CARPE DIEM
CENTRE FOR WATER RESOURCES RESEARCH
DELIVERABLE X 2
HYDROLOGICAL MODEL COMPARISON AND EFFECTS OF SPATIAL VARIABILITY
DRAFT

by

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Chapter 1

Discharge-based assessment for use in flood monitoring and forecasting

1.1 Introduction

It is one thing to compare the performance of various methods of estimating precipitation. However, the purpose of a flood forecasting system is to predict the timing and magnitude of discharge peaks. Thus it is appropriate that the value of the various data sources and models be assessed in terms of their contribution to peak flow estimation.

1.2 Performance criteria for flow rate estimation

Various equations are used to assess the performance of the different flow prediction techniques. Those are the basis for the comparison between the computed hydrographs and the measured hydrographs. The first three function take into account of the whole time-series (MSE, MRs, MAE, Nash), the next two focus on the peak estimation (NPE, ANPE) and the last two on the peak timing estimation (PTE, APTE). Peak timing and estimation optimisation is a requirement for a flood forecasting system. Those criteria are therefore extremely important in the context of this study. MSE and MRs can be computed both for continuous discharge values and peak values. Peaks are picked up in the recorded flow series, and the simulated flow rates are compared to them.

Notation:

- Q_{o_i}: the observed flow discharge at time step i,
- Q_{c_i}: the computed flow discharge at time step i,
- n: the number of time intervals or the number of flow peaks considered.

1.2.1 The Mean square error (MSE)

The MSE function is defined as:

$$MSE = \frac{1}{n} \sum_{i=1}^{n} \left(Q_{c_i} - Q_{o_i}\right)^2 \tag{1.1}$$

It is to be noted that the MSE emphasises errors of high absolute values.

1.2.2 Mean of residuals (MRs)

The mean of residuals, noted MRs is the mean of the differences between two data series:

$$MRs = \frac{1}{n} \sum_{i=1}^{n} \left(Q_{c_i} - Q_{o_i}\right) \tag{1.2}$$

It gives us information on the bias in flow rate estimates.

1.2.3 The Mean absolute error (MAE)

The error is measured in absolute terms. The MAE function is defined as:

$$MAE = \frac{1}{n} \sum_{i=1}^{n} |Q_{c_i} - Q_{o_i}| \tag{1.3}$$

1.2.4 The Nash criterion (NC)

Also known as the R^2 efficiency criterion, the Nash criterion (Nash and Sutcliffe, 1970) may be expressed as:

$$NC = 1 - \frac{MSE}{F_o} \tag{1.4}$$

where MSE denotes the Mean Square Error and is defined as:

$$MSE = \frac{1}{n}\sum_{i=1}^{n}\left(Q_{c_i} - Q_{o_i}\right)^2 \tag{1.4$'$}$$

and F_o is expressed as:

$$F_o = \frac{1}{n}\sum_{i=1}^{n}\left(Q_{o_i} - \overline{Q_{cal}}\right)^2 \tag{1.4$''$}$$

where $\overline{Q_{cal}}$ is the long-term average of the observed flow over the calibration period. The Nash criterion may also be expressed as a percentage.

The following points regarding the NC are worth noting:

- the quantity is non-dimensional,
- its upper limit is 1,
- this criterion is an expression of the relative improvement of the substantive model over a notional primitive model equivalent to the long-term mean,
- the criterion may assume values less than zero in calibration.

A subjective notion based on the modeler's experience is relied upon to assess the model efficiency evaluated in terms of NC. The experience indicated that a NC value in the range over 90% is indicative of a very good model performance, that in the range 80%-90% it is indicative of a fairly good level of performance whereas less than 80% it may be considered that the model fit is unsatisfactory.

1.2.5 The Normalised peak error (NPE)

For a single event, the NPE is defined as, after Masnoudi and Habaieb (1993):

$$NPE = \frac{Q_c^{max} - Q_o^{max}}{Q_o^{max}} \tag{1.5}$$

where Q_c^{max} is the computed peak discharge and Q_o^{max}. It represents the relative error between the observed and the computed flow peak for one event. The computed peak is defined as the highest value of the 9 computed flow estimates around the time of the corresponding observed peak. The observed peak is defined as a value higher than 15 m^3/s, being preceded by two increasing values and followed by two decreasing values.

1.2.6 The Average normalised peak error (ANPE)

Following Equation (1.5) and for a number of events n, the ANPE is defined as:

$$ANPE = \frac{1}{n}\sum_{j=1}^{n}\left|\frac{Q_{c_j}^{max} - Q_{o_j}^{max}}{Q_{o_j}^{max}}\right| \tag{1.6}$$

where $Q_{c_j}^{max}$ is the corresponding computed peak discharge in peak j and $Q_{o_j}^{max}$ is the observed peak discharge in peak j. It represents the average relative error between the observed and the computed flow peaks considered.

1.2.7 The Peak timing error (PTE)

For a single event, the PTE is defined as:

$$PTE = T_c^{max} - T_o^{max} \tag{1.7}$$

where T_c^{max} is the time of occurrence of the computed peak discharge and T_o^{max} is the time of occurrence of the the observed peak discharge.The PTE is the difference in the time of occurrence of the computed and observed peak discharges for one event.

1.2.8 The Average peak timing error (APTE)

Following Equation (1.7) and for a number of events n, the APTE is defined as:

$$APTE = \frac{1}{n}\sum_{j=1}^{n}\left|T_{c_j}^{max} - T_{o_j}^{max}\right| \tag{1.8}$$

where $T_{c_j}^{max}$ is the time of occurrence of the computed peak discharge in peak j and $T_{o_j}^{max}$ is the time of occurrence of the observed peak discharge in peak j. It is the average difference in the time of occurrence of the computed and the observed flow peaks considered.

1.3 Conclusion

Adjustment factors are used to correct radar estimated rainfall. They are derived from the comparison of raingauge with radar. We define six different adjustment factors in this Chapter. A new adjustment factor, based on the minimisation of the mean square error is presented. Three spatial adjustment factors and three uniform adjustment factors are defined. Different statistics are defined for the purpose of comparing rainfall estimates and flow rates series. For the comparison of peak flows, comparative statistics assessing the error in peak estimation and in peak timing estimation, which are important for flood forecasting, are introduced (ANPE, APTE).

Chapter 2

Analysis of flow rate estimates

2.1 Introduction

The accuracy of the flow rate time-series obtained using the three catchment models (see Chapter ??) and the different precipitation input estimates, including raingauges, adjusted and raw radar data, is assessed in this Chapter. First, the calibration of the hydrological models is described. Then, the results for the different simulations are given.

2.2 Calibration of the models and simulation runs

The three models considered, namely the unit-hydrograph, SMARG and Topkapi are calibrated using the calibration year 2002/2003 (H0203) with hourly data. The physically based model Topkapi is calibrated using the raingauge data (T1). The SMARG and the unit-hydrograph are calibrated for each type of rainfall. A simulation using the parameters fitted for the calibration year is produced both for the calibration and the validation years.

2.2.1 Unit-hydrograph

The unit-hydrograph was calibrated for a set of storm events selected in the year H0203 (see Table 2.1). The types of rainfall considered were: T4, T5, T61, T62, T7, T81, T82 and T83 and a unit-hydrograph was computed for each rainfall type (see

Figure 2.1 and 2.2 for the calibration of the UH on the raingauge and the radar. The other radar UH are similar).

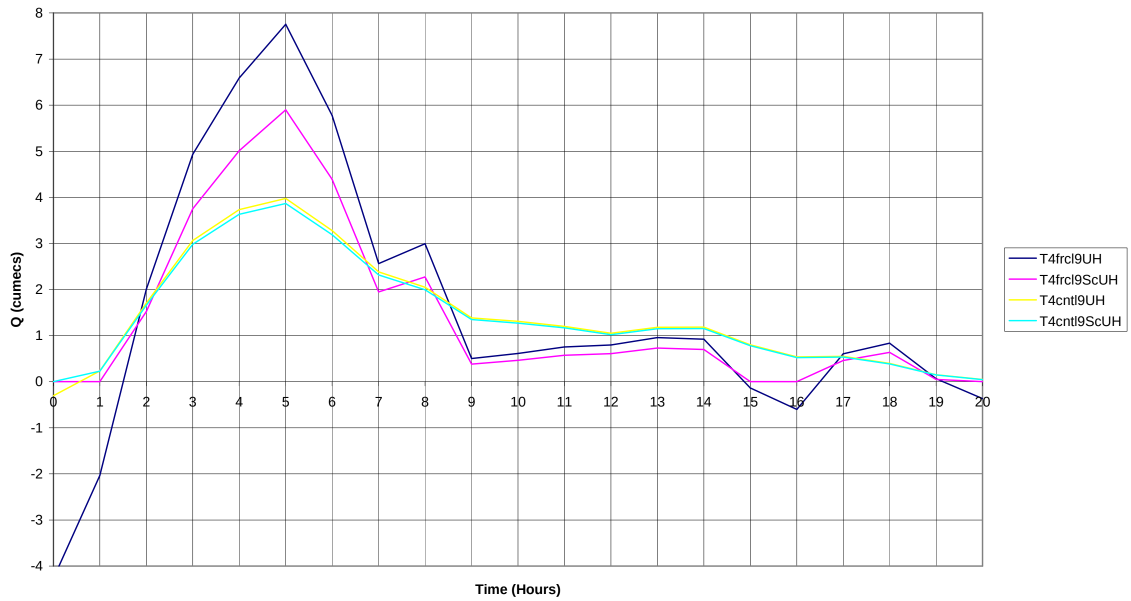

Figure 2.1: UH for Rain T4

The direct runoff was estimated using a straight line between the beginning of the rise of the hydrograph and the start of the slow recession period. For each type of rainfall considered, effective rainfall was computed using two different methods: (1) constant fraction and (2) constant rate, so that the volume of effective rainfall equates the volume of the direct runoff.

Fortran program "ker6tm" (Bruen and Dooge, 1984) was used to compute the unit-hydrograph ordinates with memory length of 20. No prior information was input and ridge regression was not applied.

The flow was then convoluted from the effective rainfall and the baseflow added for year H0203. For the validation year H0304, effective rainfall was derived using the loss function parameters in Table 2.2, which were derived for year H0203. The baseflow was removed using flow values derived for year H0203 (see Table 2.3). Refer to Figures 2.3, 2.4, 2.5, 2.6, 2.7, 2.8, 2.9, 2.10 for examples of results.

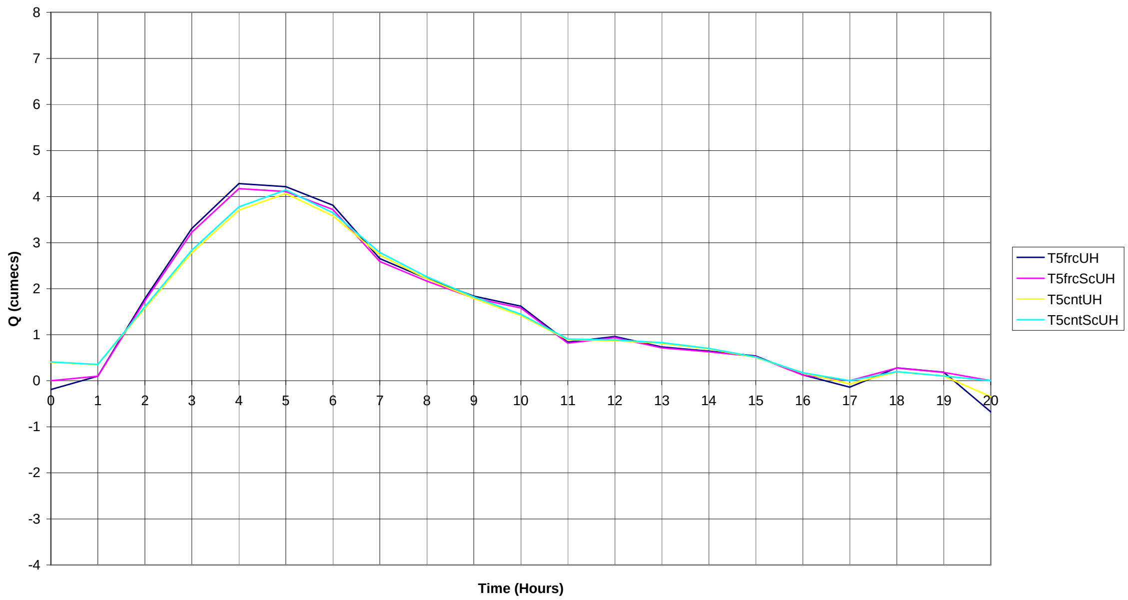

Figure 2.2: UH Rain T5

Year H0203		Year H0304	
Storm event ID	Period (days)	Storm event ID	Period (days)
St1	243-268	Stv1	498-561
St2	671-699	Stv2	708-745
St3	776-799	Stv3	992-1016
St4	1051-1107	Stv4	1045-1066
St5	1353-1419	Stv5	1417-1441
St6	1948-1974	Stv6	1484-1508
St7	2587-2608	Stv7	2552-2589
St8	2664-2687	Stv8	6375-6392
St9	3604-3662	Stv9	7729-7756
St10	4946-4969	Stv10	7768-7793
St11	5165-5198	Stv11	7831-7874
St12	5883-5912		
St13	6527-6548		

Table 2.1: Storm events used for the UH method.

Period and parameter	T4	T5	T61	T62	T7	T81	T82	T83
Summer frc	10.78	3.09	9.06	6.00	3.52	10.45	6.90	9.71
Summer cnt	3.55	0.61	3.28	1.81	0.76	3.81	2.20	3.44
Winter frc	5.39	1.75	5.05	3.33	1.90	5.60	3.72	5.23
Winter cnt	2.37	0.34	2.95	1.41	0.40	3.50	1.70	3.03

Table 2.2: Parameters of the loss functions.

Period in a year (days)	Baseflow (m^3/s)
1-1200	1.0
1200-3800	3.0
3800-end	3.0 down to 1.0 (line)

Table 2.3: Baseflow values.

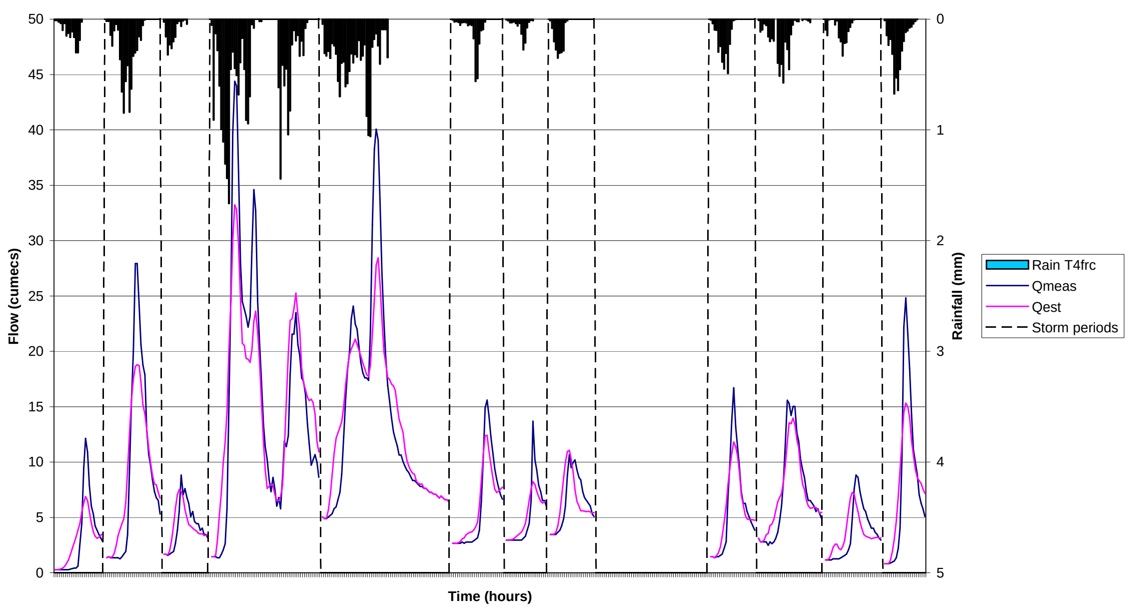

Figure 2.3: UH results for Rain T4frc over h0203

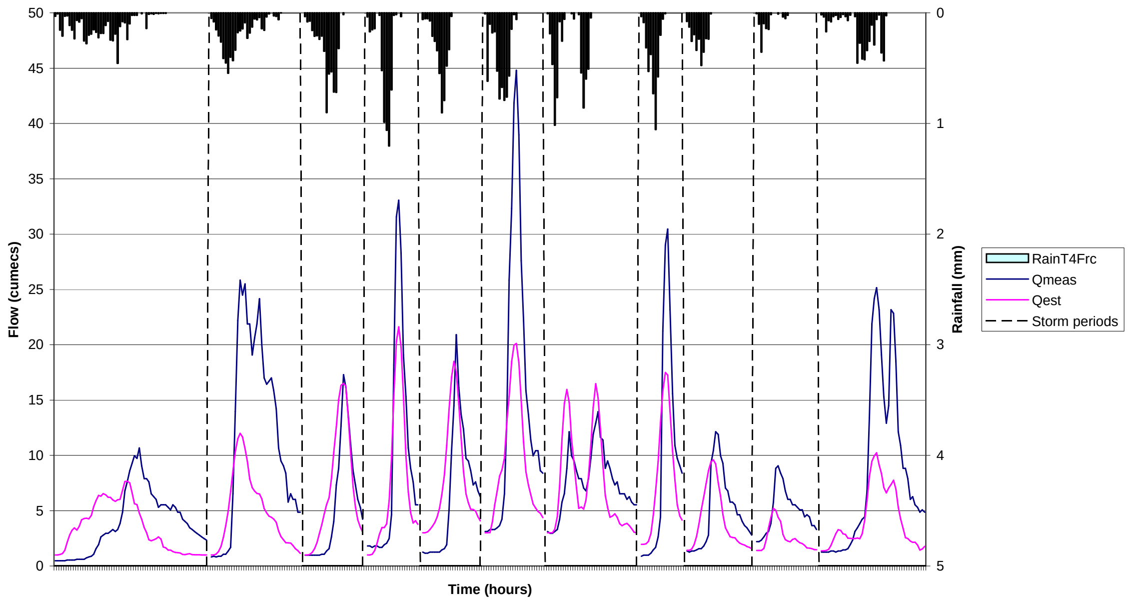

Figure 2.4: UH results for Rain T4frc over h0304

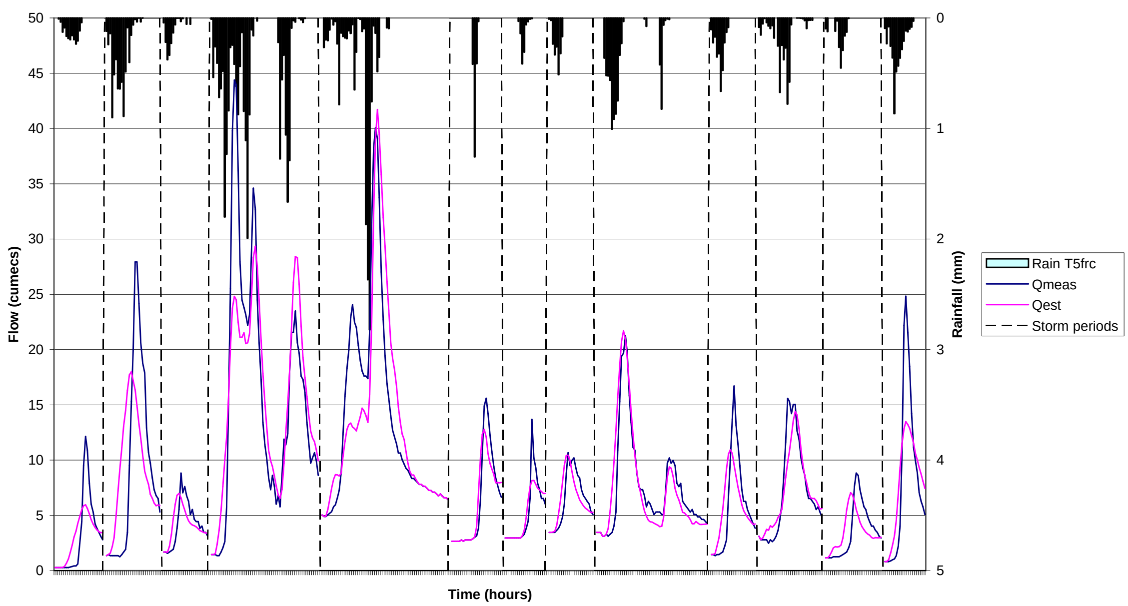

Figure 2.5: UH results for Rain T5frc over h0203

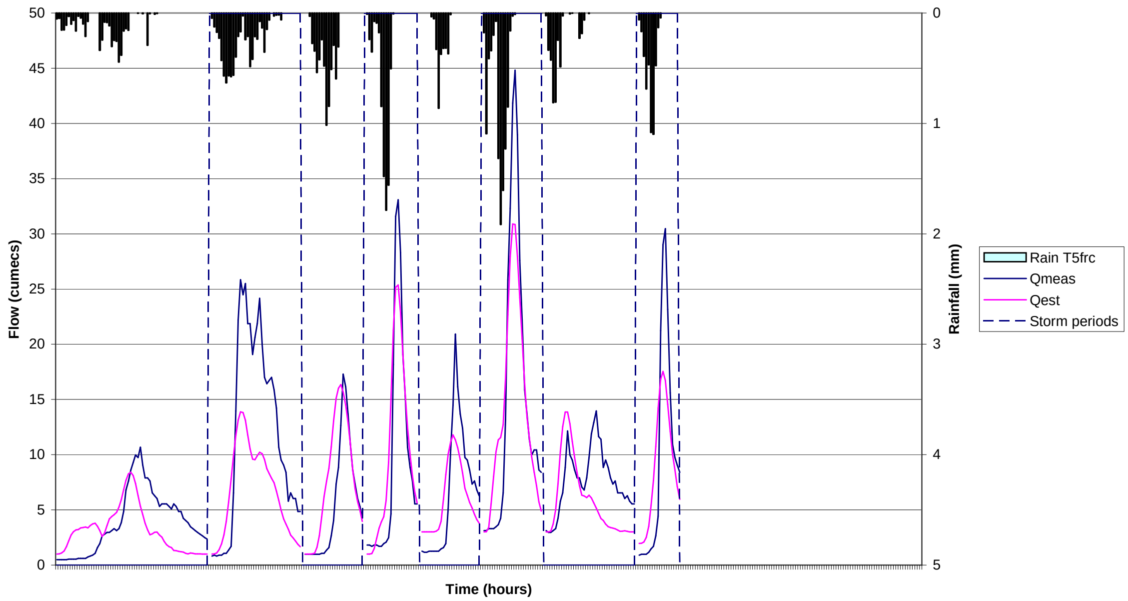

Figure 2.6: UH results for Rain T5frc over h0304

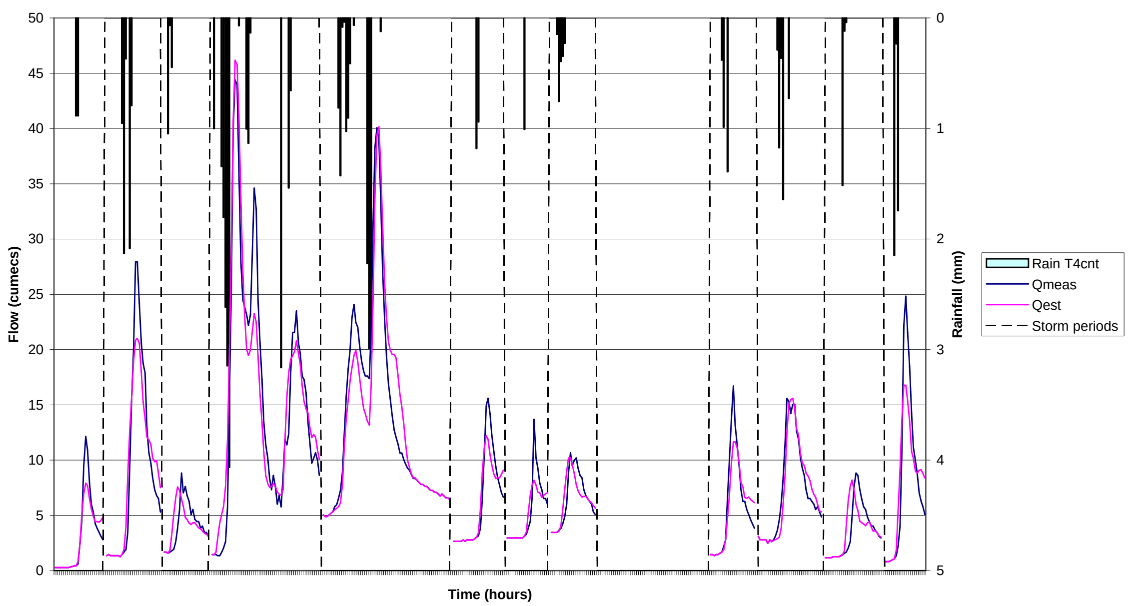

Figure 2.7: UH results for Rain T4cnt over h0203

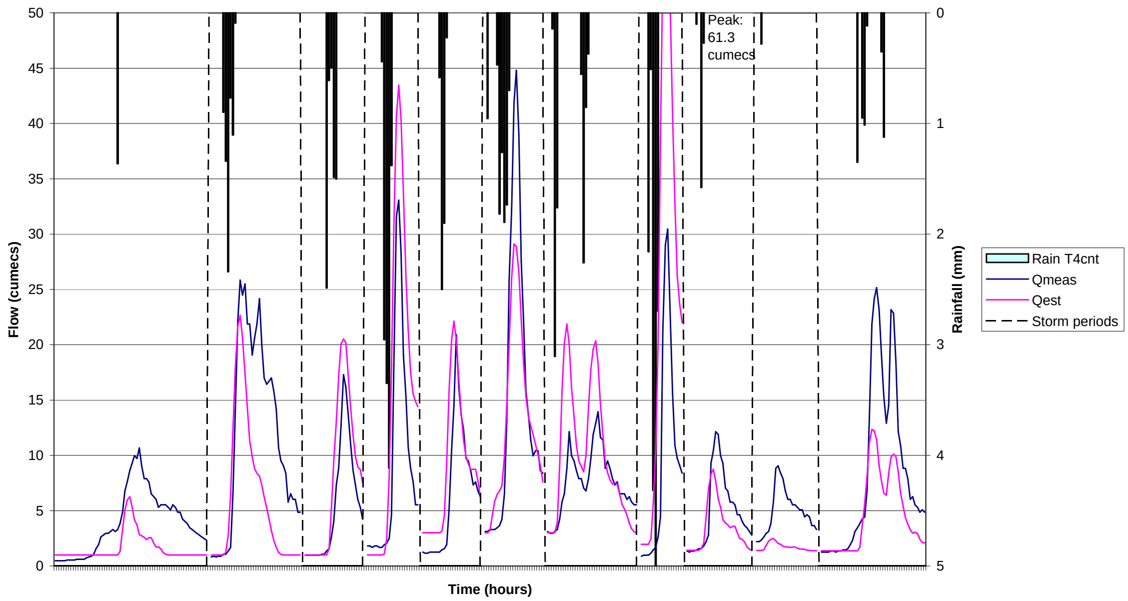

Figure 2.8: UH results for Rain T4cnt over h0304

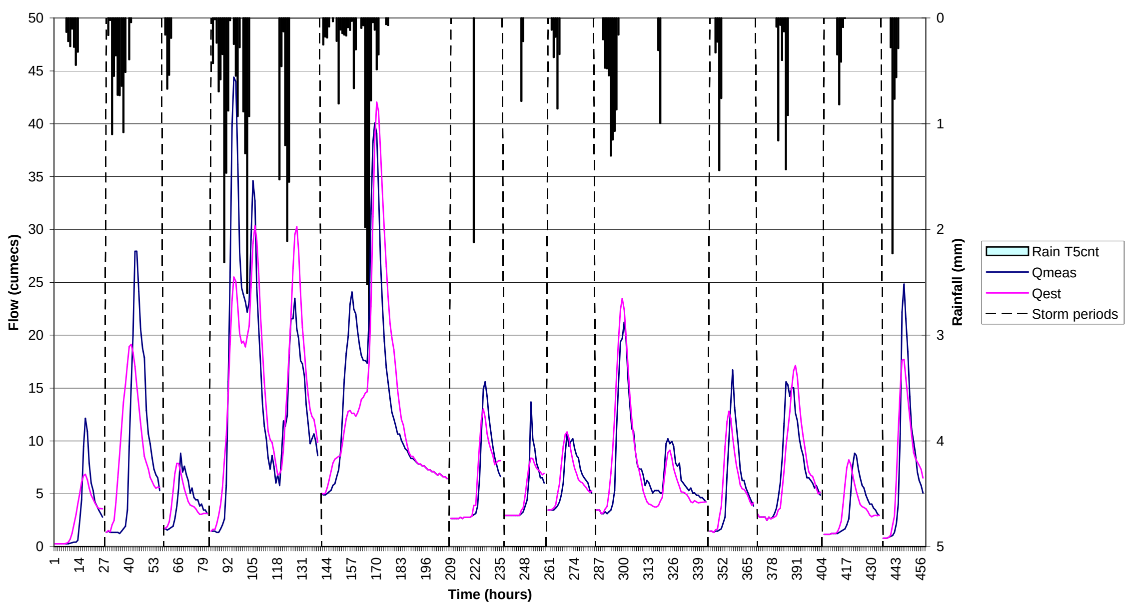

Figure 2.9: UH results for Rain T5cnt over h0203

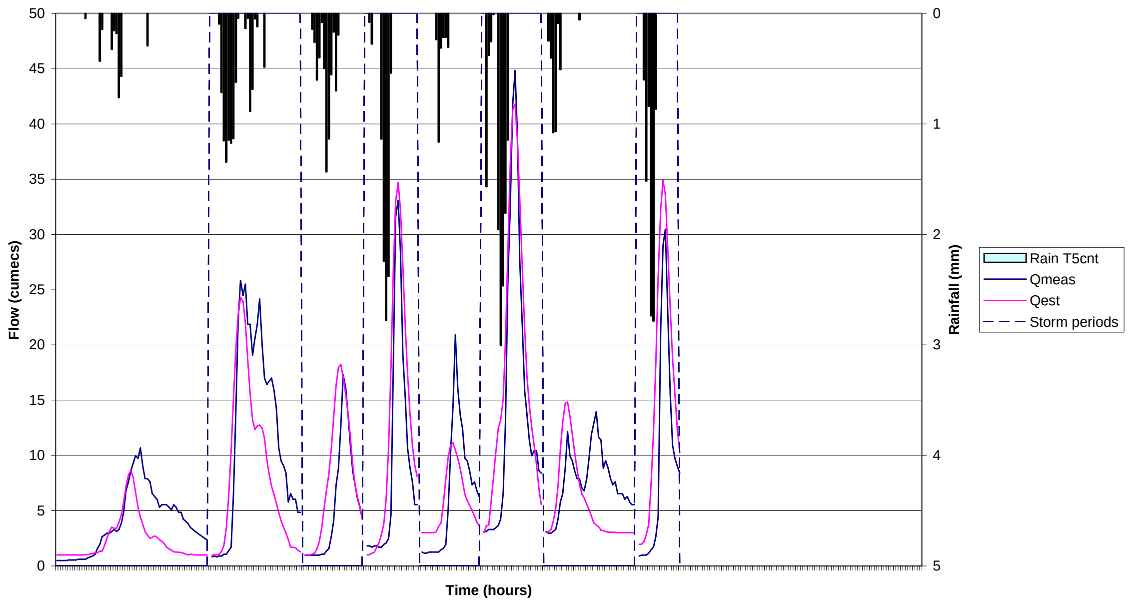

Figure 2.10: UH results for Rain T5cnt over h0304

2.2.2 SMARG model

The SMARG model was calibrated using evaporation, rainfall and flow rate data for year H0203. The model was calibrated for the uniform rainfall types: T4, T5, T61, T62, T7, T81, T82 and T83.

A specific objective function was fitted to the source code in order to optimise the simulated peak flow values. Peak were selected with a threshold of 15 m^3/s and at least two rising preceding ordinates and two decreasing subsequent ordinates.

Initial parameters values were selected from a previous run with the visual version of the model (see Table 2.4). The karstic parameter was set to 0 value. A unit-hydrograph memory length of 15 was chosen, as it is about 3 to 4 times the time to peak for the catchment considered. The fitted parameters for each input types are found in Table 2.4.

The simulation for the calibration and validation years were run with the same program, which can calibrate and simulate the flow for two subsequent periods.

Param.	Initial set up			Fitted parameters for each input type							
	Init.	Min	Max	T4	T5	T61	T62	T7	T81	T82	T83
T	0.557	0.5	1.0	0.99	0.50	0.99	0.88	0.57	0.82	0.68	0.82
H	0.031	0	1	0.004	0.76	0.10	0.44	0.79	0.00	0.00	0.00
Y	100	10	100	16.5	43.9	49.2	42.2	59.1	39.4	54.7	32.3
Z	102	25	125	114.3	114.3	25.0	25.0	113.3	25.1	124.9	25.1
C	0.92	0.50	1.00	0.79	0.72	0.89	0.75	0.78	0.76	0.99	0.71
F	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
G	0.81	0.0	1	0.65	0.04	0.74	0.76	0.0	0.75	0.75	0.73
N	1.79	1	10	1.03	2.62	1.83	1.92	1.00	1.00	1.00	1.00
NK	8.07	1	10	9.99	7.15	9.99	9.46	6.41	7.77	2.20	7.49
G	1384	1	6000	395	1.00	325	210	1083	421	304	378

Table 2.4: Initial and fitted SMARG parameters.

2.2.3 TOPKAPI model

The TOPKAPI model was calibrated using temperature, rainfall and flow rate data for year H0203. The model was calibrated for the all the available rainfall types.

The calibration was carried out manually using rainfall raingauge type T1. Physically realistic parameters were first used, using USDA tables and previous knowledge on the catchment. They were then tuned to optimise the simulation for peak flows. The fitted parameters can be found in Table 2.5 below.

Evaporation component					
K_{evap}=0.8					
Soil component Soil type (Irish clas.)	k_s	ν_s	ν_r	α	L
Peaty podzols (1)	1.2E-04	0.453	0.041	2.5	3.00
Lithosols-outcropping(4)	1.2E-04	0.453	0.041	2.5	3.00
Brown podzolics (8)	8.5E-05	0.453	0.041	2.5	3.0
Brown podzolics (9)	6.0E-04	0.463	0.027	2.5	3.0
Grey brown podzolics (30)	8.5E-05	0.453	0.041	2.5	3.0
Grey brown podzolics(38)	8.5E-05	0.463	0.027	2.5	3.0
Surface component Class	n_o				
Pasture	0.035				
Non agric. vegetation	0.105				
Forest	0.100				
Arable	0.040				
Building and grounds	0.025				
Channel component Channel order	n_c				
1	0.090				
2	0.060				
3	0.050				

Table 2.5: TOPKAPI fitted parameters.

Initial conditions normally influence the model output for the beginning of the simulation. However, taking a dry enough period to start the simulation, and using a full year, the effect of the initial conditions on the overall model performance are negligible. This would not be true if only short period (e.g. a few hours) was considered for the simulation.

A sensitivity study was carried out to investigate the model sensitivity to the changes in its parameters. It is noticeable that the thicker the soil layer is, the smaller the peaks are, the soil layer acting as a huge storage reservoir in the model.

The model is run for the validation year using the same set of parameters.

2.3 Comparison of flow rates data from models simulations

An analysis is performed on the simulated discharges from the three models considered. Charts and statistics are provided for the whole year periods to compare SMARG and TOPKAPI and for the periods corresponding to the unit-hydrograph storm events only to compare SMARG, TOPKAPI and the unit-hydrograph method (noted UH).

Dublin Airport weather radar was down due to maintenance operations: from 12 August 2003 to 2 September 2003 (in H0203) and from 14 August 2004 to 7 September 2004 (in H0304). The data for those periods are excluded from the analysis.

2.3.1 Comparison of SMARG and TOPKAPI over the entire periods

Comparative statistics for the two years 2002/2003 (calibration) and 2003/2004 (validation) are computed, taking the observed flow rates as the reference.

MSE, MRs and MAE statistics were computed for the continuous flow rate estimates series (see Tables 2.6, 2.7, 2.8).

MSE, MRs, ANPE and APTE statistics were calculated for the peaks only (see Tables 2.9, 2.10, 2.11, 2.12). There were 14 peaks in the calibration year and 7 peaks in the validation year in the observed flow series.

As the two hydrological models were calibrated for the peaks, interpretations are made of the results for the peak statistics. In terms of peak MSE, the best performance for TOPKAPI is for T1 and T4 in calibration. Results are poorer in validation, except for corrected radar T31, T61, T83 and T101 which are better than the raingauge T1. For the SMARG results are best for T4 and T61 in calibration. Results are slightly worse in validation. There is no obvious improvement in the TOPKAPI results using spatial rainfall input. SMARG results are in most cases better than TOPKAPI results, especially for raw radar data.

As for the residuals peak MRs, TOPKAPI performs best with T1 in calibration. Uncorrected radar gives poor results. In validation, corrected radar inputs (e.g. T31) perform better than raingauge (T1 and T4). Results for the SMARG are much more consistent and better than for the TOPKAPI, although SMARG tends to underestimate the peaks.

For the APTE criterion, TOPKAPI performs best for T1 and T5 in calibration, but in validation T2 gives the best results. The SMARG results are only better for T4, T5, T61 and T62.

2.3.2 Comparison of SMARG, TOPKAPI and UH over the selected UH storms

Comparative statistics for the periods corresponding to the unit-hydrographs events are computed, taking the observed flow rates as the reference. frc and cnt refer to the fraction and constant loss functions. They only apply to the UH rainfall inputs. In year 2002/2003, storm 9 is exluded since the flow estimates are missing for the uh simulation with Rain T4frc and T4cnt. In year 2003/2004, storms v9, v10 and v11 are exluded, since the radar was not operating during the corresponding periods.

MSE, MRs and MAE statistics were computed for the continuous flow rate estimates series (see Tables 2.13, 2.14, 2.15).

MSE, MRs, ANPE and APTE statistics were calculated for the peaks only (see Tables 2.16, 2.17, 2.18, 2.19) for rain types T4 to T83 (uniform rainfall only). There were 8 peaks in the calibration year and 7 peaks in the validation year.

SMARG tends to perform better than TOPKAPI, especially in calibration. The unit-hydrograph outperforms the two other models in calibration. In validation, the constant loss function gives worst results. In calibration T4cnt is the best, whereas radar T5frc, T61frc and T62frc are best in validation.

From the MRs statistics, it can be observed that the SMARG underestimates the flows for the non corrected radar only. TOPKAPI underestimates the flows also with A_{S3} corrected rainfall (T62, T82).

In terms of peak MSE, TOPKAPI does not perform well. SMARG and UH are similar in calibration, but the UH is worst much worse than the SMARG in validation. There is a noticeable sensitivity to the loss function used.

However, the timing of peaks is best predicted by the UH. This is always true, except for T5, T61 and T62. No obvious improvement from using spatial correction factors.

2.4 Conclusion

The unit-hydrograph, the SMARG and the TOPKAPI models were calibrated for a selection of precipitation estimates types. Two different loss function to derive the effective rainfall were used with the unit-hydrograph method. The models were run for the full calibration and validation years.

Model outputs were compared over the whole two years and over the periods corresponding to the unit-hydrograph events.

Over the two years, for peaks, the best performance for TOPKAPI are found with the input used for its calibration (T1) and with T4. There is no obvious improvement using spatial rainfall and spatial adjustment factors. Topkapi does not perform well at all with raw radar data. The SMARG model shows more consistent results, especially in terms of peak bias (MRs).

Over the unit-hydrograph event periods, the unit-hydrograph method shows high sensitivity to the loss function used. The constant rate loss function can give peak which are severely over estimated. Although the unit-hydrograph method generally gives better estimates for the timing of the peak, it does not out perform SMARG for the other statistics. The TOPKAPI model results are the worst.

Overall, the SMARG model shows best results. It is calibrated to each precipitation estimate type and is adapted to each type. The UH method results depend highly on the arbitrary choice of a loss function. The TOPKAPI model calibration is carried out for one type of rainfall and does not perform for some other types (e.g. weak raw radar estimates).

Type	Topkapi		SMARG	
	Cal.	Val.	Cal.	Val.
T1	8.70	5.32		
T2	7.03	4.47		
T31	10.91	6.68		
T32	5.10	3.93		
T4	8.84	5.28	6.07	3.48
T5	6.98	4.46	8.21	5.44
T61	10.78	6.65	7.32	4.68
T62	5.11	3.97	5.63	4.48
T7	6.75	4.50	8.91	5.87
T81	13.75	7.11	9.04	5.01
T82	5.18	4.12	6.81	4.87
T83	10.71	6.13	7.87	4.58
T9	6.73	4.49		
T101	14.07	7.22		
T102	5.15	4.09		
FD	11.48	6.23		

Table 2.6: MSE criterion for entire calibration and validation year for TOPKAPI and SMARG.

Type	Topkapi		SMARG	
	Cal.	Val.	Cal.	Val.
T1	2.14	1.48		
T2	-0.25	-0.01		
T31	2.06	1.63		
T32	0.83	0.75		
T4	2.13	1.46	1.24	0.49
T5	-0.23	-0.01	-1.33	-1.29
T61	2.05	1.59	1.23	0.74
T62	0.81	0.72	-0.32	-0.48
T7	-0.16	0.01	-1.30	-1.33
T81	2.36	1.72	1.85	1.12
T82	1.00	0.81	0.34	0.01
T83	2.09	1.54	1.53	0.88
T9	-0.16	0.02		
T101	2.39	1.78		
T102	1.03	0.85		
FD	2.03	1.48		

Table 2.7: MRs criterion for entire calibration and validation year for TOPKAPI and SMARG.

Type	Topkapi		SMARG	
	Cal.	Val.	Cal.	Val.
T1	2.23	1.73		
T2	1.29	1.14		
T31	2.26	1.87		
T32	1.48	1.31		
T4	2.23	1.71	1.51	1.06
T5	1.29	1.14	2.11	1.81
T61	2.25	1.85	1.58	1.27
T62	1.47	1.30	1.55	1.40
T7	1.28	1.14	2.13	1.84
T81	2.51	1.95	1.99	1.43
T82	1.55	1.35	1.35	1.20
T83	2.29	1.82	1.74	1.29
T9	1.28	1.14		
T101	2.54	1.99		
T102	1.56	1.36		
FD	2.24	1.78		

Table 2.8: MAE criterion for entire calibration and validation year for TOPKAPI and SMARG.

Type	Topkapi		SMARG	
	Cal.	Val.	Cal.	Val.
T1	55.57	92.15		
T2	415.91	467.73		
T31	120.70	34.17		
T32	132.68	184.96		
T4	55.02	84.89	39.98	83.27
T5	415.98	467.13	65.44	69.83
T61	120.83	33.10	39.36	49.56
T62	144.88	199.13	48.93	57.82
T7	400.94	478.27	81.98	104.02
T81	252.20	51.65	56.45	56.96
T82	118.20	220.03	74.73	52.14
T83	150.09	59.49	58.85	56.15
T9	397.74	476.77		
T101	267.59	47.06		
T102	108.03	205.67		
FD	305.5	97.78		

Table 2.9: MSE criterion for peaks over entire calibration and validation year for TOPKAPI and SMARG.

Type	Topkapi		SMARG	
	Cal.	Val.	Cal.	Val.
T1	2.19	-6.27		
T2	-18.79	-19.95		
T31	4.61	-1.38		
T32	-9.96	-12.67		
T4	2.46	-6.52	-1.80	-3.23
T5	-18.72	-19.92	-3.70	-6.85
T61	4.54	-1.66	-1.69	0.23
T62	-10.24	-13.06	-2.18	0.92
T7	-18.32	-20.01	-2.03	-8.37
T81	8.39	-1.83	-1.84	-3.30
T82	-8.44	-13.23	-0.41	-2.76
T83	4.36	-4.39	-1.95	-3.12
T9	-18.29	-19.99		
T101	8.81	-0.99		
T102	-7.97	-12.81		
FD	-8.15	-12.79		

Table 2.10: MRs criterion for peaks over entire calibration and validation year for TOPKAPI and SMARG.

Type	Topkapi		SMARG	
	Cal.	Val.	Cal.	Val.
T1	0.29	0.27		
T2	0.74	0.72		
T31	0.38	0.21		
T32	0.39	0.47		
T4	0.29	0.26	0.19	0.20
T5	0.73	0.72	0.25	0.24
T61	0.39	0.20	0.18	0.27
T62	0.39	0.48	0.21	0.32
T7	0.71	0.72	0.31	0.29
T81	0.50	0.22	0.21	0.18
T82	0.34	0.47	0.29	0.19
T83	0.41	0.23	0.22	0.18
T9	0.71	0.72		
T101	0.49	0.21		
T102	0.32	0.46		
FD	0.44	0.24		

Table 2.11: ANPE criterion for peaks over entire calibration and validation year for TOPKAPI and SMARG.

Type	Topkapi		SMARG	
	Cal.	Val.	Cal.	Val.
T1	1.36	2.43		
T2	1.64	1.14		
T31	2.36	2.00		
T32	2.07	1.86		
T4	1.57	2.43	1.29	2.14
T5	1.36	1.43	1.64	1.14
T61	2.50	2.29	2.07	0.86
T62	2.07	2.00	2.00	1.29
T7	1.43	1.29	2.21	2.14
T81	2.21	2.00	2.21	2.00
T82	1.71	2.00	2.57	2.71
T83	2.14	2.00	2.21	2.14
T9	1.57	1.14		
T101	2.00	2.00		
T102	1.64	1.86		
FD	2.21	2.00		

Table 2.12: APTE criterion for peaks over entire calibration and validation year for TOPKAPI and SMARG.

Type	Topkapi		SMARG		UH	
	Cal.	Val.	Cal.	Val.	Cal.	Val.
T4frc	36.57	39.00	35.64	47.71	8.97	33.38
T4cnt					5.73	55.39
T5frc	68.62	61.81	32.55	18.44	15.27	21.80
T5cnt					15.81	22.11
T61frc	48.33	47.78	34.93	43.29	15.19	21.55
T61cnt					26.47	121.87
T62frc	32.33	37.15	31.35	40.09	15.17	21.40
T62cnt					22.38	63.54
T7frc	66.29	63.43	43.79	35.80	17.78	28.92
T7cnt					20.25	26.35
T81frc	75.63	45.84	40.24	39.62	17.96	29.05
T81cnt					32.57	69.90
T82frc	30.66	38.61	54.60	65.52	17.92	29.13
T82cnt					28.85	45.87
T83frc	52.96	39.98	38.71	40.25	17.78	28.93
T83cnt					31.95	65.43

Table 2.13: MSE criterion for the unit-hydrograph events in calibration and validation year for TOPKAPI, SMARG and UH.

Type	Topkapi		SMARG		UH	
	Cal.	Val.	Cal.	Val.	Cal.	Val.
T4frc	3.61	1.46	4.23	3.61	-0.09	-1.77
T4cnt					-0.10	0.85
T5frc	-4.42	-3.32	-0.80	-0.80	-0.06	-1.12
T5cnt					-0.03	0.06
T61frc	2.58	1.97	3.35	4.36	-0.06	-1.06
T61cnt					-0.03	2.69
T62frc	-1.62	-1.15	1.53	3.35	-0.06	-1.05
T62cnt					-0.03	1.58
T7frc	-4.25	-3.31	-0.41	-1.26	-0.06	-1.66
T7cnt					-0.03	-1.15
T81frc	3.83	2.07	3.55	3.12	-0.06	-1.70
T81cnt					-0.03	-0.82
T82frc	-1.00	-1.09	0.56	0.74	-0.07	-1.69
T82cnt					-0.04	-0.91
T83frc	2.71	1.40	3.20	3.02	-0.06	-1.66
T83cnt					-0.03	-0.65

Table 2.14: MRs criterion for the unit-hydrograph events in calibration and validation year for TOPKAPI, SMARG and UH.

Type	Topkapi		SMARG		UH	
	Cal.	Val.	Cal.	Val.	Cal.	Val.
T4frc	4.31	4.75	4.85	4.94	1.88	4.17
T4cnt					1.51	4.57
T5frc	5.47	5.21	4.37	3.40	2.38	3.50
T5cnt					2.42	3.46
T61frc	4.54	4.95	4.57	5.21	2.38	3.48
T61cnt					3.03	6.90
T62frc	4.03	4.53	4.20	4.93	2.38	3.47
T62cnt					2.80	5.41
T7frc	5.35	5.24	4.80	4.59	2.55	3.58
T7cnt					2.58	3.75
T81frc	5.40	4.88	4.89	4.62	2.56	3.85
T81cnt					3.11	5.66
T82frc	3.88	4.54	5.08	5.84	2.56	3.87
T82cnt					2.93	4.80
T83frc	4.69	4.70	4.63	4.61	2.55	3.85
T83cnt					3.09	5.50

Table 2.15: MAE criterion for the unit-hydrograph events in calibration and validation year for TOPKAPI, SMARG and UH.

Type	Topkapi		SMARG		UH	
	Cal.	Val.	Cal.	Val.	Cal.	Val.
T4frc	22.71	84.89	48.58	83.27	64.58	185.97
T4cnt					31.41	229.40
T5frc	496.81	467.13	95.13	69.83	86.00	105.58
T5cnt					71.40	31.66
T61frc	147.65	33.10	60.74	49.56	58.84	101.47
T61cnt					125.73	412.59
T62frc	178.32	199.13	76.26	57.82	85.71	100.26
T62cnt					109.78	153.52
T7frc	485.34	478.27	120.84	104.02	107.10	168.49
T7cnt					104.65	84.40
T81frc	293.77	51.65	94.89	56.96	108.40	170.49
T81cnt					189.64	241.37
T82frc	159.20	220.03	120.70	52.14	106.44	168.58
T82cnt					166.13	134.89
T83frc	180.97	59.49	98.88	56.15	107.10	168.65
T83cnt					185.21	218.56

Table 2.16: MSE criterion for peaks for the unit-hydrograph events in calibration and validation year for TOPKAPI, SMARG and UH.

Type	Topkapi		SMARG		UH	
	Cal.	Val.	Cal.	Val.	Cal.	Val.
T4frc	2.52	-6.52	-2.09	-3.23	-7.00	-11.37
T4cnt					-3.77	1.12
T5frc	-20.45	-19.92	-4.83	-6.85	-6.81	-9.32
T5cnt					-5.58	-2.70
T61frc	4.96	-1.66	-3.00	0.23	-6.81	-9.06
T61cnt					-5.23	9.73
T62frc	-11.46	-13.06	-3.42	0.92	-6.80	-9.01
T62cnt					-5.10	4.33
T7frc	-20.03	-20.01	-2.87	-8.37	-7.48	-11.37
T7cnt					-6.08	-6.56
T81frc	8.83	-1.83	-2.79	-3.30	-7.52	-11.47
T81cnt					-5.19	-1.85
T82frc	-9.55	-13.23	-0.46	-2.76	-7.39	-11.39
T82cnt					-5.15	-3.10
T83frc	4.34	-4.39	-2.89	-3.12	-7.48	-11.38
T83cnt					-5.15	-1.49

Table 2.17: MRs criterion for peaks for the unit-hydrograph events in calibration and validation year for TOPKAPI, SMARG and UH.

Type	Topkapi		SMARG		UH	
	Cal.	Val.	Cal.	Val.	Cal.	Val.
T4frc	0.17	0.26	0.19	0.20	0.25	0.40
T4cnt					0.17	0.43
T5frc	0.75	0.72	0.27	0.24	0.26	0.35
T5cnt					0.23	0.20
T61frc	0.36	0.20	0.22	0.27	0.26	0.34
T61cnt					0.31	0.52
T62frc	0.41	0.48	0.25	0.32	0.26	0.34
T62cnt					0.29	0.36
T7frc	0.72	0.72	0.37	0.29	0.28	0.41
T7cnt					0.24	0.29
T81frc	0.55	0.22	0.30	0.18	0.28	0.42
T81cnt					0.33	0.57
T82frc	0.36	0.47	0.40	0.19	0.28	0.41
T82cnt					0.31	0.43
T83frc	0.45	0.23	0.31	0.18	0.28	0.41
T83cnt					0.32	0.53

Table 2.18: ANPE criterion for peaks for the unit-hydrograph events in calibration and validation year for TOPKAPI, SMARG and UH.

Type	Topkapi		SMARG		UH	
	Cal.	Val.	Cal.	Val.	Cal.	Val.
T4frc	1.38	2.43	1.25	2.14	0.75	1.43
T4cnt					1.00	1.57
T5frc	1.25	1.43	1.75	1.14	1.63	1.71
T5cnt					1.63	1.57
T61frc	2.50	2.29	2.38	0.86	1.63	1.57
T61cnt					1.75	2.00
T62frc	2.00	2.00	2.25	1.29	1.63	1.57
T62cnt					1.75	1.86
T7frc	1.38	1.29	2.25	2.14	1.75	1.14
T7cnt					1.63	1.71
T81frc	2.38	2.00	2.38	2.00	1.75	1.14
T81cnt					1.25	1.71
T82frc	1.88	2.00	2.63	2.71	1.75	1.14
T82cnt					1.00	2.00
T83frc	2.25	2.00	2.38	2.14	1.75	1.14
T83cnt					1.25	1.86

Table 2.19: APTE criterion for peaks for the unit-hydrograph events in calibration and validation year for TOPKAPI, SMARG and UH.

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