Table 2.4 Adopted parameters for the Distributed Field-Williams Model

Parameter		Value	(Range)
S_ϕ	Sorptivity, initial infiltration	3.85 mm/hr$^{1.2}$	(0–3.85)
ϕ	Long-term infiltration rate	6.5 mm/hr	(6.5–40)
n	Mannings coefficient	0.03	(0.025–0.035)
C_r	Conveyance coefficient for 30 m wide sheetflow	7.0	(6–8.5)
e_m	Conveyance exponent	1.66	
c_s	Surface storage coefficient	0.03	
γ	Surface storage exponent	0.375	

3 Erosion model calibration

3.1 Overview

Natural rainfall runoff events for the caprock and batter sites were supplied by staff of the Geomorphology Branch at ***eriss***. Table 3.1 summarises the sediment yield data used in this study. Maps of the field sites are provided in appendix A and the data used in the study are tabulated in appendix C.

Data for a range of rainfall simulation data were provided in report and computer readable form. The computer data are summarised in table 3.2. These simulator rainfall-concentration data have been checked for consistency and appear to be accurate, with no obvious signs of error.

Table 3.1 Sediment yield data supplied for caprock and batter sites[c]

	Caprock sites[a]						Batter sites		
Storm	WT1	WT2	WT3	RT1	RT2	OUT	RT2	WT1	WT2
7/1/91 (20:50) [b]	✓	×		×	×	?			
7/1/91 (14:55) [b]	×	✓		✓	×	?			
8/1/91						?			
10/1/91 (7:55) [b]						?			
10/1/91 (14:00) [b]	×	×		×		?			
11/1/91				×		?			
21/1/91	✓	✓					×		
28/1/91							×		
30/1/91							×	×	
4/2/91		✓				×	×	✓	
6/2/91			✓				✓	✓	✓
13/2/91							✓	✓	
16/2/91	✓		✓				✓	✓	✓
22/2/91							✓	✓	

(a) Site notation as per Neave (1991);

(b) Two events supplied for this day, approximate beginning time in 24 hour clock;

(c) Notation is ✓ = data appears to have reliable matching discharge data, × = no matching reliable discharge data; ? = part or whole of the matching discharge hydrograph is questionable.

Table 3.2 Computer readable rainfall simulator data supplied

Datafile	Run	Date	Area (m^2)	Slope
Batter: B1RF1QSS	plot1 (runs 1–5), uncovered	5–7/10/90	1.2	0.152
	plot2 (runs 1–5), covered	5–7/10/90	0.99	0.185
Batter: B1RF2QSS	plot1 (runs 1–3)	17–18/10/91	1.2	0.152
	plot2 (runs 1–3)	17–18/10/91	10.2	0.187
	plot3 (run 1)	17/10/91	0.99	0.99
	plot4 (runs 2–3)	18/10/91	107.7[(b)]	0.19
Cap: C1RT2SS	plot1 (runs 2–4)	23–25/4/90	113.5	0.021
	plot2 (runs 2–4)	23–25/9/90	116.5	0.025
Cap: MESO	plot1 (runs 1–5)[(a)]	22–25/4/90	7.8	
	plot2 (runs 1–5)[(a)]	22–25/4/90	4.5	

[(a)] the suspended solids data for plot1 run5 and plot2 run 4 were not available;
[(b)] area possibly erroneous (see section 2.3.2)

The intention of this section is to calibrate the instantaneous sediment transport model described by equation 1.5.2. This will be converted to the long-term erosion rate in section 4.3. There are thus 3 parameters that require determination: β_1, m_1 and n_1, the transport rate, and the exponents on the discharge and slope respectively. The process adopted will be to use multiple regression on the available data, over a range of discharges, catchment areas and slopes, to estimate these parameters.

3.2 Natural rainfall data

The range of sediment transport events from natural rainfall events were examined and the data used to calibrate a sediment transport relationship of the form of equation 1.5.2. A number of events were discarded because either the sediment data or the discharge data were suspect. For instance, many of the storm event data were only for the falling limb of the hydrograph.

A common characteristic of the data was that if the rising limb at the start of the storm had been observed the first datum point at the start had an anomalously high concentration. This behaviour is not uncommon and is commonly believed to result from rainfall detachment of particles at the start of the event, while depressions are being filled, and before runoff has begun. This hyper-concentrated water is then flushed in the first minutes of the storm after which concentrations fall back to normal levels (Loch, pers comm). The total mass of sediment in that first flush is not a significant proportion of the total mass of the event and because these data bias the multiple regression procedure they were deleted from those events where they were observed.

The result of the multiple regression analysis with the remaining reliable data yield a relationship of the form

$$c = 0.27\, q^{0.22}\, S^{0.01} \;\; ; \;\; r^2 = 0.29 \qquad 3.2.1$$

The overall fit of this expression to the data is quite poor as indicated by the correlation coefficient. Figures 3.1 and 3.2 show the concentration data against the slope and discharge. Partial regression tests indicate that the exponent on discharge is significantly different from 0, as is the multiplicative constant at the 5% level, while that for slope is not. Finally, there was no significant difference between the sediment concentrations for the wash traps and the rill traps.

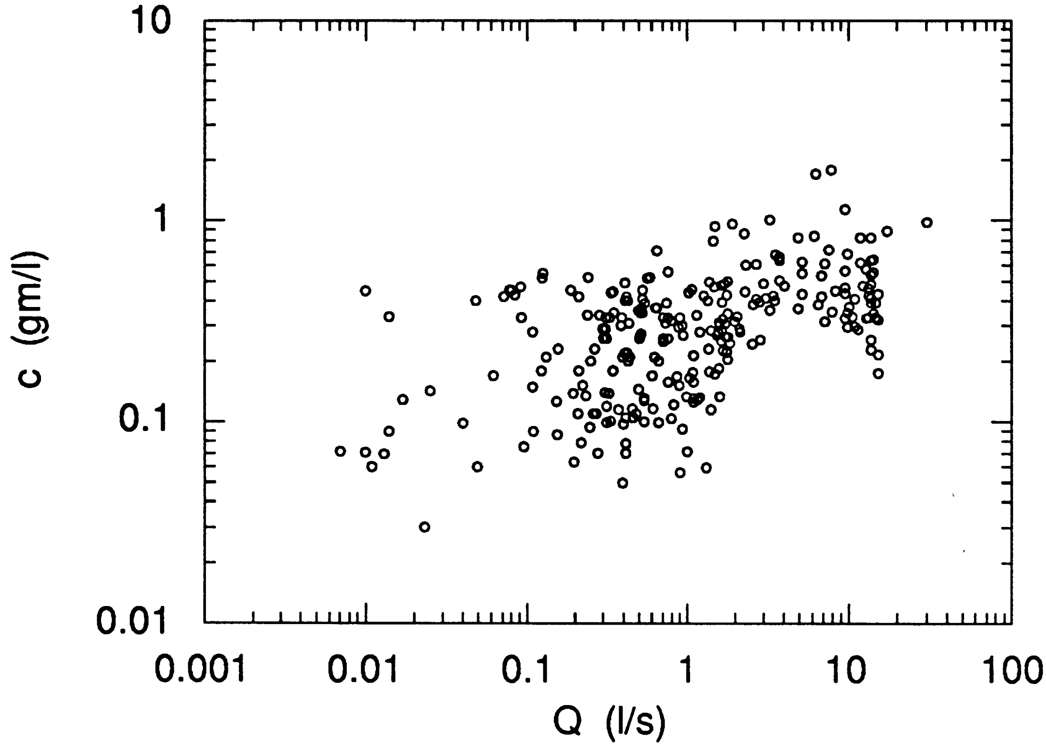

Figure 3.1 Concentration versus discharge for the natural rainfall events on both the batter and the caprock sites

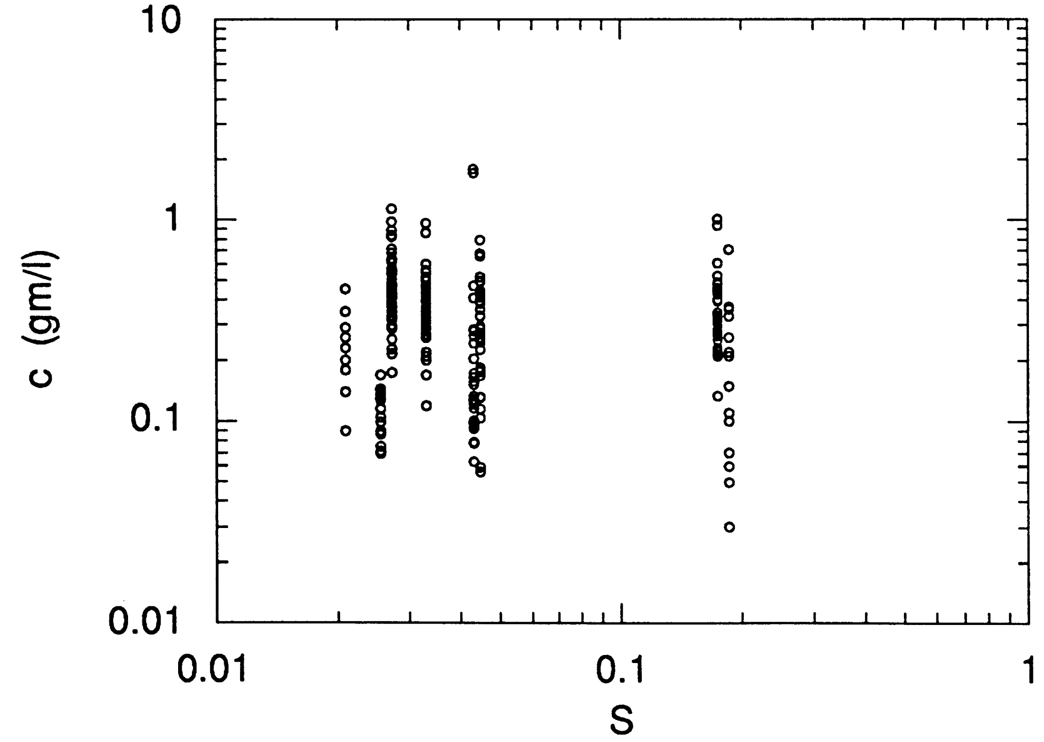

Figure 3.2 Concentration versus slope for the natural rainfall events on both the batter and the caprock sites

The independence of the concentration from slope is surprising and disturbing but a close examination of the results in figure 3.2 suggest a reason. The concentrations for the batter sites (slope ≈ 0.2) are notably lower than those of the caprock sites (slope ≈ 0.02–0.04). In the initial culling of the data it was not possible to remove all the data that came from events where only the falling limb of the data was sampled otherwise very little data would have been left. The rating curves with discharge indicated that clockwise loop ratings were common, though not universal. This type of rating is indicative of sediment concentrations peaking before the hydrograph (Williams 1989) but may also be a result of sediment starvation. If only the falling limb of the hydrograph is sampled then the concentrations will be lower than the mean values. Examination of the data suggest that the higher slope sites on the batter seemed to have sampled the falling limbs of the hydrograph more often than the caprock sites so that the concentrations on the batter slopes were biased downwards. This effect clearly reduces the reliability of the slope estimate for concentration.

3.3 Rainfall simulator data

The larger simulator catchments from the batter and cap plot 4 from B1RF2QSS and C1RF2QSS (see table 3.1) were used to calibrate the fluvial sediment transport equation of equation 1.5.2 on the presumption that they would be least dominated by rainsplash. That way multiple regression could be used to directly fit the parameters on discharge and slope.

Figures 3.3 and 3.4 show the variation of the concentration with the discharge and slope for these large plots. The result of the multiple regression was

$$c = 3.55\ Q^{0.42}\, S^{0.66}\ ;\ r^2 = 0.620 \qquad 3.3.1$$

The correlation coefficient indicates that the fit of this equation is better than that obtained with the natural rainfall data. The exponent on discharge is consistent with fluvial transport according to Einstein-Brown sediment transport on a rilled surface (about 0.3–0.5, Willgoose et al 1989) and other field data (Loughran 1977, Moore & Burch 1986). The variation of concentration with discharge for one rainfall simulation experiment is illustrated on figure 3.5. Note that the apparent decline in concentration with time is strongly associated with the period of initially increasing discharge and that this apparent starvation effect appears to be complete within about 20 minutes. Thereafter, concentration decreases with decreasing discharge as expected in the non starved case.

The exponent on the slope in equation 3.3.1, however, is considerably less than that expected for a rilled surface (about 1.5–2). One possible explanation for this deviation is that the batter (hence higher slope) plots may have had a coarser lag layer (compared with the caprock plots) so reducing the transport rate on the higher slope surfaces. The exponent of 1.5–2 is derived using the assumption that the material grading properties do not change with discharge or slope. Grading of samples taken from the caprock and batter regions suggest that there are minor differences in the lag layer, but not of the magnitude needed to explain the deviations from theory observed.

To calibrate the diffusive transport, the data were fitted using multiple regression with trial and error estimates for the diffusive transport by using the transformation

$$c - \frac{DS}{q} = \beta_1\, q^{m_1 - 1}\, S^{n_1} \qquad 3.3.2$$

The best estimate that was obtained by this process was

$$c = 3.59\ q^{0.68}\ S^{0.69} + \frac{0.178RS}{q}\ ;\ r^2 = 0.638 \qquad 3.3.3$$

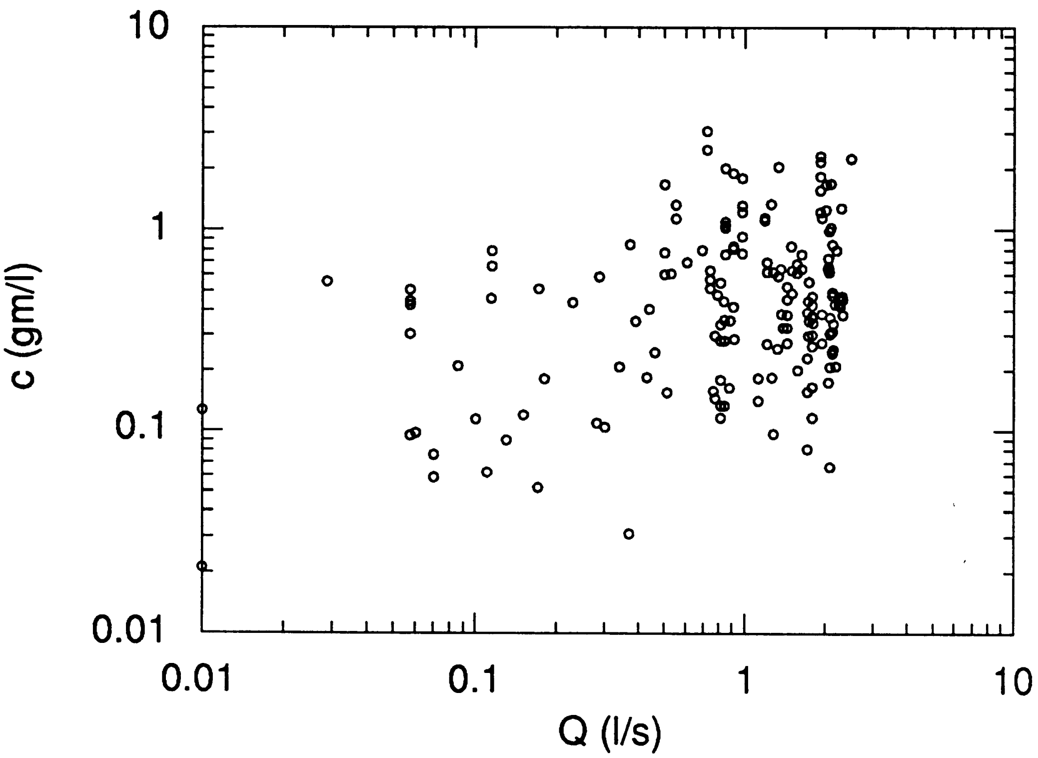

Figure 3.3 Concentration versus discharge for the large plots

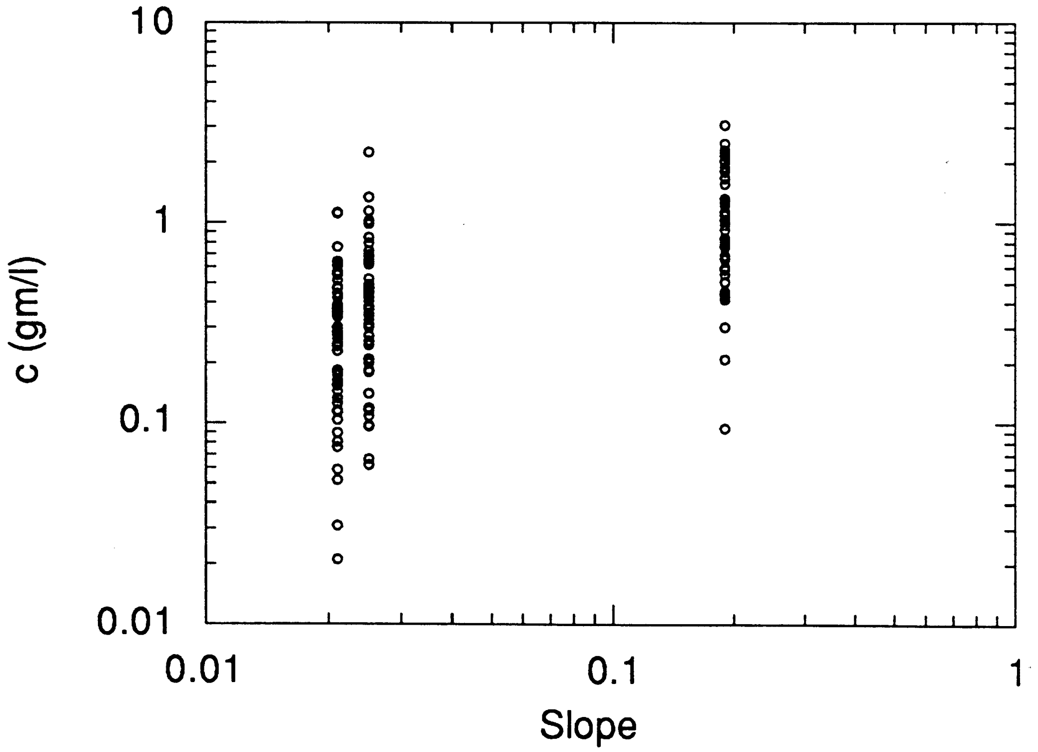

Figure 3.4 Concentration versus slope for the large plots

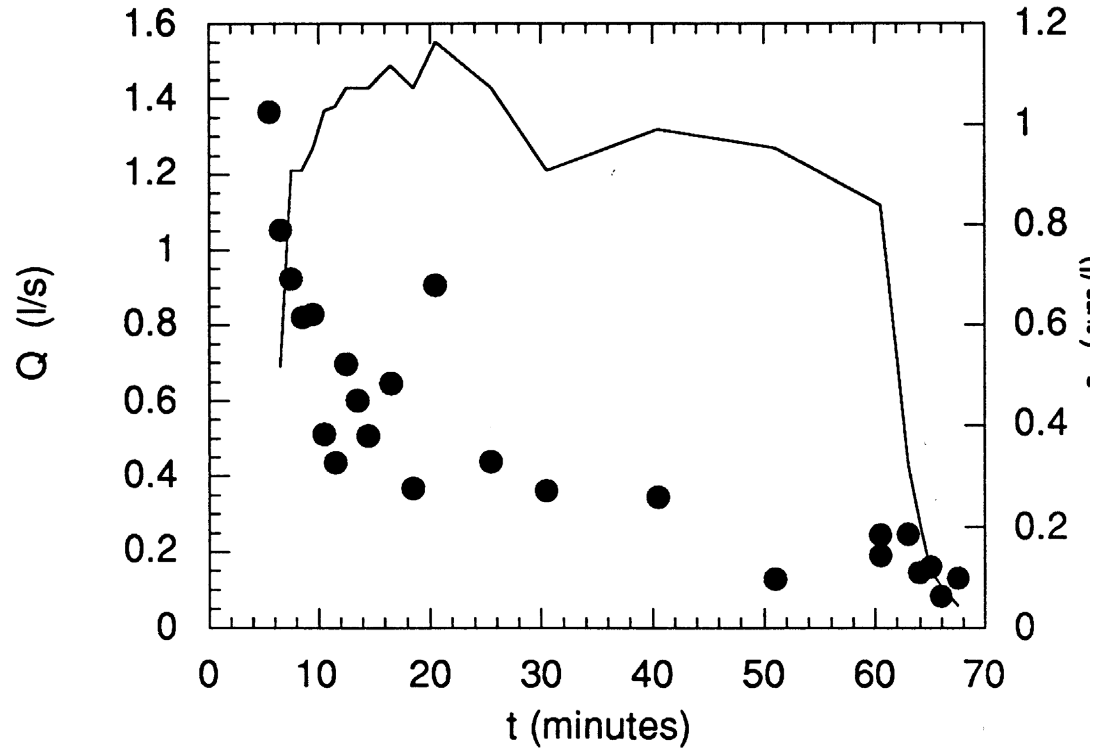

Figure 3.5 Sample hydrograph and sediment samples for caprock, large plot rainfall simulation

The estimated parameters are only slightly different from those determined from the case ignoring diffusive transport in equation 3.3.1 and there was a small, though significant, improvement in the correlation coefficient for this case. The exponent on the discharge was significantly increased, though the value is still in the range to be expected for rill flow. The exponent on slope was not significantly changed.

The diffusivity obtained for the small plot data for the batter (plots 1 and 2 from B1RF1QSS) were used to independently check the diffusivity calculated above. These plots have comparable area and slope and vary only in that one was covered and one was not. The purpose of the covering was to break the fall of the raindrops and thus dissipate the rainsplash energy. On the small area of 1 m^2 rainsplash is expected to dominate overland erosion. The difference in the transport of the two plots could thus be expected to be a good indicator of the magnitude of the rainsplash transport and thus the diffusivity.

The concentration versus discharge for the two plots is illustrated in figure 3.6. This change in concentration for the two plots can be expressed as

$$\Delta c = \beta_1 q^{m_1 - 1} S^{n_1} - \left(\beta_1 q^{m_1 - 1} S^{n_1} + \frac{DS}{q} \right) = \frac{DS}{q} \qquad 3.3.4$$

This calculation gave a value of D = 0.26. This value is in good agreement with the value calculated from the large area plots of D = 0.178. It is worthwhile to note that the plots' behaviour was consistent with the Fickian diffusion mechanism with transport being independent of discharge, validating its use for the modelling small scale sediment transport behaviour.

Finally the MESO rainfall simulator plots were examined. The areas of these plots (5–8 m^2) were mid-range area between the small plot (1 m^2) and the large plots (100 m^2) so that they would be expected to exhibit behaviour midway between that of the small and large plots. This was the case. For the lower rainfall rates (and thus lower discharges) rainsplash (diffusive) transport was dominant. For higher rainfall rates the behaviour appeared more like the fluvial transport mechanism (figs 3.7 & 3.8). However, of note was that if all the MESO data was plotted together there is a clear downward trend with increasing discharge (fig 3.9).

This appears to be due to sediment starvation, as the MESO experiments were performed over 4 days with increasing rainfall rates (yielding large discharges) being applied in each day. It is believed that each day's erosion was starved because of the depletion of the sediment store that had occurred with the previous days experiments. It is important, however, to observe that during each high rainfall rate experiments there was a positive correlation with discharge, consistent with all the results for the other plots discussed above. It is asserted here that the parameters m_1, n_1 and D fitted above are adequate for describing sediment transport during any event, but that the parameter β_1 may vary from event to event reflecting the amount of sediment removed from storage by previous days' runoff events.

3.4 Conclusion

The data for the natural rainfall data and the simulator rainfall data have a significantly different functional dependence on slope though similar relationship with discharge. The problem remains as to which are the most reliable data. To this end the two sets of data were aggregated and examined as a whole. These data are plotted against discharge and slope in figures 3.10 and 3.11.

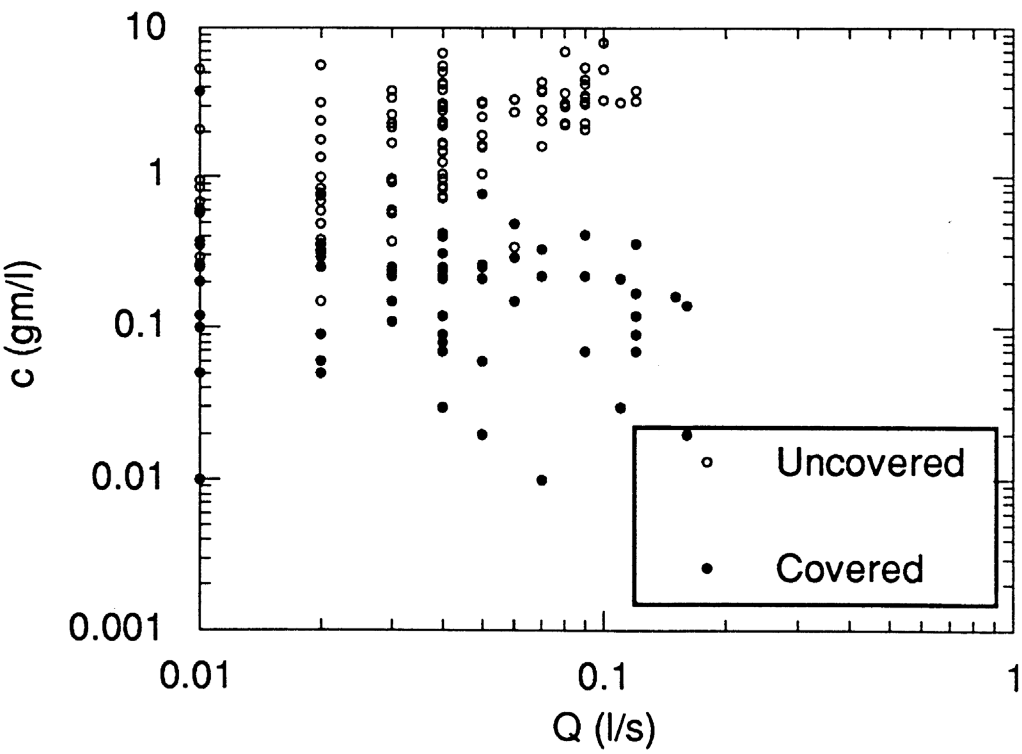

Figure 3.6 Concentration versus discharge for the covered and uncovered plots

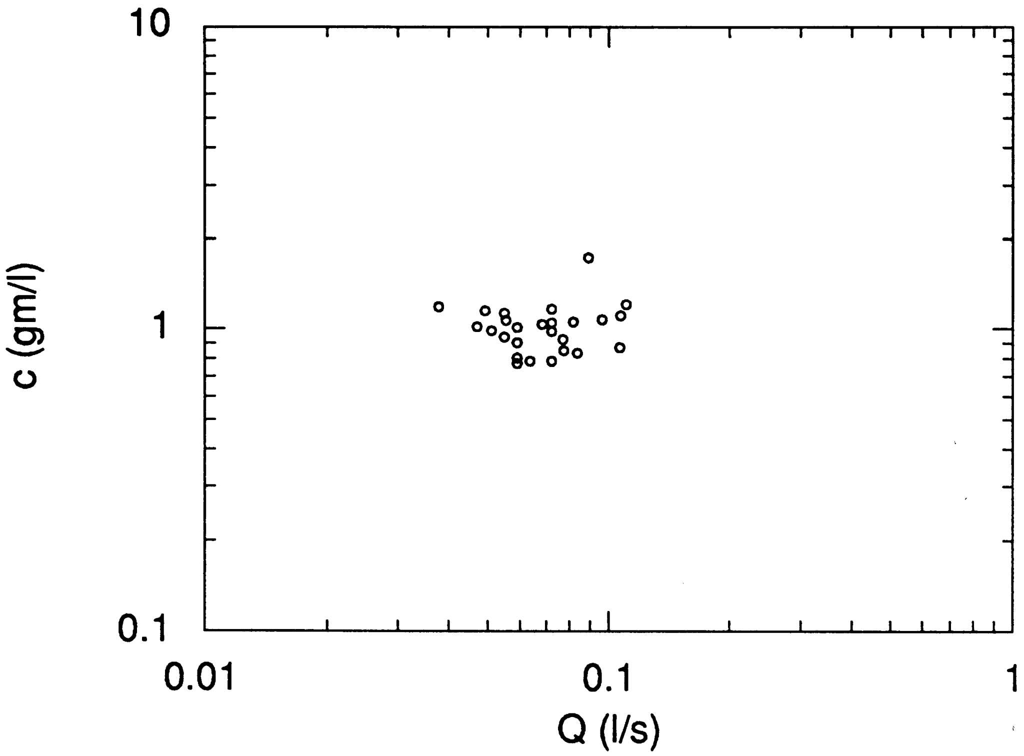

Figure 3.7 MESO plot (area 7.8 m2) for low discharge. Note the lack of any trend with discharge

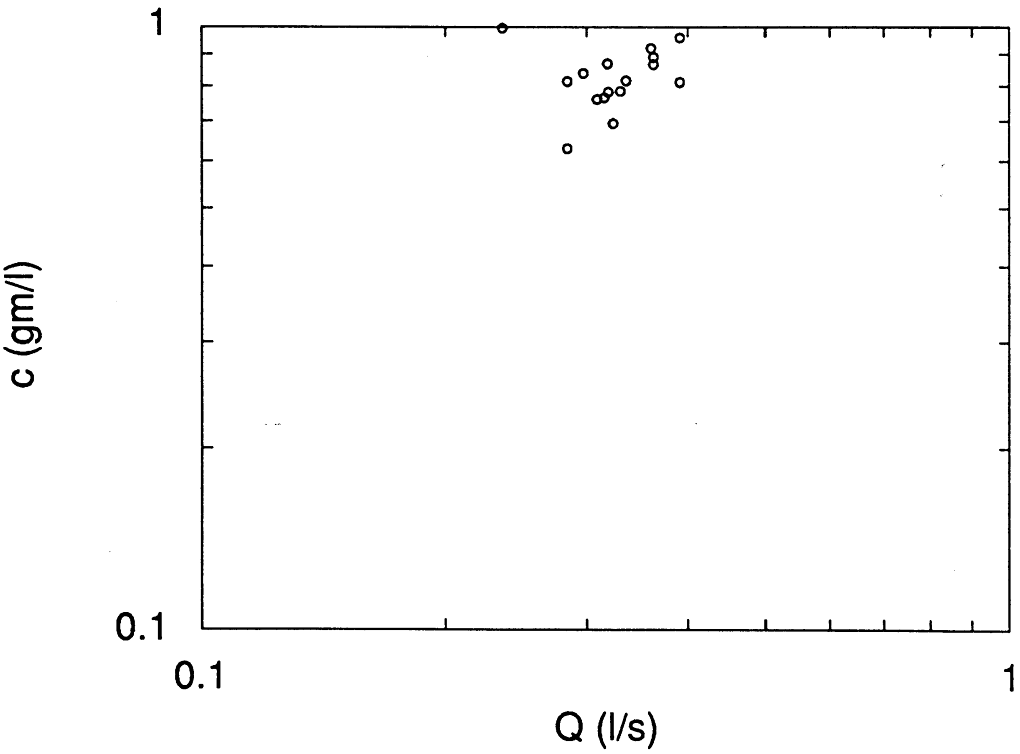

Figure 3.8 MESO plot (area 7.8 m2) for high discharge. Note the positive trend with discharge

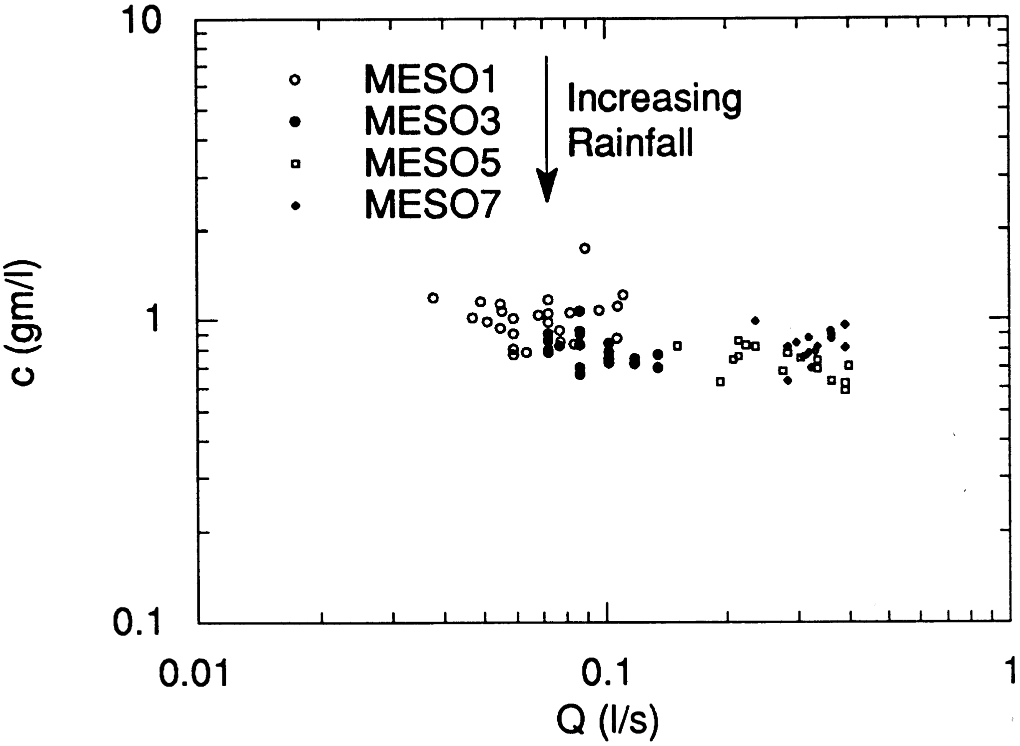

Figure 3.9 All available concentration-discharge data for the MESO plot of area 7.8 m^2

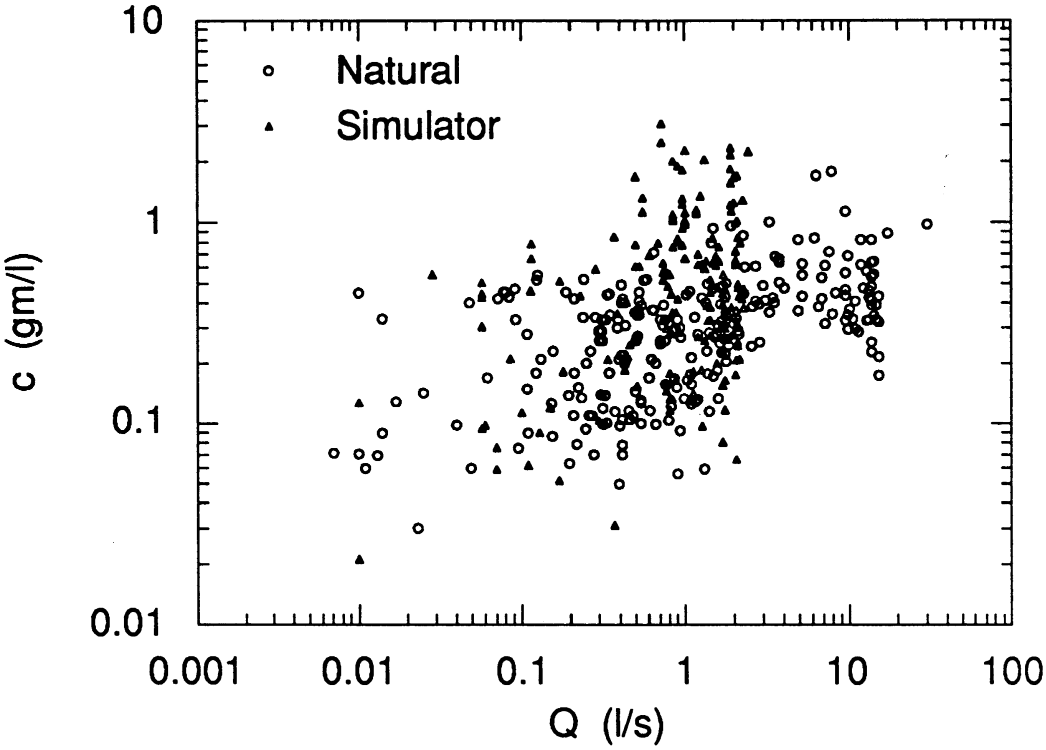

Figure 3.10 Concentration versus discharge for both the natural events and simulated data

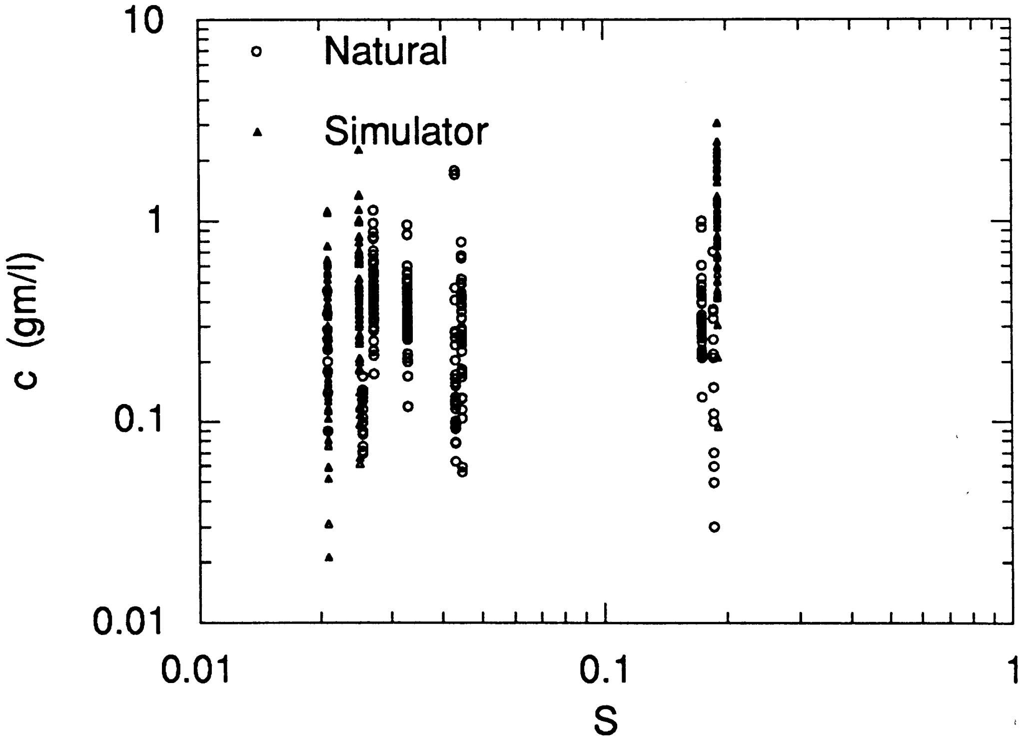

Figure 3.11 Concentration versus slope for both the natural events and simulated data

An examination indicates that the concentrations for the natural rainfall experiments are lower than the simulator results, particularly for high slopes. This behaviour is marked and suggests a bias in the natural data, as noted in section 3.2. In the graph of concentration versus discharge (fig 3.10) the results for the natural rainfall and simulated rainfall are little different, with the low discharge values for the natural event appearing to plot only slightly higher than the simulator.

Not surprisingly, a multiple regression of these data yields a result somewhat midway between the two results discussed in previous sections

$$c = 0.96\, q^{0.26}\, S^{0.34} \;\; ; \;\; r^2 = 0.29 \qquad 3.4.1$$

It is notable, however, that this fit is little better than that obtained for the natural data, and considerably worse than the fit for the simulation data. Furthermore, attempting to fit the diffusion coefficient, as was done for the simulated rainfall data, did not improve the significance of this fit. Given these considerations it was decided that the adopted sediment transport relation for this study should be the one fitted in equation 3.3.3 for the rainfall simulator experiments, ie

$$c = 3.59\, q^{0.68}\, S^{0.69} + \frac{0.178RS}{q} \;\; ; \;\; r^2 = 0.638 \qquad 3.4.2$$