CHAPTER 5

MODEL CALIBRATION AND VALIDATION

"In a thorough scientific test of physically based runoff models, it has appeared desirable to include events with a range of initial conditions, time pattern of rainfall, and total rainfall (and runoff) amounts. This ensures that the ability of the model to handle small- and large-scale spatial variability will be tested. However, it is important to appreciate the very sensitive nature of surface runoff modeling for small events (where the runoff is a small proportion of the rainfall) so that we don't have unrealistic expectations"

David A, Woolhiser, 1996

The CASC2D-SED model is used to predict discharge and erosion rates at Goodwin Creek. The basin is defined at 90-m spatial resolution. The model is manually calibrated for one event and later validated for two other events. Calibration and validation hydrographs, sedigraphs and sediment yield are shown at the basin outlet and at other internal locations. Spatially distributed net erosion is shown for the calibration event.

5.1. CASC2D-SED SET UP

5.1.1. Watershed Definition

The Goodwin Creek Watershed was used to calibrate and validate the model. Input DEM, soil type and land use maps are resampled at 90-m spatial resolution. The watershed characteristics are defined in CHAPTER 4.

5.1.2. Precipitation Events

CASC2D-SED was calibrated for the storm event of October 17, 1981 (event 1). This event began at 9:19 p.m. and had a total rainfall duration of 4.8 hours with very little rainfall preceding this event. Precipitation data was taken from sixteen raingages that are located within and just outside the watershed (see Figure 4-3). The total rainfall depth for this event varied from 66 to 78.7 mm with an average value of 73.6 mm. The average rainfall intensity was 14.7 mm/h with a maximum of 51.6 mm/h.

For the validation, two different events were chosen. The rainfall event on September 20, 1983 (event 2) had very little rainfall preceding the event, and an averaged rainfall depth twice as much as the calibration event. On the contrary, the rainfall event on August 28, 1982 (event 3) was preceded by wet conditions. The mean rainfall depth for event 3 (66.7 mm) was closer to the calibration event but the rainfall intensities were the largest of the three events.

Table 5-1 shows the summary data for the precipitation events, while the antecedent rainfall daily depths are shown in Appendix III. The input 'rainfall file' for event 1 is found also in Appendix III.

Table 5-1. Rainfall events used for calibration (event 1) and validation (event 2, 3, and 4)

Rainfall event	Event 1 17-Oct-81	Event 2 20-Sep-83	Event 3 28-Aug-82
Rainfall duration [hr]	4.8	9.8	6
Mean rainfall depth [mm]	73.6	147.5	61.7
[1]Rainfall depth range [mm]	66.0 -78.7	135.4 - 154.9	39.1 - 91.7
Mean rainfall intensity [mm/h]	14.7	10.1	10.3
[1]Rainfall intensity range [mm/h]	0 - 51.6	0 - 65.5	0 - 90.3

[1]At any raingage for the rainfall event

5.1.3. Parameter Set

The model was calibrated for event 1 depending on soil type (see Table 4-1) and the LULC (see Table 4-2) and according to the range of possible values found in classical sources (Rawls *et al.*, 1983; Saxton *et al.*, 1986; Wishmeier and Smith, 1978; USDA, 1975; Woolhiser, 1975, Woolhiser *et al.*,1990). The parameter set values used in the calibration run are shown in Table 5-2 and Table 5-3. Because there is no data on the soil initial moisture a uniform value was used. Event 1 parameter set and simulation control variables are found in the 'control file' in Appendix III.

Table 5-2. Soil infiltration and erosion parameter values for the calibration run

Soil series	Drainage condition	Ks[a] [cm/s]	G[a] [cm]	Md [cm^3/cm^3]	K_{USLE}[b]	% Sand[c]	% Silt[c]
Calloway	Poor	0.336	22	0.29	0.4	25	55
Fallaya	Poor	0.307	14	0. 29	1	25	55
Grenada	Moderate	0.355	17	0. 29	0.2	30	60
Loring	Mod/well	0.365	22	0. 29	0.4	25	55
Collins	Mod/well	0.346	18	0. 29	0.2	30	60
Memphis	Well	0.432	22	0. 29	0.1	30	60
Gullied Land	Poor	0.384	15	0. 29	0.1	25	55

[a]Rawls *et al.* (1983); [b]Wischmeier and Smith (1978); [c]USDA (1975) texture triangle

Table 5-3. Land use parameter values for the calibration run.

Land Cover	Roughness[a]	Interception[b] [mm]	C_{USLE}[c]	P_{USLE}[c]
Forest	0.25	3	0.0036	1
Water	0.01	0	0	1
Cultivated	0.15	1	0.18	1
Pasture	0.2	1.5	0.072	1

[a]Woolhiser (1975); [b]Woolhiser (1995) ; [c]Wischmeier and Smith (1978)

5.2. RESULTS

5.2.1. Calibration Event

At the outlet (station 1), CASC2D-SED was able to correctly predict peak flow and time to peak, slightly overestimating the flows at recession. At internal locations, the rising and falling limbs of the hydrograph and the time to peak flow were correctly simulated. Peak flows were underestimated for the smallest sub-basins (stations 6, 8 and 14). For the bigger sub-basin (station 4) the peak flow was simulated properly. Observed and simulated values of the flow at the outlet and other internal locations are shown in Figure 5-1.

The simulated sediment graphs were calibrated to match those observed at the outlet and at other internal locations. Results are shown in Figure 5-2. At the outlet, it was possible to match volumes and the shape of the sediment graph. The simulated sediment graph was delayed with respect to the observed one. At internal locations, the sediment graph rising limb was matched with observations. The falling limb was correctly predicted only for the largest sub-basins. In general, CASC2D-SED fails to predict instantaneous pulses of washload observed at internal locations.

The 'summary file' included in Appendix III provides with the simulation's predicted hydrological and erosion variables. Flow discharge and sediment discharge at the outlet and other internal locations are shown in the 'discharge and sediment discharge files' (see Appendix III).

At the beginning, only the washload fractions (silt and clay) are found in the simulated sediment graph. Later, with increasing water discharge, the sand will add on to the total sediment load. The effect of differences in settling rates and transport capacities for each size fraction result in different percentages of the total eroded material to leave the watershed at the outlet. Although the clay fraction represented only 10-15% of the parent material, it is the fraction that corresponds to 44% of the total eroded material leaving the watershed. This fraction is transported essentially as washload. The silt fraction at the outlet represents 52% of the total sediment yield, while the sand, transported primarily as bed material, represents only 4%. This result is comparable to observations, yet there are no data available to validate these results. Figure 5-3 shows the simulated maximum flux-averaged concentration (ration of sediment discharge to discharge) by size fraction at simulation time t = 240 min. The sediment graph by size fraction at the outlet is shown in Figure 5-4.

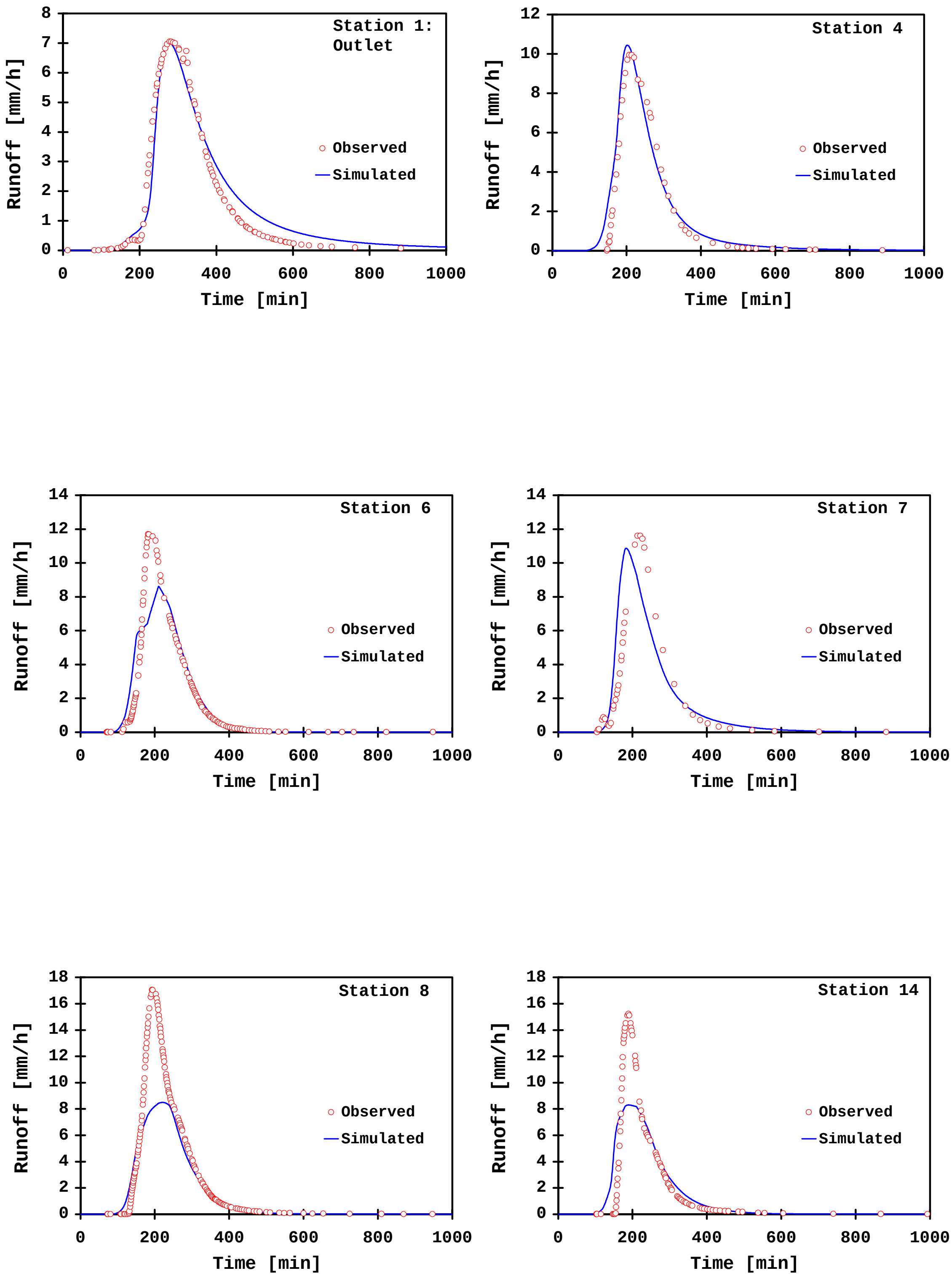

Figure 5-1. Calibrated hydrographs for event 1

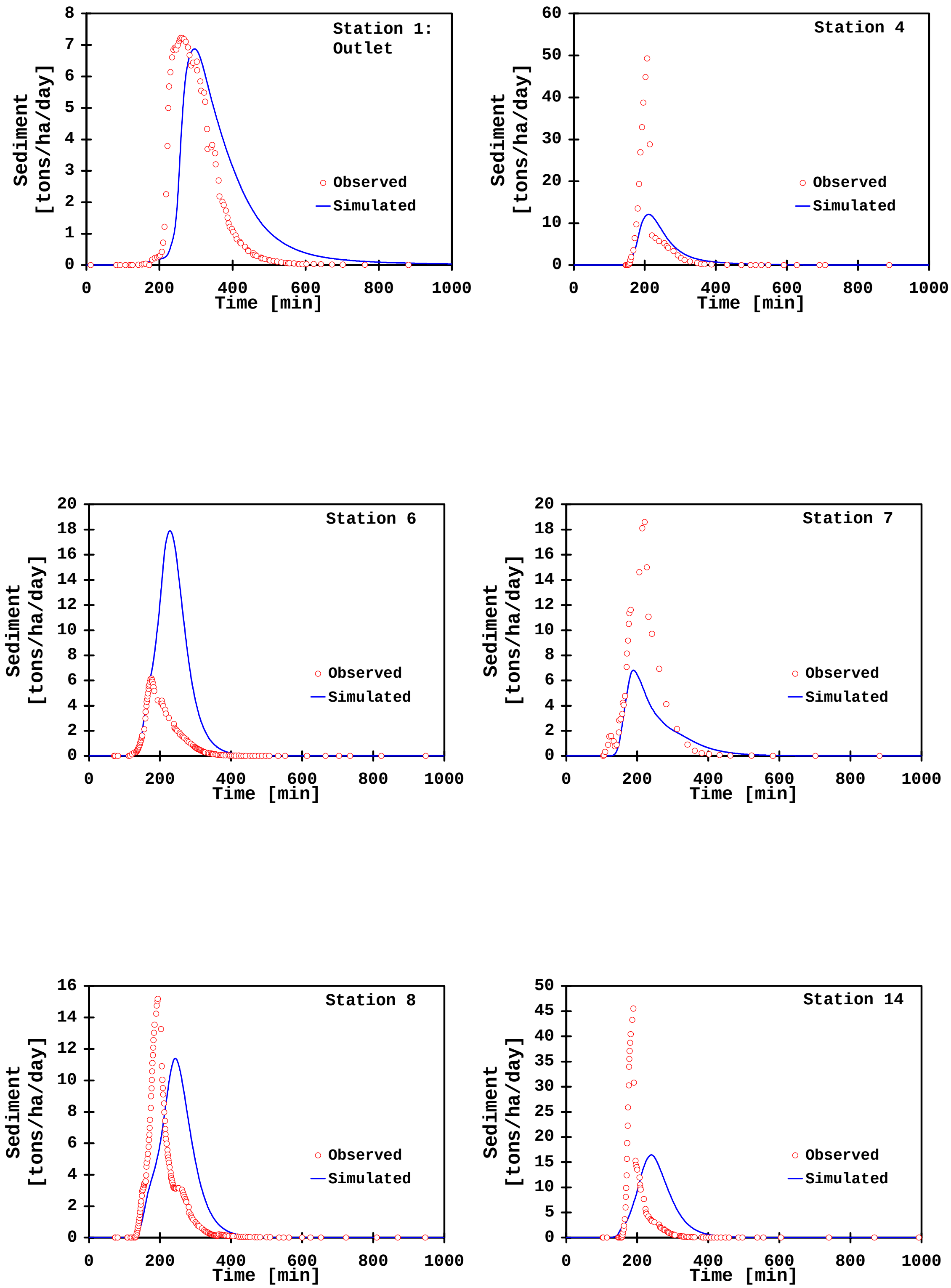

Figure 5-2. Calibrated sediment graphs for event 1

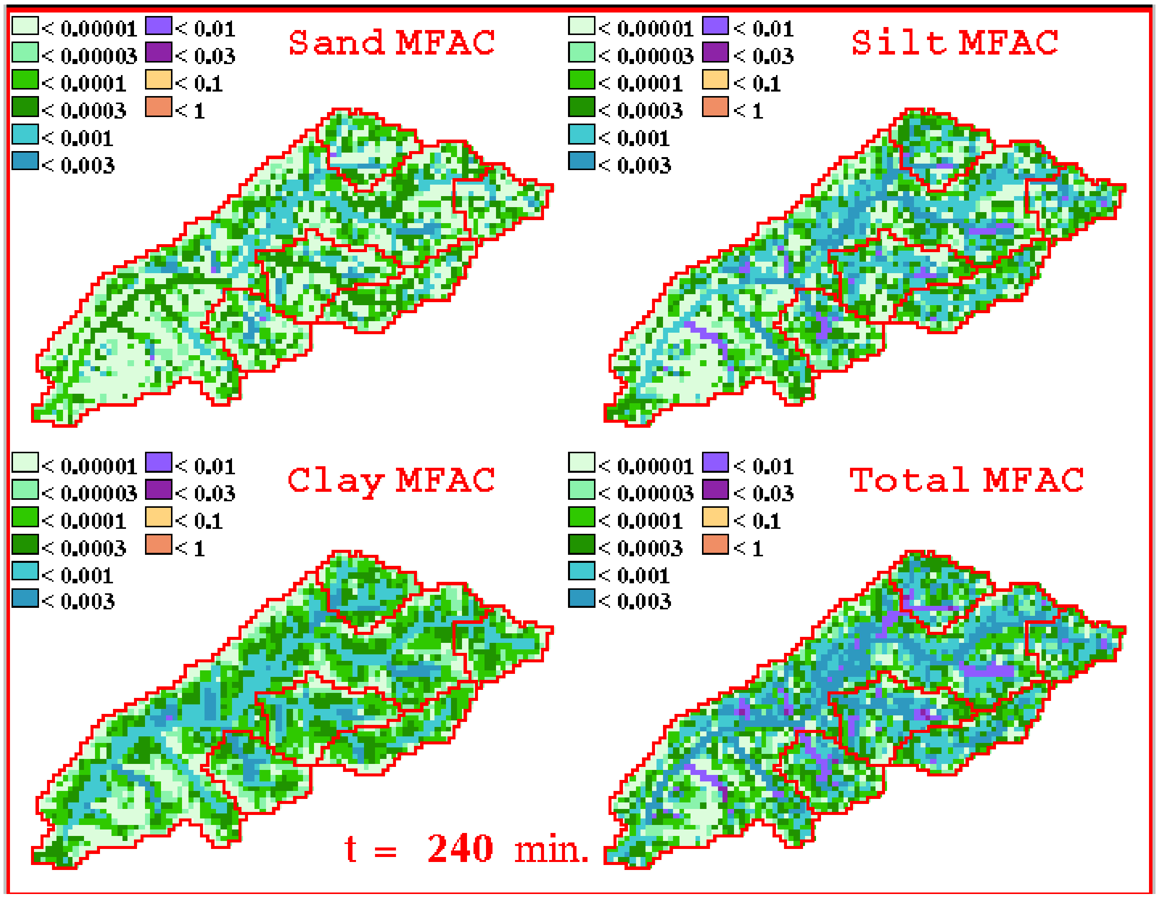

Figure 5-3. Maximum flux-averaged concentration by size fraction and total simulated in the calibration run (time 240 min.).

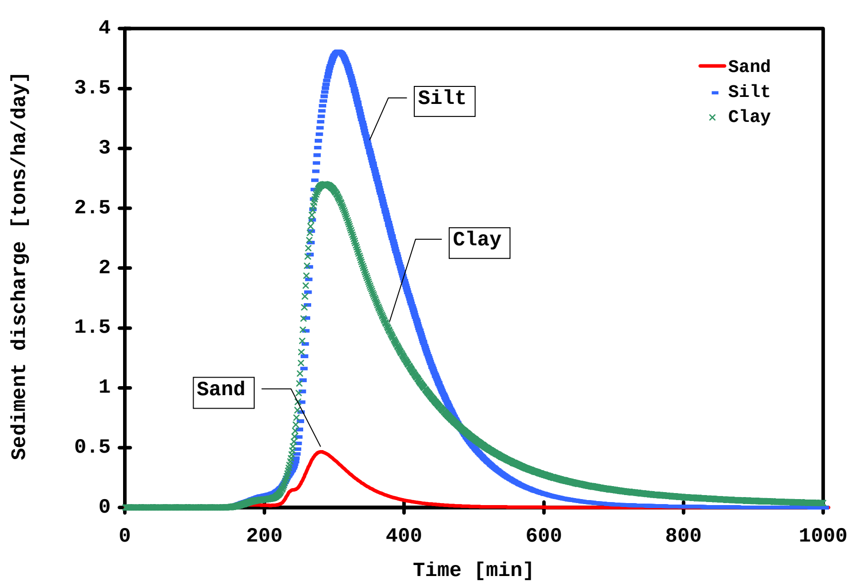

Figure 5-4. Sediment graph at the outlet by size fraction

Spatially, there is practically no suspended sediment remaining at the end of the simulation but for a small amount of clay remaining in water sinks. For about half of the total eroded sediment deposits in the overland and about 15% deposits in channels (see Table 5-4). The percentages of the total sand, silt and clay depositing on the overland are 68, 26 and 5% respectively. This is due to the differences in the settling velocities of each of the size fractions. There is almost no deposition of clay in channels while 26.6% of the eroded sand and 13.1% of the eroded silt deposit in the channels. The effect of both settling rates and transport capacity for each size fraction result in about 5.4, 32.4 and 93.5% of the total eroded sand, silt and clay respectively, to leave the watershed at the outlet.

Table 5-4. Percentages of eroded sediment remaining in the overland and channel cells and leaving the watershed

Size Fraction	Remaining		
	Overland	Channels	Yield
[1]Sand [%]	68.0	26.6	5.4
[2]Silt [%]	54.5	13.1	32.4
[3]Clay [%]	4.9	0.3	93.5
[4]Total [%]	49.7	14.7	35.0

Percentage of the total eroded [1]sand, [2]silt and [3]clay. [4] Percentage of total eroded material

In general, at internal gaging locations, the sediment volume was predicted with a difference of ±50% from observations (see Figure 5-5). The range of ±200% is generally accepted by sedimentation engineers as being acceptable when comparing computed sediment yields versus actual sediment yields (Johnson, 1997). At station 6, the sediment volume was largely overpredicted due to a zone of cultivated land directly delivering sediment to the channel network.

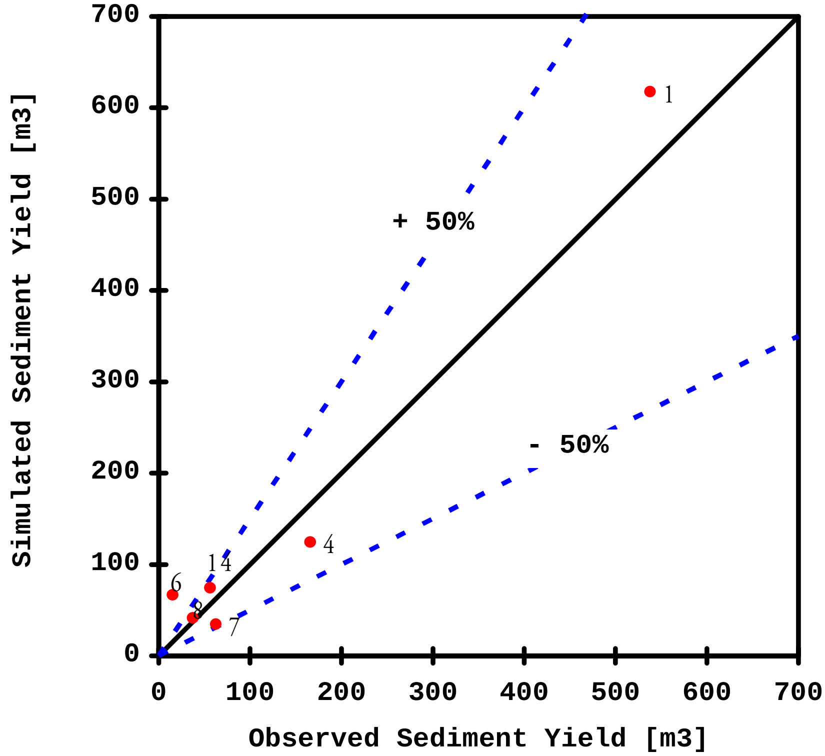

Figure 5-5. Observed vs. simulated sediment yield at the outlet (station 1) and at internal locations (stations 4, 6, 7, 8, and 14) for event 1

Spatially, net erosion values simulated for the calibration event are shown in Figure 5-6 in 3-dimensions, using the watershed DEM as the 3-d surface where the net erosion values are draped. Warm colors represent erosion while cold colors represent deposition. Using the Cs-137 technique, it has been observed (Norton, 1986; Martz and de Jong, 1987; Vesseth, 1990; Sutherland, 1991; Busacca *et al.*, 1993) that, generally, convex ridge tops and mid-slope knobs have the most erosion, while concave shapes with convergent runoff exhibit the more sedimentation. It has been also observed that midslopes have either zones of erosion or deposition, suggesting they are zones of soil transport. (Busacca *et al.*, 1993) and that phases of net aggradation alternate with phases of volumetric loss (Campbell, 1981). These observations are discernible in Figure 5-6.

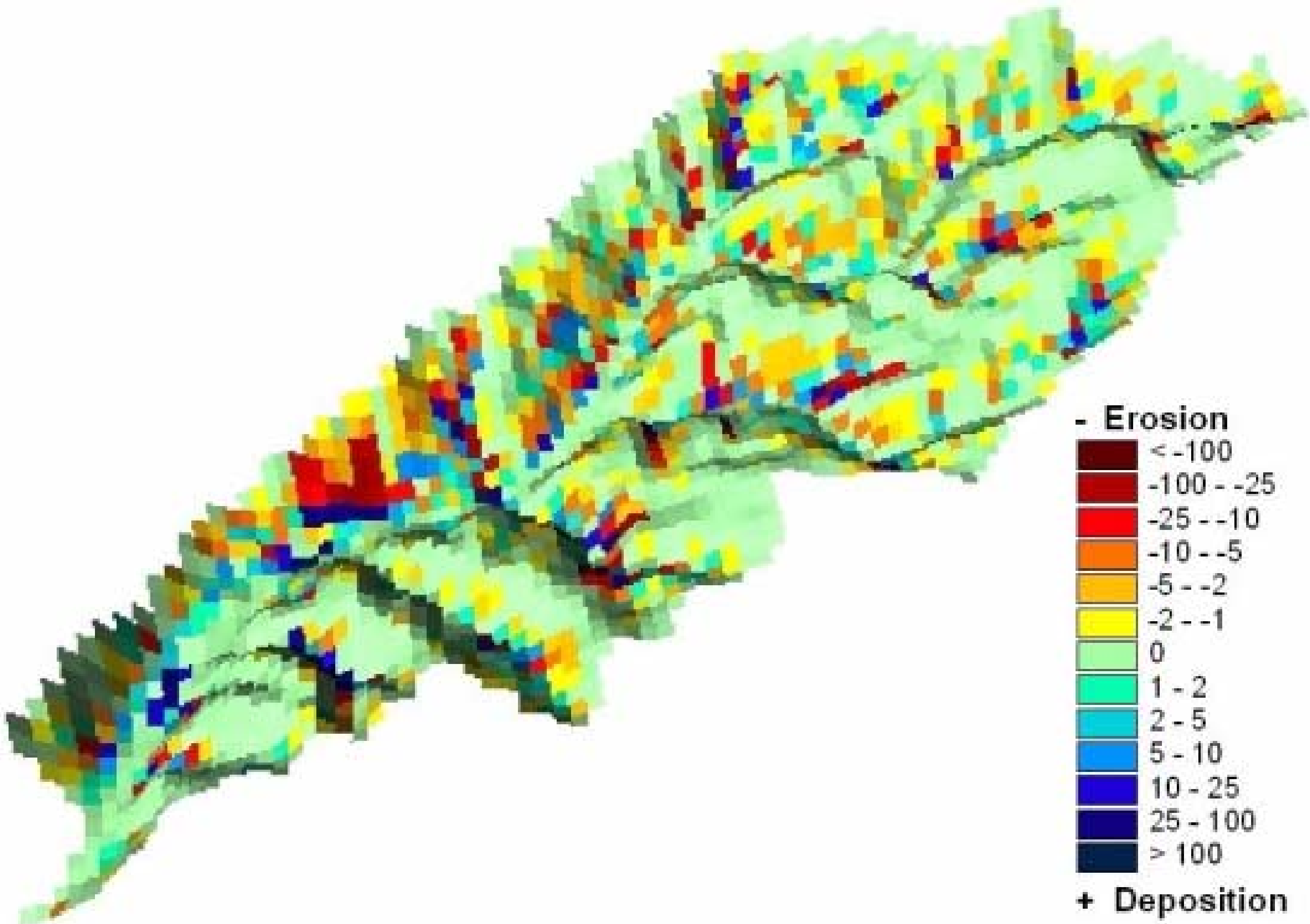

Figure 5-6. Three-dimensional view of the net erosion (tons/ha) at the end of the event 1 simulation.

The cited observations were made on agricultural lands, thus not taking into consideration land use or soil type variabilities. Taking all the factors into account, zones of net soil gain and loss may further change. Figure 5-7 shows the relationship between topography, land use and soil movement rates in the north-south or cross-drainage direction at two cross sections. In general, zones of steep slopes associated with agricultural lands or pasture are the ones presenting a net soil loss. Deposition occurs mostly in flatter or concave areas or in areas with forest land. Net erosion is observed at the watershed boundary. and convex surfaces (in general, in ridges). Erosion rates at these locations are not as large as the ones predicted by equations taking only into account landscape representation (example, USLE) since predicted flow depths are small. Observed high rates of erosion in elevated or exposed areas may include aeolian transport (Sutherland, 1991) which CASC2D-SED does not simulate.

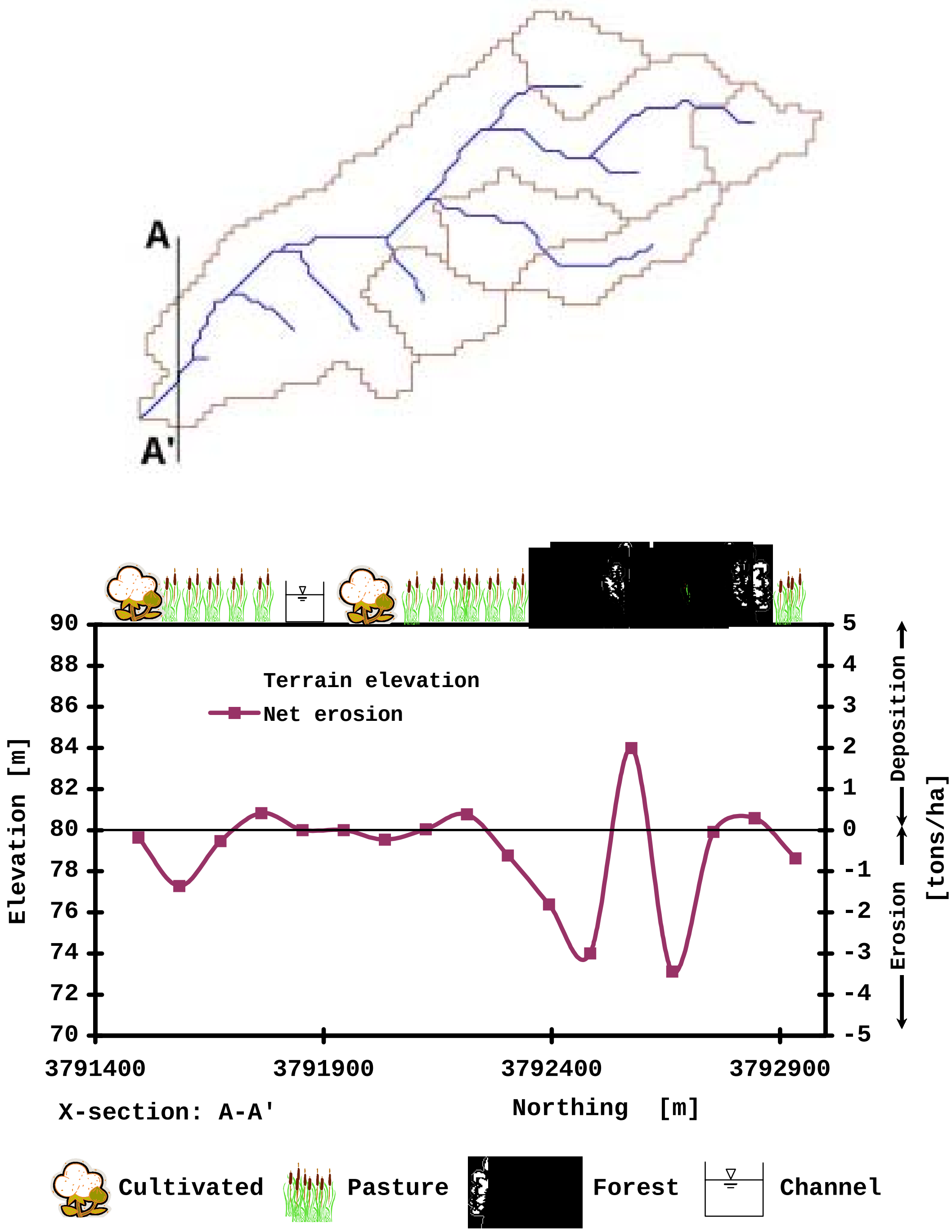

Figure 5-7. Elevation and net erosion at cross section A-A'

5.2.2. Validation Events

Two different events were used to validate the model. Event 2 has a peak discharge for about three times the one observed in event 1, very wet initial conditions and a late peak. Event 3 has larger rainfall intensity rates and distribution, and dry antecedent conditions. In order to match observed and simulated hydrographs, only the initial soil moisture was changed. For event 2, the initial moisture deficit was decreased while this value was increased in the case of event 3. The observed and simulated hydrographs at the outlet and other internal locations for both events are shown in Appendix III. Figure 5-8 shows the summary of the hydrological variables for both the calibration and validation runs at all stream gages. At the outlet, outflow volumes, peak flows and times to peak are very closed to those observed. At internal locations, outflow volumes and peak rates are in general underpredited, while the hydrographs timings are very close to those observed.

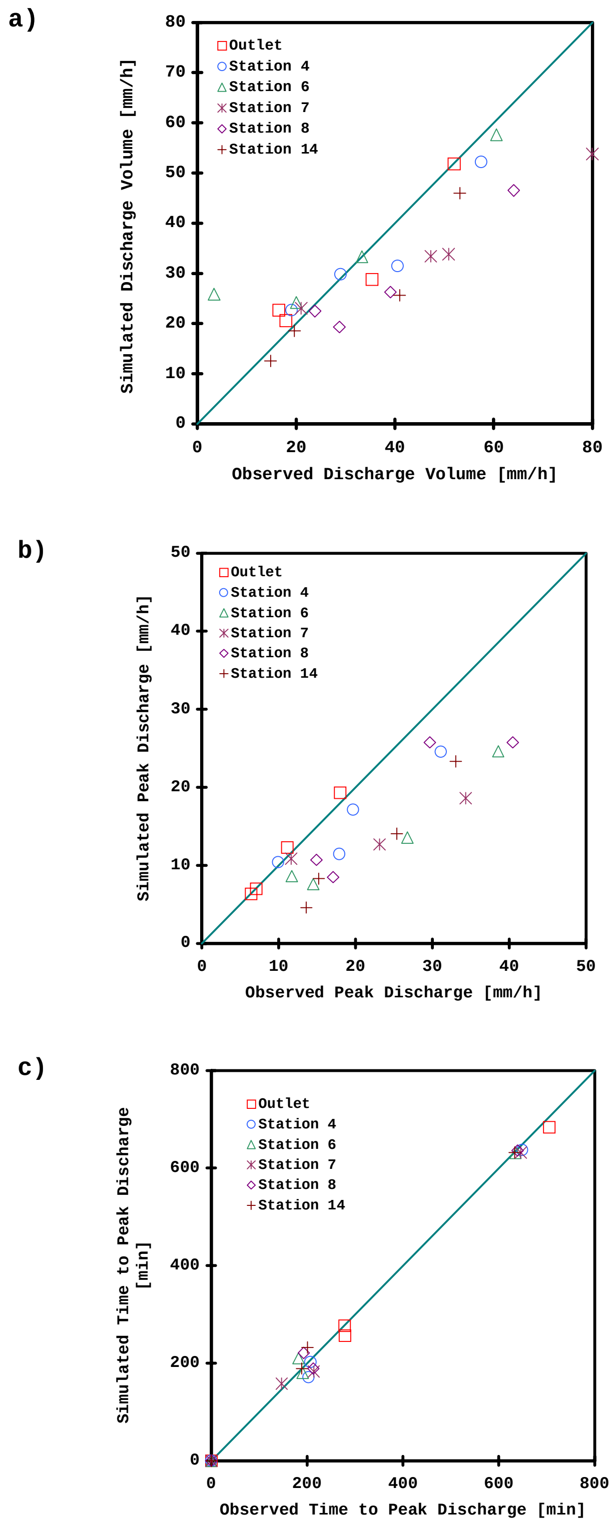

Figure 5-8. Observed vs. simulated a) discharge volume, b) peak discharge and c) time to peak for all the events and at all stations

Since the cover factor, C_{USLE}, is a parameter that depends on the crop conditions, it was changed a certain percentage below (for event 2) and above (event 3) the one used in the calibration run. The observed and simulated sedigraphs at the outlet and other internal locations for both events are shown in Appendix III. Figure 5-9 shows the observed vs. simulated values of the sediment yield for events 2 and 3. In both cases, the majority of the points lie within the ±50% frame, over- or underestimating for the cases of the small sub-basins.

Figure 5-10 shows the historical observed rating curves at the outlet and at stations 4 and 7. These curves show a difference of a couple of orders of magnitude between the observed flow rate and the observed sediment discharge The simulated rating curves for the calibrated and validated events, superposed over the observed values, lie within the range of variability of the observed ones.

a)

b)

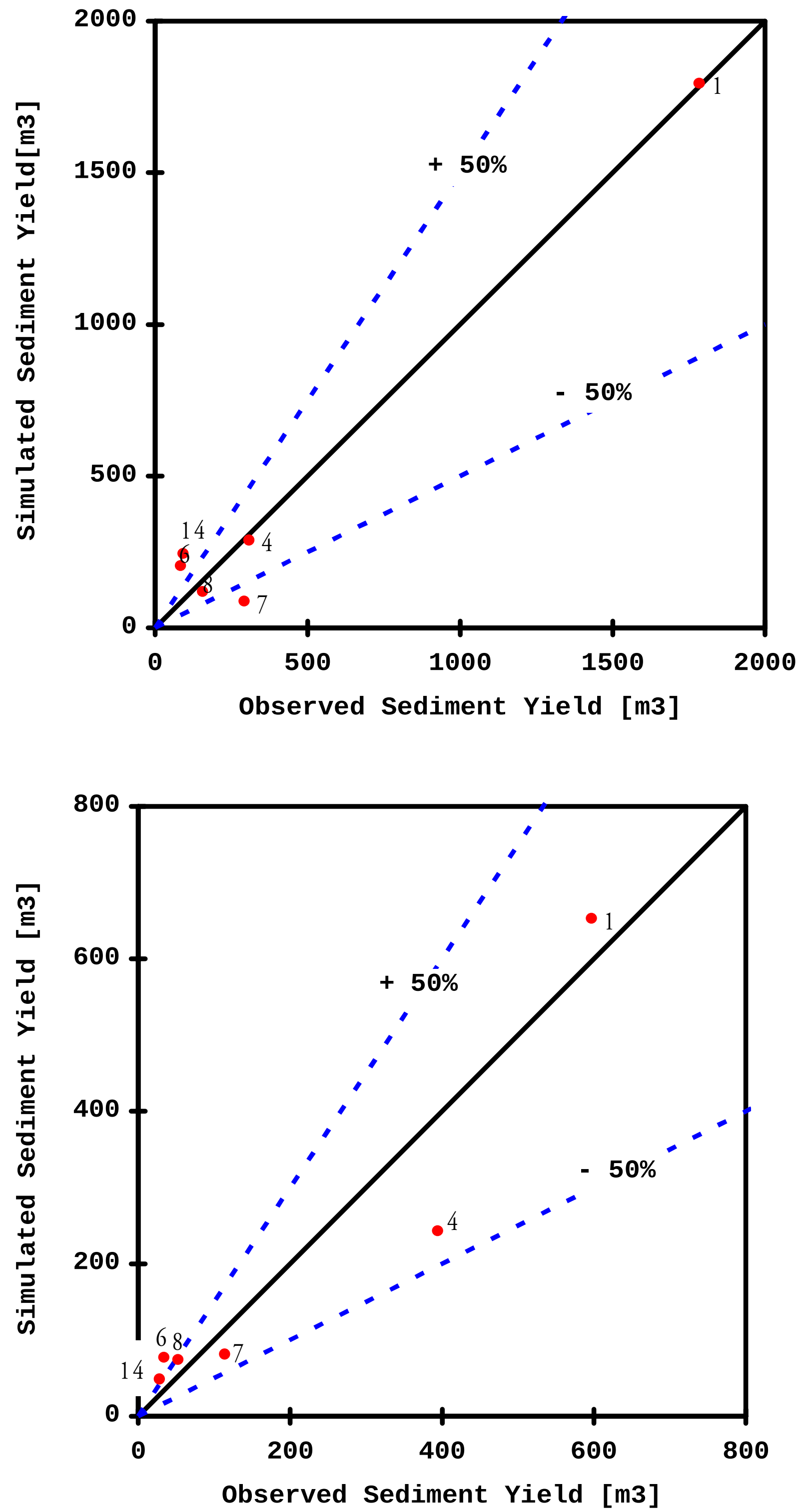

Figure 5-9. Observed vs. simulated sediment yield at the outlet (station 1) and at internal locations (stations 4, 6, 7, 8, and 14) for a) event 2 and b) event 3

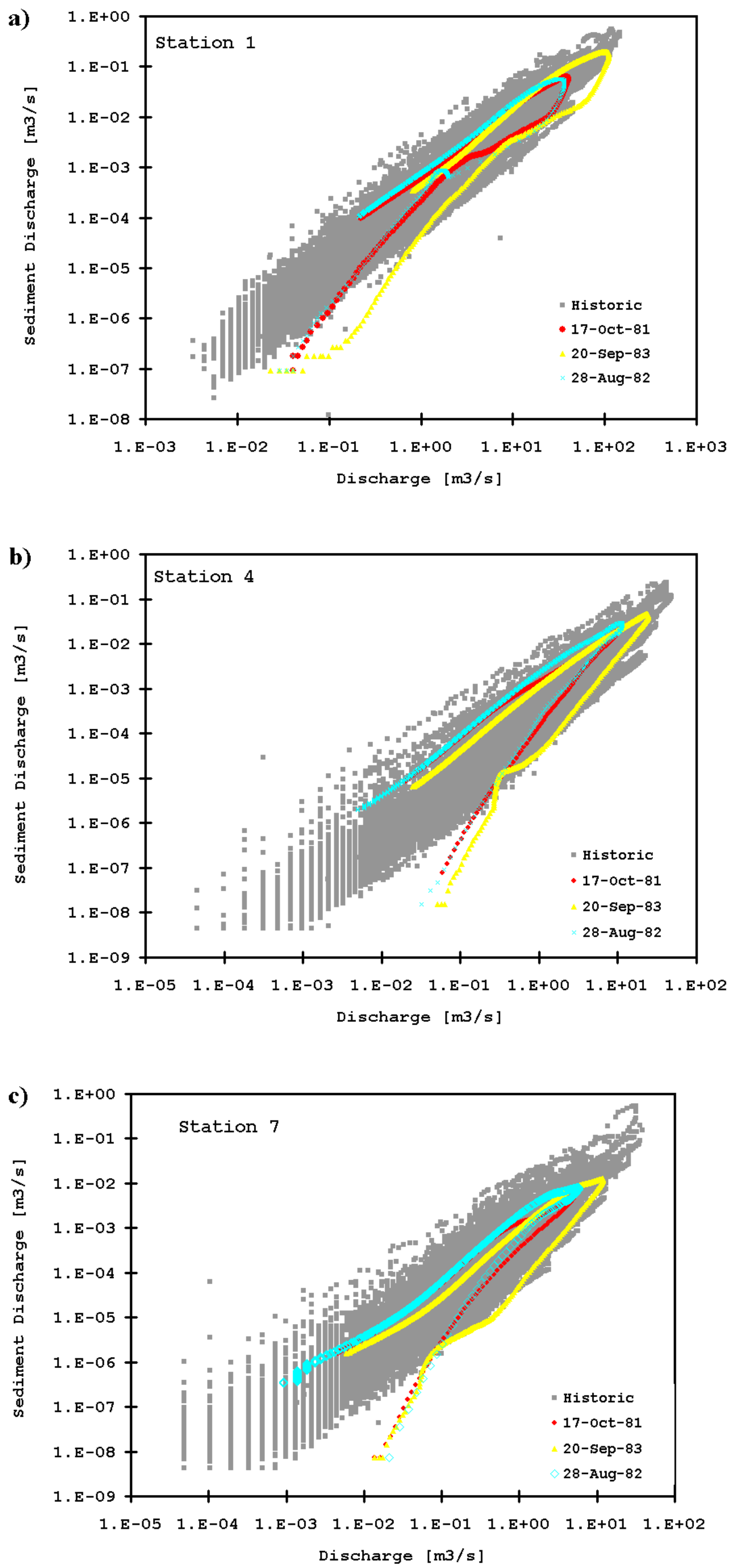

Figure 5-10. Sediment rating curves at the outlet (station 1) and at two internal nested locations (stations 4 and 7) for the calibration and validation events.

5.3. SUMMARY

The model CASC2D-SED was calibrated and validated on Goodwin Creek, Mississippi, using rainfall data from 16 meteorological stations and 6 stream and sediment gaging stations. The following has been seen in this chapter:

(1) CASC2D-SED is able to simulate the hydrological response of a watershed subject to a spatially and temporally variable rainfall field. At the outlet, simulated values of peak discharge, discharge volume and time to peak discharge are very close to the observed values.

(2) CASC2D-SED is able to simulate the sediment graph at the basin outlet. Sediment yield at the outlet and at internal locations was predicted within a range of ±50% of the observed values. Observed rating curves show how for the simulated outflows range, the sediment flows vary within two orders of magnitude. Simulated rating curves fl inside the observed ones.

(3) The effect of differences in settling rates and transport capacities for each size fraction result in different percentages of the total eroded material to leave the watershed at the outlet. The clay fraction, representing the smallest percentage in the parent material, made up most of the sediment yield at the outlet. This fraction is carried mostly as washload, with little deposition in the watershed or the channels. The sand fraction, carried primarily as bed load material, has the largest deposition rates and thus a small percentage of this fraction is found at the outlet.

(4) CASC2D-SED predicts erosion and deposition zones in a watershed. Visual inspection of the net erosion map show that there is erosion in convex and steep areas and deposition in concave or flat areas. In a basin cross section, it can be observed that zones of steep slopes associated with agricultural lands or pasture are the ones presenting the largest net soil loss. Deposition occurs mostly in flatter or concave areas or in areas with forest land.

(5) Geovisualization and animation of the CASC2D-SED output grids proved helpful in the testing phase of the model. These GIS techniques are used as a form of model validation of the sediment transport dynamics and net erosion patterns where measured data are not available.