified have to be considered in model calibration. The following methods are conceivable to improve parameter estimates of distributed hydrological models. Data transformation is adequate to stabilise the observed variation of error variance, autocorrelation of the errors can be met with auto regressive time series models (as described by Kuczera (1983) and Troutman (1985b)). Furthermore, adjustment factors of the input variables can be applied to lessen the systematic error, e.g. by multiplication of rainfall depths. Also, the spatial variability of the errors has to be addressed. A multi-site calibration scheme relating to sub-basins based on Multi-Objective Optimisation Algorithms (e.g. as presented by Muschalla et al. (2005)), is a convenient approach to realise an internal evaluation of simulated variables. This calibration concept permits a site-specific adjustment of parameters, thus lessening compensation effects within the basin, as well as a consideration of error properties adapted to the particular sub basin.

The results obtained from this study should be confirmed by the analysis of more events. Nevertheless, they offer a suitable basis to implement and test the impact and benefit of the described methods to improve parameter estimates. Current research work at IHWB is going on in this direction.

## References

- Berenguer, M., Corral, C., Sanchez-Diezma, R. and Sempere-Torres, D., 2005: Hydrological validation of a radar-based nowcasting technique. *Journal of Hydrometeorology*, **6**(4): 532-549.
- Corral, C., Berenguer, M., Sempere-Torres, D. and Escaler, I., 2002: Evaluation of a conceptual distributed rainfall-runoff model in the Besòs catchment in Catalunya using radar information, 2nd European Conference on Radar in Meteorology (ERAD), Munich, pp. 409-415.
- Kavetski, D., Franks, S.W. and Kuczera, G., 2003: Confronting Input Uncertainty in Environmental Modelling. In: Q. Duan, Gupta, H., Sorooshian, S., Rousseau, A.N., Turcotte, R. (Editor), Calibration of Watershed Models. Water Science and Application. American Geophysical Society, Washington.
- Kavetski, D., Kuczera, G. and Franks, S.W., 2006: Bayesian analysis of input uncertainty in hydrological modeling: 1. Theory. *Water Resources Research*, **42**(3).
- Klawitter, A., 2006: Ein Modellkonzept zur integrativen Betrachtung von Urban- und Ruralhydrologie auf Einzugsgebietsebene, Technische Universität Darmstadt, Darmstadt, 146 pp.
- Kuczera, G., 1983: Improved Parameter Inference In Catchment Models .1. Evaluating Parameter Uncertainty. *Water Resources Research*, **19**(5): 1151-1162.
- Lempert, M., 2000: Ein GIS-gekoppeltes rasterbasiertes Modell zur Berechnung des Wasserhaushaltes kleiner Einzugsgebiete, Technische Universität Darmstadt, Darmstadt. 183 pp
- Muschalla, D., Ostrowski, M., Schröter, K. and Wörsching, S., 2005: Integrated modelling and multi-objective evolution strategy as a method for water quality oriented optimization of urban drainage systems, 10th ICUD International Conference on Urban Drainage, Copenhagen Denmark.
- Ostrowski, M., 1991: The Effect of Data Accuracy On The Results Of Soil Moisture Modeling. *IAHS Publication*, **204** (Hydrological Interaction between atmosphere, soil and vegetation).
- Oudin, L., Perrin, C., Mathevet, T., Andreassian, V. and Michel, C., 2006: Impact of biased and randomly corrupted inputs on the efficiency and the parameters of watershed models. *Journal of Hydrology*, **320**(1-2): 62-83.
- Singh, V.P. and Woolhiser, D.A., 2002: Mathematical Modeling of Watershed Hydrology. *Journal of Hydrologic Engineering*, **7**(4): 270-292.
- Troutman, B.M., 1983: Runoff Prediction Errors And Bias In Parameter-Estimation Induced By Spatial Variability Of Precipitation. *Water Resources Research*, **19**(3): 791-810.
- Troutman, B.M., 1985a: Errors And Parameter-Estimation In Precipitation-Runoff Modeling .1. Theory. *Water Resources Research*, **21**(8): 1195-1213.
- Troutman, B.M., 1985b. Errors And Parameter-Estimation In Precipitation-Runoff Modeling .2. Case-Study. *Water Resources Research*, **21**(8): 1214-1222.
- Velasco-Forero, C., Sempere-Torres, D., Sánchez-Diezma, R., Cassiraga, E. and Gómez-Hernández, J., 2005: Automatic estimation of rainfall fields for hydrological applications: blending radar and rain gauge data in real time, 32nd Conference on Radar Meteorology, Albuquerque-EUA, pp. --.