CHAPTER 4

DISCUSSION OF RESULTS

Fundamental to the design of drainage facilities are analyses of peak rates of runoff, volumes of runoff, and time distribution of flows. Large errors in the estimations result in a structure that is either undersized, which could cause drainage problems, or oversized, which is more costly than necessary. Thus, three metrics are used in this study to evaluate the difference between the simulated and observed runoff hydrograph peak flows, runoff volumes, and times to peak. These metrics are used to compare different model structures to each other as well as to observed results.

Metrics

These metrics were used to evaluate the subdivision models. All of the metrics use the concept of error or relative error. The first metric is simply an arithmetic mean of relative errors (in percent)

$$AVG = \frac{1}{N}\sum_{i=1}^{N}\left(\frac{\left|X_S - X_O\right|}{X_O}\right)_i \qquad (4.1)$$

where X_S and X_O are simulated values (Q_P, T_P, or V) and observed values (Q_P, T_P, or V) and N is the total number of storm event used. Ideally this metric should be zero, and the sign of the metric helps convey a systematic bias. The second metric is a relative root-mean square error (in percent), again based on relative error

$$RRMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(\frac{X_S - X_O}{X_O}\right)_i^2} \qquad (4.2)$$

Ideally this metric should also be zero, and does not convey a systematic bias. For time-series type comparison, these *RRMSE* metrics are sensitive to large deviations and relatively insensitive to small deviations. The last metric, unique to this research, is similar to the acceptance criteria approach of Cleveland and others (2006). A metric called minimum count, *MIN_COUNT*, is simply a count of the number of storms for which a particular subdivision performs best (better than the other configurations for that watershed). For example, suppose data for a given watershed represents five storms. Further suppose there are five different subdivision configurations. If, in this hypothetical case, the 3-subdivision configuration has smaller *AVG* and *RMSE* than all other configurations for 2 of the 5 storms, then *MIN_COUNT* for 3-subdivision configuration is assigned the value 2. These metrics are shown in Tables 4.1 to 4.3.

Table 4.1. Summary of Peak Discharge Analysis

Watershed	Peak Discharge	No. Subdivisions					Selected No. Subdivisions
		1	2	3	5	7	
Onion	*AVG (%)*	200.06	285.30	324.68	281.96	331.20	1
	RRMSE (%)	233.08	294.30	366.57	313.13	367.94	1
	MIN_COUNT	2	0	0	0	0	1
South Mesquite	*AVG (%)*	9.67	5.00	16.04	27.63	9.13	2
	RRMSE (%)	16.47	12.09	20.78	32.53	14.50	2
	MIN_COUNT	2	3	1	0	0	2
Little Fossil	*AVG (%)*	78.52	98.97	85.48	123.41	97.63	1
	RRMSE (%)	189.92	214.92	203.43	258.12	224.63	1
	MIN_COUNT	5	2	0	2	0	1
Olmos	*AVG (%)*	244.10	240.92	246.95	149.12	261.98	5
	RRMSE (%)	333.61	331.35	367.80	239.54	382.17	5
	MIN_COUNT	0	0	1	6	0	5
Trinity North	*AVG (%)*	14.42	22.96	17.70	28.83	10.06	7
	RRMSE (%)	72.22	72.90	67.85	74.15	62.77	7
	MIN_COUNT	2	0	0	3	4	7

Table 4.2. Summary of Runoff Volume Analysis

Watershed	Runoff Volume	No. Subdivisions					Selected No. Subdivisions
		1	2	3	5	7	
Onion	*AVG (%)*	520.10	432.31	465.07	467.38	465.56	2
	RRMSE (%)	662.52	538.34	586.73	589.33	587.29	2
	MIN_COUNT	0	1	1	0	0	2, 3
South Mesquite	*AVG (%)*	3.72	5.63	0.51	0.45	0.43	7
	RRMSE (%)	21.82	18.90	16.52	17.24	16.44	7
	MIN_COUNT	3	1	1	1	0	1
Little Fossil	*AVG (%)*	107.48	104.54	99.59	100.50	105.56	3
	RRMSE (%)	218.30	223.19	223.15	224.10	229.74	1
	MIN_COUNT	4	1	2	0	2	1
Olmos	*AVG (%)*	267.83	263.85	244.71	243.75	231.39	7
	RRMSE (%)	305.66	301.46	288.12	287.03	273.06	7
	MIN_COUNT	0	0	0	0	7	7
Trinity North	*AVG (%)*	33.34	20.22	20.01	17.96	18.29	5
	RRMSE (%)	87.92	72.62	68.93	67.81	68.00	5
	MIN_COUNT	0	1	4	4	0	3, 5

Table 4.3. Summary of Time to Peak Analysis

Watershed	Time to Peak	No. Subdivisions					Selected No. Subdivisions
		1	2	3	5	7	
Onion	*AVG (%)*	26.80	22.98	18.74	29.77	25.01	3
	RRMSE (%)	33.45	25.20	23.32	32.40	27.11	3
	MIN_COUNT	0	0	2	0	0	3
South Mesquite	*AVG (%)*	2.76	2.30	0.12	2.77	3.87	3
	RRMSE (%)	9.10	10.09	8.49	11.05	11.96	3
	MIN_COUNT	1	1	1	1	2	7
Little Fossil	*AVG (%)*	6.79	2.03	11.56	12.15	10.18	2
	RRMSE (%)	10.64	13.55	34.91	25.62	23.02	1
	MIN_COUNT	1	5	1	0	2	2
Olmos	*AVG (%)*	15.15	15.87	13.34	8.30	8.49	7
	RRMSE (%)	21.61	23.13	17.27	11.84	10.68	7
	MIN_COUNT	0	0	1	2	4	7
Trinity North	*AVG (%)*	9.20	9.47	13.70	13.95	11.22	1
	RRMSE (%)	31.08	31.36	33.97	34.98	33.22	1
	MIN_COUNT	4	3	1	0	1	1

Evaluating the Results

It can be seen from the above tables that there is no single watershed discretization scheme that performs optimally of all observed storms on a particular watershed. In other words, there is no consistent pattern on whether lumped or multiple subbasins produce superior results.

Figures 4.1, to 4.4 are illustrations of the favorable and unfavorable results of the observed and simulated runoffs for two of the representative watersheds. In cases where runoff volume simulated and observed are close (favorable predictions,) there is no apparent significant difference among the hydrographs. In many storms, the runoff generated in the model did not reproduce runoff volume close to observed results (unfavorable predictions).

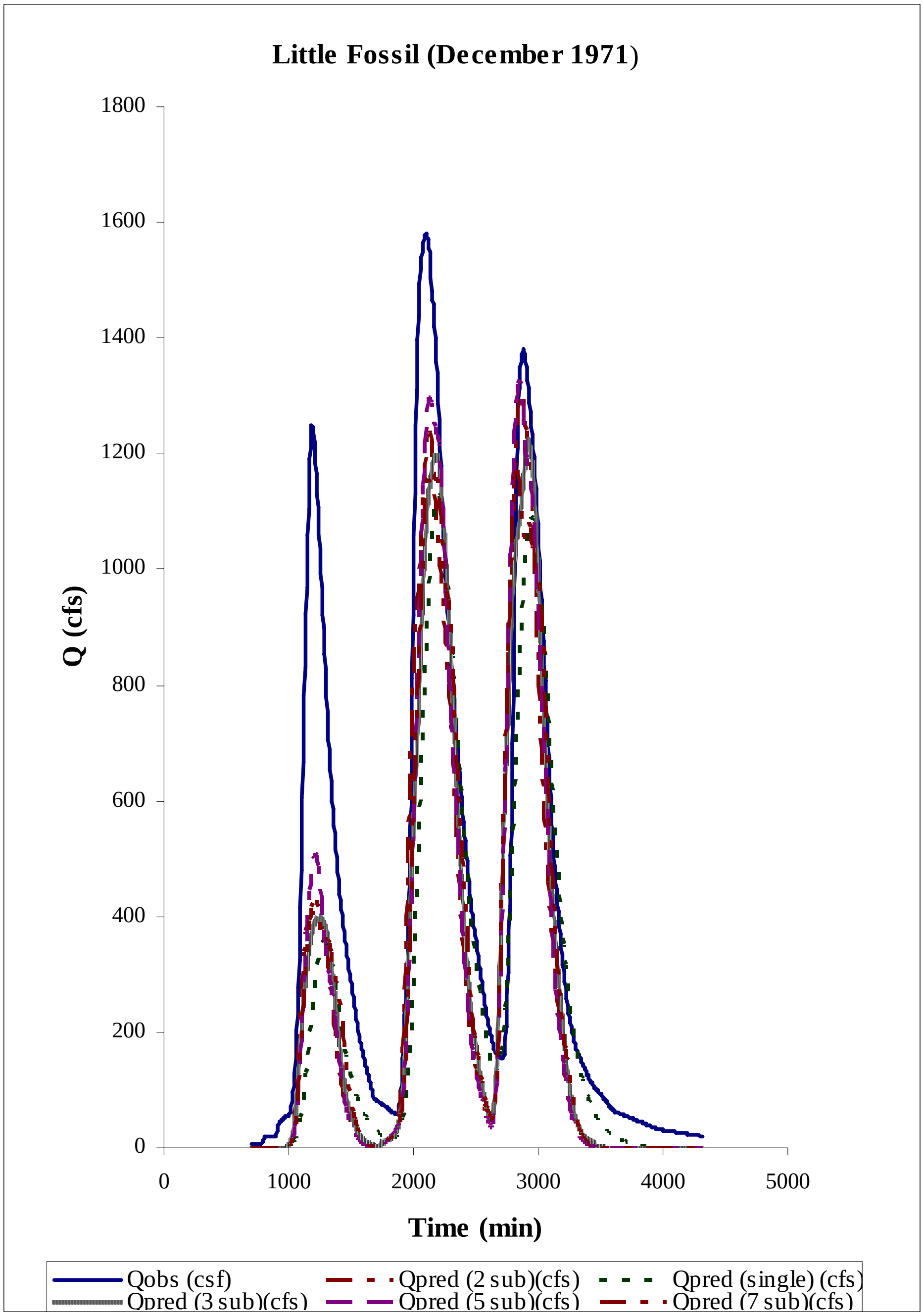

Figure 4.1. Simulated and observed hydrographs (Little Fossil 12/1971)

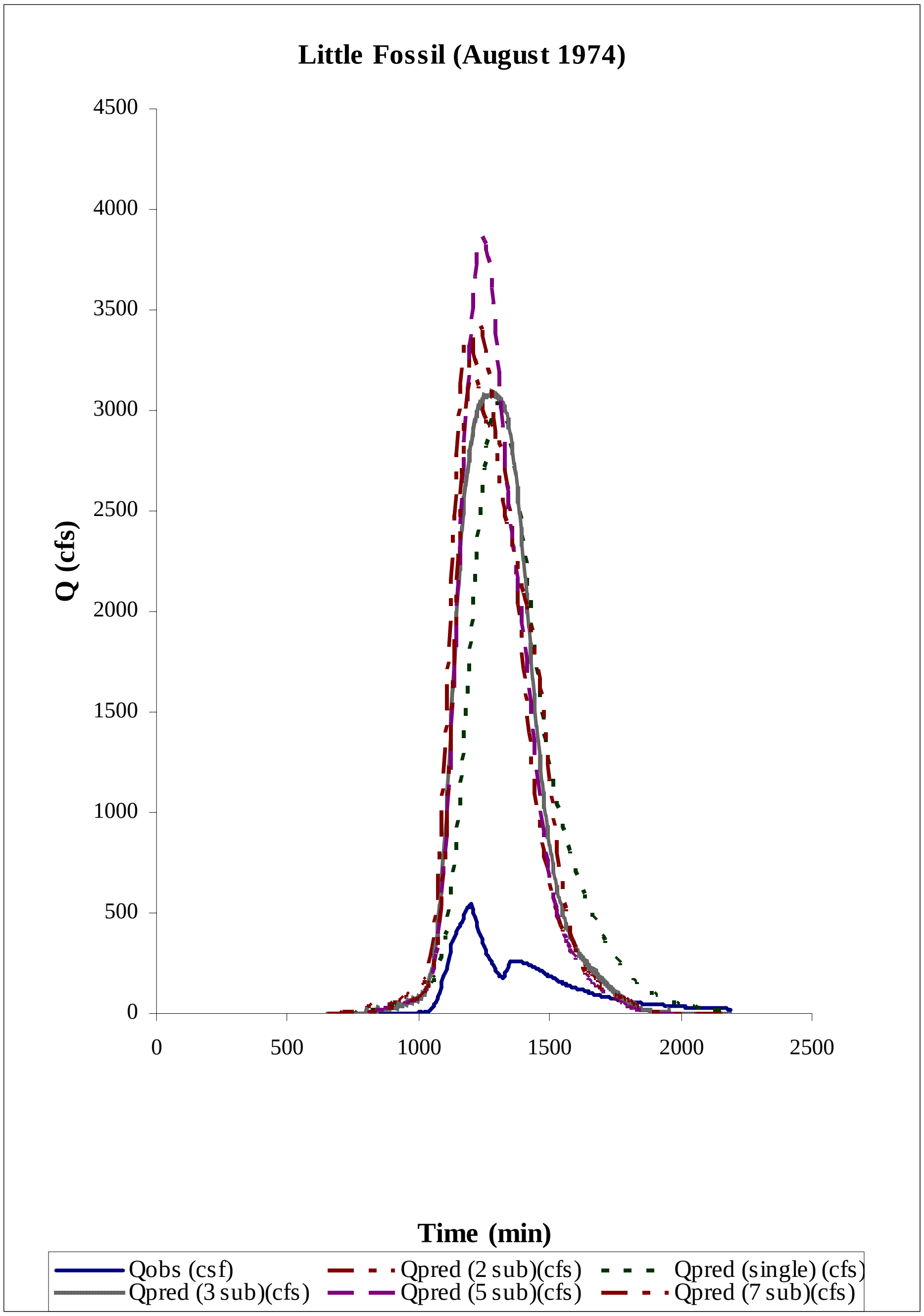

Figure 4.2. Simulated and observed hydrographs (Little Fossil 8/1974)

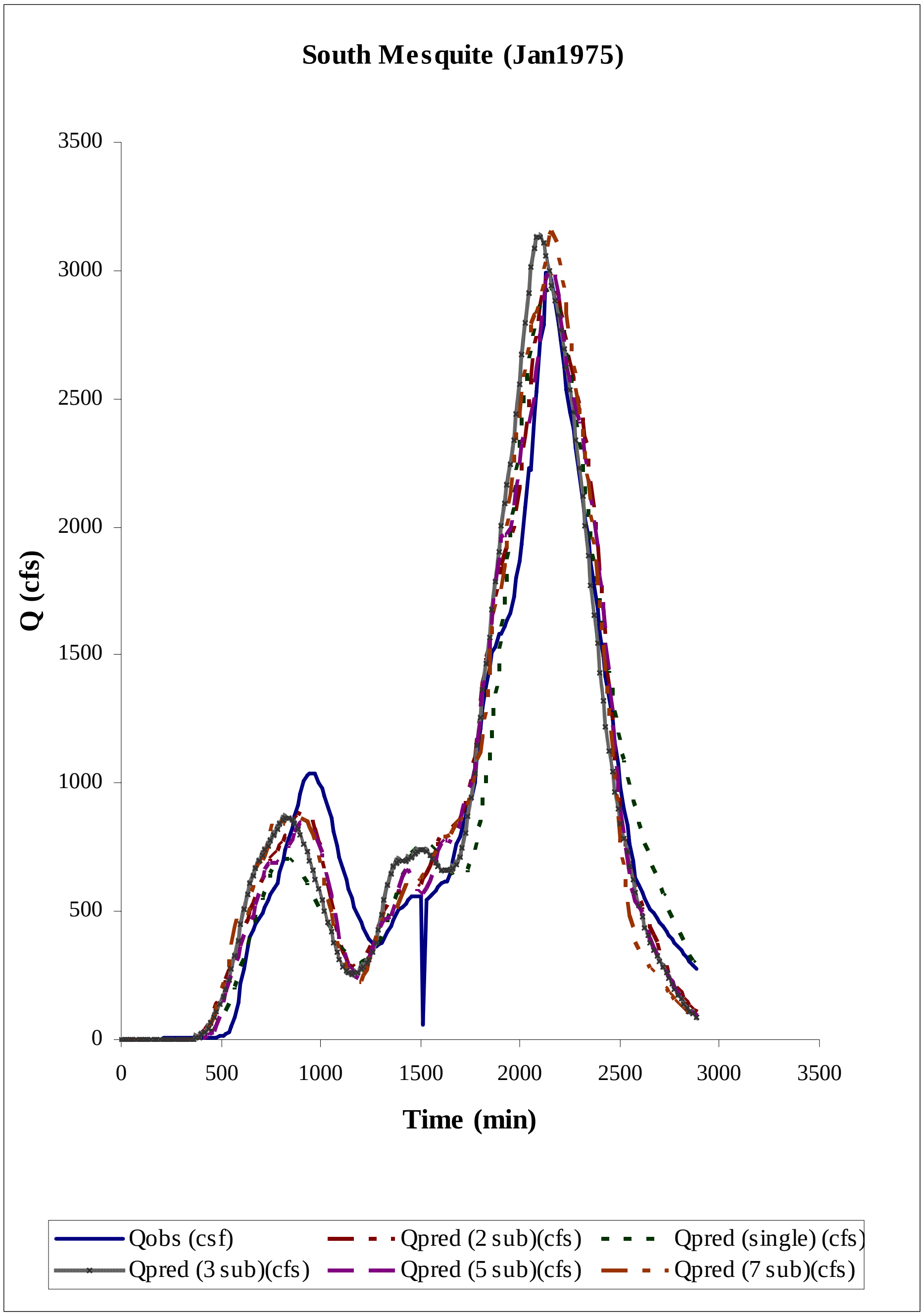

Figure 4.3. Simulated and observed hydrographs (South Mesquite 1/1975)

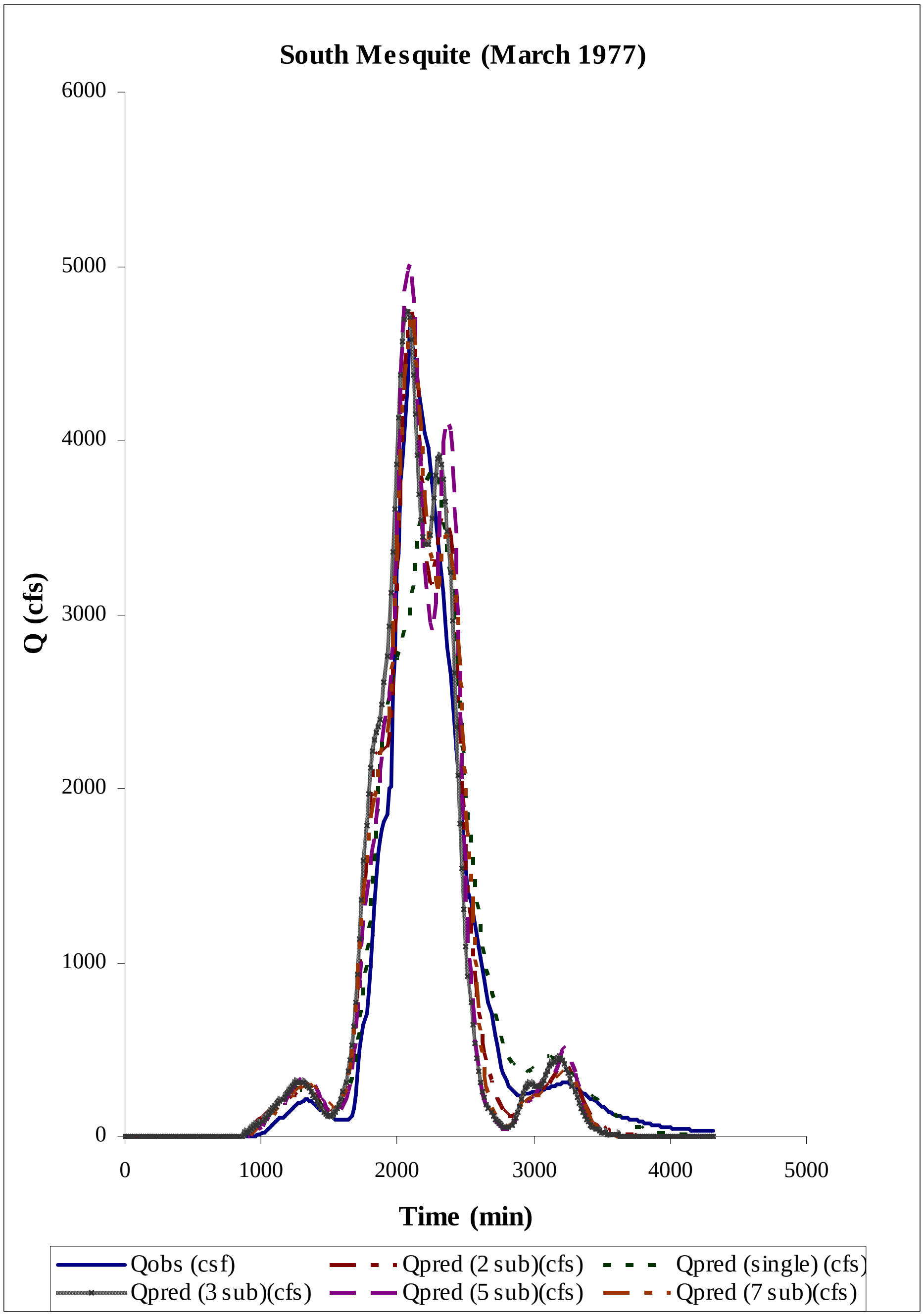

Figure 4.4. Simulated and observed hydrographs (South Mesquite 3/1977)

It can be seen from Figures 4.1, 4.3, and 4.4 that there is no significant difference between the simulated runoff hydrographs for the subdivision and the single basin schemes and the observed hydrographs. The reason is the spatial variability of the watershed is not large enough for the simulation results to be sensitive to the selected subdivision scheme. The use of soil type and land use properties to determine spatial variability is plausible because they are the major factors considered when estimating runoff curve numbers which HEC-HMS uses to estimate the volume of runoff. In this study, the area weighted mean curve number was almost identical across a watershed for all subwatershed scenarios. This finding results in little variation in the total runoff volumes between the subwatershed configurations. The curve number for every unique soil and land use combination in the study watersheds was estimated assuming good hydrologic condition; however, this condition might not be true for all watersheds. Until the appropriate CN of the subbasin is accurately determined and incorporated into models, the results may never be satisfactory.

Figure 4.2 is an example of an unfavorable prediction. Similar results were found on the Onion Creek (Austin) and the Trinity Basin – North (rural area). The quantity of simulated runoff hydrograph is not equal to the observed flow as shown in this figure. It is likely explained by incomplete or missing raingage data. These data were hand-entered from written reports and therefore, data might have been lost during the entry phase or lost in the original data collections (Williams-Sether and others 2004). Also, the assumption that these rainfall amounts were representative of rainfall across the drainage area might not be valid. The actual rainfall amounts might not be distributed over the entire watershed. The geographic location of the watershed is also a significant factor which affects the runoff generation. The presence of site-specific water impoundments as reservoirs or ponds is inclusive.

The South Mesquite January 1975 hydrographs (Figure 4.3) are much more uniform.

They fit the assumptions of unit hydrographs better than the March 1977 hydrographs (Figure 4.4). This is evident by the failure of the March 1977 lumped model to maintain the shape of the observed hydrograph. In most cases, when hydrographs of subdivision are compared to the single basin, the pattern of peak discharge is similar to the finding in earlier studies. The peak discharge of a single basin is less than the subdivision peak. The peak discharge increased very little between the single and the subdivision scenarios in most cases indicating that the peak flow component is relatively insensitive to changes in the number of subwatersheds. This result implies that the model-predicted runoff is not heavily dependent on the degree of watershed subdivision. These findings are consistent with the results of Bingner et al. (1997), FitzHugh and MacKay (2000), and Jha (2002).

Also, regardless of subdivision, with the exception of few storms, the peak discharges in simulated and observed occur almost at the same times which supports the utility the Kerby-Kirpich approach suggested in TxDOT research project 0-4696-2.

As an important note, the models were intentionally left uncalibrated with respect to observed runoff behavior. In this sense the models represent engineering analyst judgment as would be applied in ungaged conditions. This comparison structure was chosen because the scope of the research was to evaluate the enhanced or diminished prediction value on watershed modeling as a function of subdivision. The author acknowledges that if each subdivision model were calibrated on a storm-by-storm basis, the models with greater subdivision count would likely outperform the lumped (single basin) models in nearly every case. The reason for this enhanced performance is because the increased subdivision count adds degrees of freedom to the calibration procedure; as in regression, such additional explainatory variables, regardless of how insignificant, always improve the model "fit" to the data better than a more parsimonious case.

As an example, South Mesquite watershed's January 1975 stream flow data was used to calibrate the following parameters: *CN*, subbasin lag, and routing lag time. The calibration procedure was automated using a systematic search strategy and an objective function based on squared error in peak flow, volume, and time to peak. The search converged to a parameter set that represents at least a local minimum for the selected objective function. Initial curve numbers for South Mesquite watershed were 91 (lumped) or 85-92 (distributed); calibrated values were 97 (lumped) or 82-97 (distributed). The calibrated subbasin lag and routing lag time for each subdivision scheme are close to the initial values. The calibrated values presented in Table 4.4 and Table 4.5 were used to simulate runoff hydrographs for the January 1975 rainfall event of the South Mesquite watershed.

Table 4.4. Initial and calibrated CN (South Mesquite)

Model Configuration	Sub-basin ID	Initial CN	Calibrated CN	Percent Change (%)
Lumped	A	91	90	-1.10
2-Sub-watershed model	A_1	91	89	-2.20
	A_2	90	86	-4.44
3-Sub-watershed model	A_1	92	96	4.35
	A_2	91	84	-7.69
	A_3	89	83	-6.74
5-Sub-watershed model	A_1	92	91	-1.09
	A_2	91	90	-1.10
	A_3	92	91	-1.09
	A_4	91	84	-7.69
	A_5	85	82	-3.53
7-Sub-watershed model	A_1	92	98	6.52
	A_2	92	86	-6.52
	A_3	92	87	-5.43
	A_4	91	86	-5.49
	A_5	91	86	-5.49
	A_6	91	87	-4.40
	A_7	85	82	-3.53

Table 4.5. Initial and calibrated t_{reach} (South Mesquite)

Model Configuration	Sub-basin ID	Initial t_{reach} (min)	Calibrated t_{reach} (min)	Percent Change (%)
Lumped	A	N/A	N/A	N/A
2-Sub-watershed model	A_1			
	A_2	217	250	15.21
3-Sub-watershed model	A_1			
	A_2	91	92	1.10
	A_3	173	174	0.58
5-Sub-watershed model	A_1			
	A_2	72	73	1.39
	A_3	57	40	-29.82
	A_4	123	141	14.63
	A_5	129	125	-3.10
7-Sub-watershed model	A_1			
	A_2	80	81	1.25
	A_3	68	69	1.47
	A_4	76	77	1.32
	A_5	90	91	1.11
	A_6	89	90	1.12
	A_7	90	91	1.11

For the January 1975 event, the simulated time to peak for the single and 2-subbasin match observed exactly, the time to peak for 3-subbasin, 5-, and 7-subbasin are within 2% and 0.7% of observed, respectively. Additionally, the simulated runoff volume for the single basin is within 1.8% of the observed runoff while runoff volumes for other subdivision are 7% less than observed runoff. The simulated peak flow of the 7-subbasin model is approximately 2% less than observed flow while the single and other finer subdivisions are with in 5% of observed. Figure 4.5 illustrates the calibrated result of the observed and simulated runoffs for the January 1975 event. Additionally, a validation test was performed for the March 1977 event using the “optimal” parameters obtained from the January 1975’s calibration. As shown is Figure 4.6, the simulated flows of the 7-subbasin model compared well with the observed flow. However, the single basin model performed more poorly than the subdivision models. It can be concluded that although the calibrated version was more accurate than the uncalibrated version, the analyses were not be able to indicate which subdivision schemes perform best.

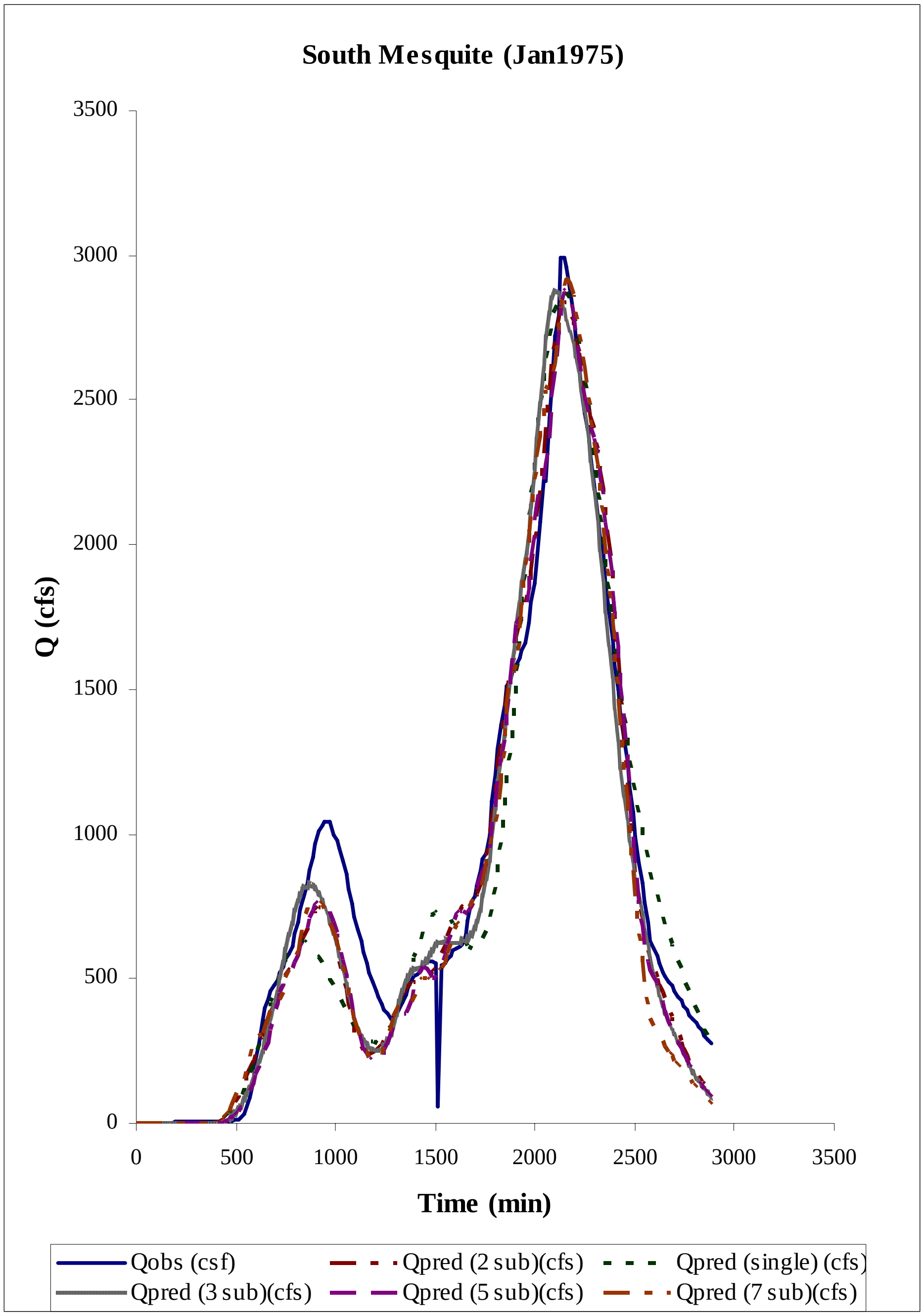

Figure 4.5. Simulated and observed hydrographs (South Mesquite 1/1975-Calibrated)

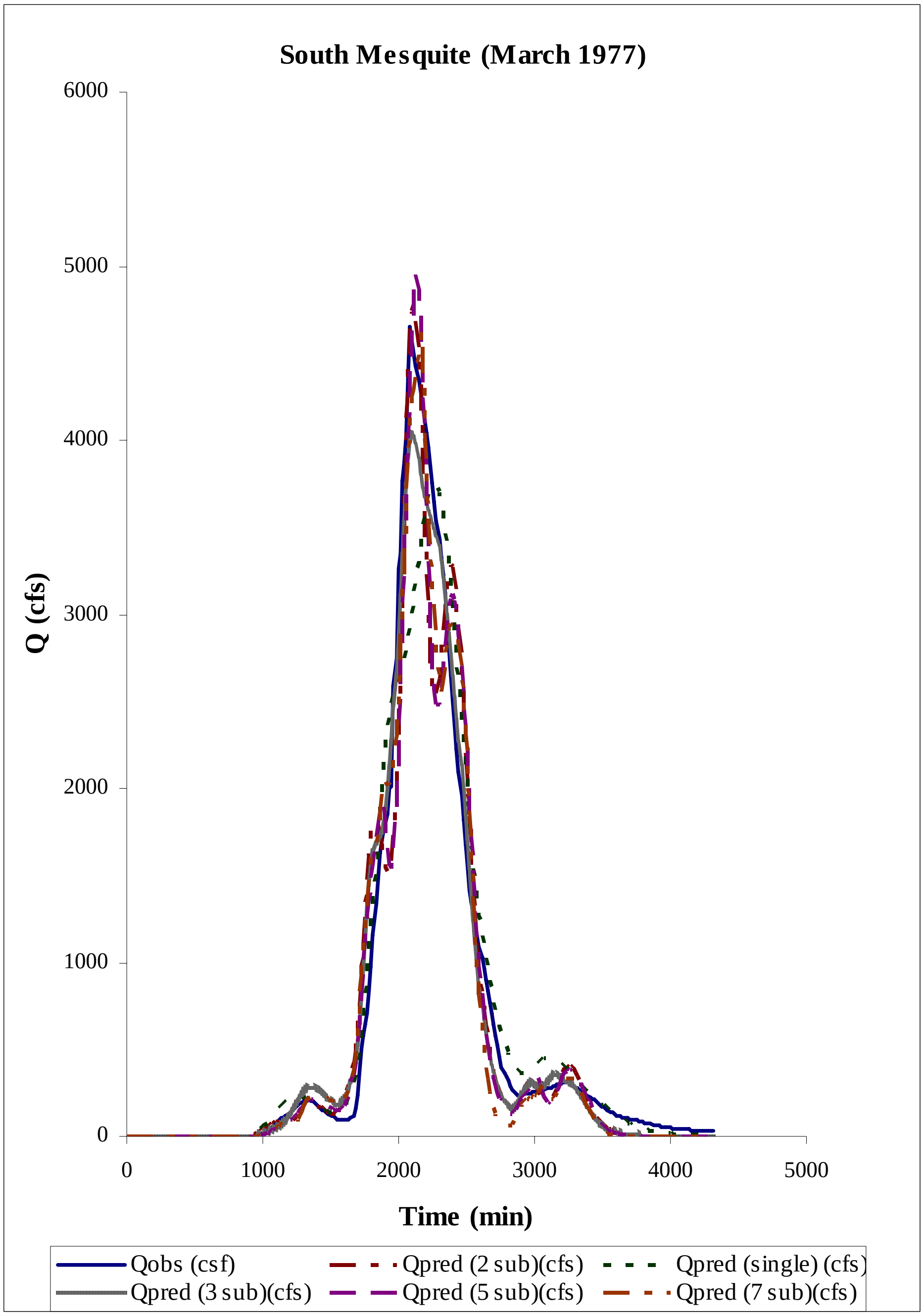

Figure 4.6. Simulated and observed hydrographs (South Mesquite 3/1977-Calibrated)