transport model is calibrated with the rainfall simulator trials then sediment starvation has to be accounted for explicitly. This study uses the natural data wherever possible to circumvent this problem. In any event, the small differences between the simulated rainfall and natural rainfall concentration data appear to have negligible effect on the relationship between discharge and concentration.

2 Hydrology model calibration

2.1 Overview

2.1.1 Data

Natural rainfall runoff events for the caprock and batter sites were supplied by staff of the Geomorphology Branch at ***eriss***. Tables 2.1 and 2.2 summarise the runoff and rainfall data that have been used in this study. Maps of the field sites are provided in appendix A and the data are tabulated in appendix B. Catchment characteristics are summarised in table 2.3.

Some of the rainfall and runoff data were checked by double mass curves. A very good correlation was found for most storms (see fig 2.1 & 2.2) as would be expected by their closeness. For the 16/2/91 event, the batter gauge appears to have missed the first peak of a two-peaked storm.

The plot characteristics (eg area, slope) were determined from the contour maps in appendix A.

Table 2.1 Runoff data supplied for caprock and batter sites(c)

	Caprock sites(a)					Batter sites		
Storm	WT1	WT2	WT3	RT1	OUT	RT2	WT1	WT2
25/12/90								
28/12/90								
7/1/91 (20:50)(b)	?				✓(d)			
7/1/91 (14:55)(b)		✓		✓	✓(d)			
8/1/91					✓(d)			
10/1/91 (7:55)(b)	✓	✓		✓	✓(d)			
10/1/91 (14:00)(b)					✓(d)			
11/1/91					✓(d)			
21/1/91	✓	✓						
27/1/91								
28/1/91					✓(d)			
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 be accurate; × = data appears to be inaccurate; ? = data conflicts with other data;
(d) Data is truncated above discharge 15 L/s.

Table 2.2 Supplied rainfall data[(b)]

	Site			Site	
Storm	CAP	BAT	Storm	CAP	BAT
25/12/90	✓		27/1/91	✓	
28/12/90	✓		28/1/91		✓
7/1/91 (20:50)[(a)]	✓		30/1/91	✓	✓
7/1/91 (14:55)[(a)]	✓		4/2/91	✓	✓
8/1/91	✓		6/2/91	✓	✓
10/1/91 (7:55)[(a)]	✓		13/2/91		✓
10/1/91 (14:00)[(a)]	✓		16/2/91	✓	×
11/1/91	✓		22/2/91		✓
21/1/91	✓	✓			

[(a)] Two events supplied for this day, approximate beginning time in 24 hour clock; [(b)] Notation is ✓ = data appears to be accurate, × = data appears to be inaccurate, ? = data conflicts with other data.

Table 2.3 Catchment characteristics

	Area (m^2)	Mean slope	Mean width (m)	Length (m)
COUT	2182	0.03	(b)	(b)
CRT1	461	0.029	(b)	(b)
CRT2	330	0.039	(b)	(b)
CRT3	731	0.034	(b)	(b)
CWT1	149 [(a)]	0.04	4.57	32.6
CWT2	102	0.035	1.87	54.4
CWT3	91	0.036	1.63	55.6

[(a)] see text; [(b)] variable width and length

2.1.2 Calibration

The primary data used for calibration of the rainfall-runoff model were the natural rainfall events. Reliable events were selected for several sites and the model parameters adjusted by trial and error to give a good fit. The broad range of hydrographs available in the provided data (single peaked versus double peaked hydrographs for a variety of closely spaced sites) exercised all components of the model. The rainfall simulator trials had less variation in discharge and did not exercise all the components of the model, making it difficult to reliably estimate their parameters. They provide useful verification data and if the natural event data were poor or unavailable would have been a crucial data source.

As far as possible parameters were determined from, or checked against, other independent data. For instance, Manning *n* values for the kinematic wave routing have been checked against measures of surface roughness.

Where extra runoff event data were available verification of the selected model parameters was carried out. This verification is an important part of the process of ensuring that the selected model and parameters are satisfactory. If the parameters are satisfactory then the predictions of the model for an independent site and runoff event should provide a satisfactory fit without adjustment of model parameters. The goodness of fit for the verification sites and events is not normally as good as for the calibration runs, for obvious reasons, but they should at least exhibit a correspondence in volume, peak discharge and its timing, and an overall shape of the hydrograph.

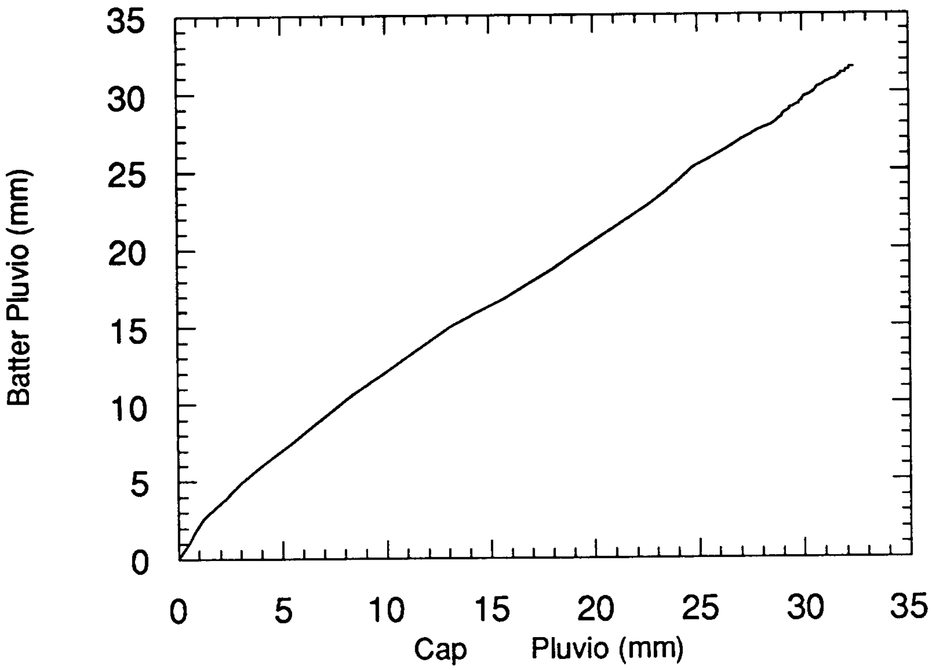

Figure 2.1 Double mass curve for the batter and caprock pluviographs used to measure the natural rainfall events

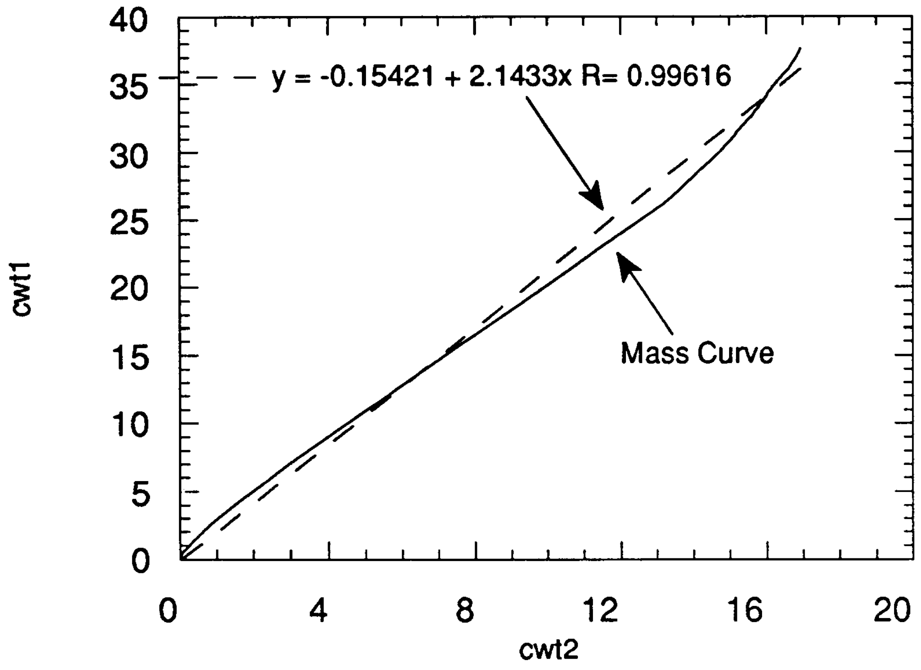

Figure 2.2 Double mass curve for catchment CWT1 and CWT2 for the event of 10/1/91

2.2 Caprock sites calibration

2.2.1 Natural rainfall data

The first of the plots to be calibrated was CWT2. Three reliable storms were chosen and parameters fitted by trial and error. The only difference for the parameters for the three storms were initial soil wetness conditions, parameterised by the initial sorptivity. The parameters adopted are given in table 2.4 (see section 2.4). The simulations of runoff for the three storms are given in figures 2.3, 2.4, and 2.5. The chosen parameters fit all aspects of the hydrographs well. There appears to be a slight problem with the data for the second peak of the hydrograph for the 7/1/91 storm but there were insufficient data to check these observed data against other data by use of double mass curves. In all cases the timing of peaks is satisfactory indicating that the conveyance parameters (ie Mannings *n*) are satisfactory. The widths of the hydrographs are satisfactory indicating that the surface storage parameters are satisfactory. Finally the volume and the distribution of this volume within the hydrographs are well matched indicating that the infiltration parameters are satisfactory.

The next plot to be calibrated was CWT3. The first attempt at calibration used the parameters as derived from CWT2. The conveyance was modified by the width of the plot given the values in CWT2. Since these plots were only about 70 m apart it was believed that the parameters of the two plots would have similar characteristics. However this gave a hydrograph that had too much volume, though the peak was satisfactory. It was possible to identify high infiltration zones within the catchment near the bottoms and the tops of the catchment. These zones had a long-term infiltration rate of about 40 mm/hr, much higher than 6.5 mm/hr found in CWT2. The two events examined, 6/2/91 and 16/2/91, are illustrated in figures 2.6 and 2.7. The predicted hydrographs are given for the adjusted CWT2 parameters and using the high infiltration zone parameters. This high infiltration rate may result from a number of causes including cracks in the surface or zones of lower compaction in the surface layer. That the infiltration rate is higher in CWT3 than elsewhere is supported by a double mass curve analysis for storm 16/2/91 using CWT1 and CWT3 (fig 2.8). This double mass curve suggests that the runoff in CWT1 is approximately four times that CWT3 even though their areas are very similar.

The parameters derived for plots CWT2 and CWT3 were then used to calibrate/verify the runoff events for plot COUT. This is believed to be one of the better data sets, however, all data have been truncated above about 15 L/s so that only lower flow values can be compared. However, the timing of the rises can be used to assess the value of the conveyance, and thus the Mannings *n*, and the lower peaks in the storms can be used to provide some support for the infiltration values for this site. It is expected that the parameters of CWT2 should be indicative of the parameters for COUT because CWT2 is a subcatchment of COUT. Indeed this was the case. Plots of estimated storms are provided in figures 2.9 and 2.10. For these storms the initial sorptivity was estimated; all other parameters are as calibrated for CWT1 (table 2.4).

Finally site CWT1 was examined. This site has a number of rainfall events that are common with the calibration events described above. To validate the model it was decided to use the parameters fitted above and the initial conditions identified above to fit the events on CWT1. This section is then a true validation test because no parameters are fitted. If the model parameters are incorrect then the predictions would be poor; otherwise they should be good. The two events used were 10/1/91 and 21/1/91. The observed and predicted runoffs are given in figures 2.11 and 2.12. An initial peak in the event of 21/1/91 has been estimated in the simulation. This appears to be an error in the observed runoff record for this site since an initial peak is indicated by both pluviograph records. The fit of the simulation data to the runoff data for these two events appears to be satisfactory.

A further verification of the model was carried out with the data for CRT1. The event of 7/1/91 was fitted for COUT. These parameters, and catchment properties from the maps were used to predict the response of CRT1. The results are shown in figure 2.13. The initial conditions on the sorptivity were those fitted for that event at COUT. The overall verification is very satisfactory with both peaks and volumes being well fitted.

2.2.2 Comparison of fitted hydrologic parameters with other data

Samples of the surface lag material were taken and their grading analysed by workers at ***eriss***. This grading data can be used to estimate a value of Mannings *n* for comparison with the value calibrated in the runoff-routing. There were 4 sites on the caprock surface C1F3S1, C1F3S2, C1F3S3, and C1F3S3 where samples were taken. Henderson (1966) gives an expression relating the size below which 75% of the material falls and Mannings *n* of

$$n = 0.031\ d_{75}^{\ 1/6} \qquad 2.2.1$$

The d_{75} of the four sites were 6, 2, 2.4 and 2 mm respectively yielding values of Mannings *n* of 0.018, 0.015, 0.015, and 0.015 respectively. These values reflect only the roughness of the surface due to the grain roughness and the actual measured Mannings *n* will be somewhat higher. They do not account for form drag on the surface (due to lumps and undulations in the surface), rapid changes in the cross section of the flow, and tortuosity of the flow paths. Chow (1959) outlines a method of allowing for these effects (table 5.5, p 109). Allowing for these effects (minor irregularity, occasional cross-section changes and appreciable meandering) suggests an increase in *n* of about 0.01–0.015 so that the Mannings *n* of the surface should be about 0.03. This value is in good agreement with the calibrated value (see table 2.4).

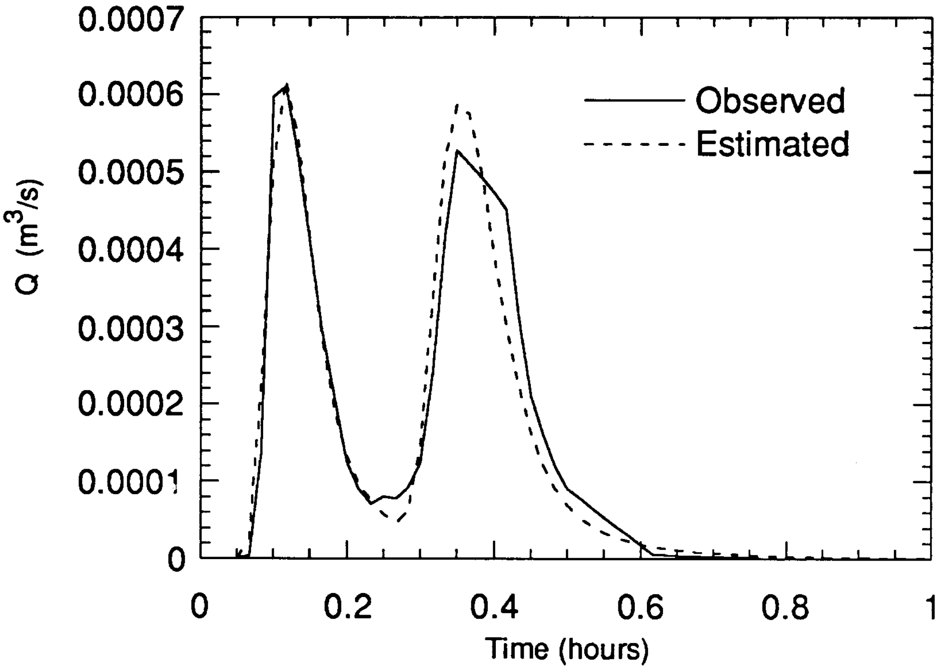

Figure 2.3 Calibration for CWT2 on 7/1/91

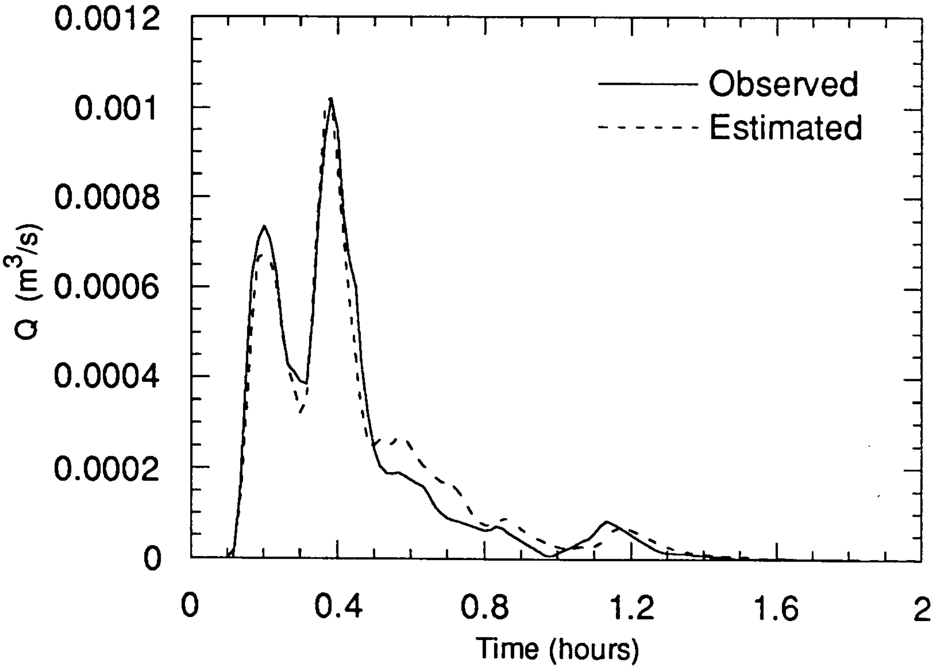

Figure 2.4 Calibration for CWT2 on 10/1/91

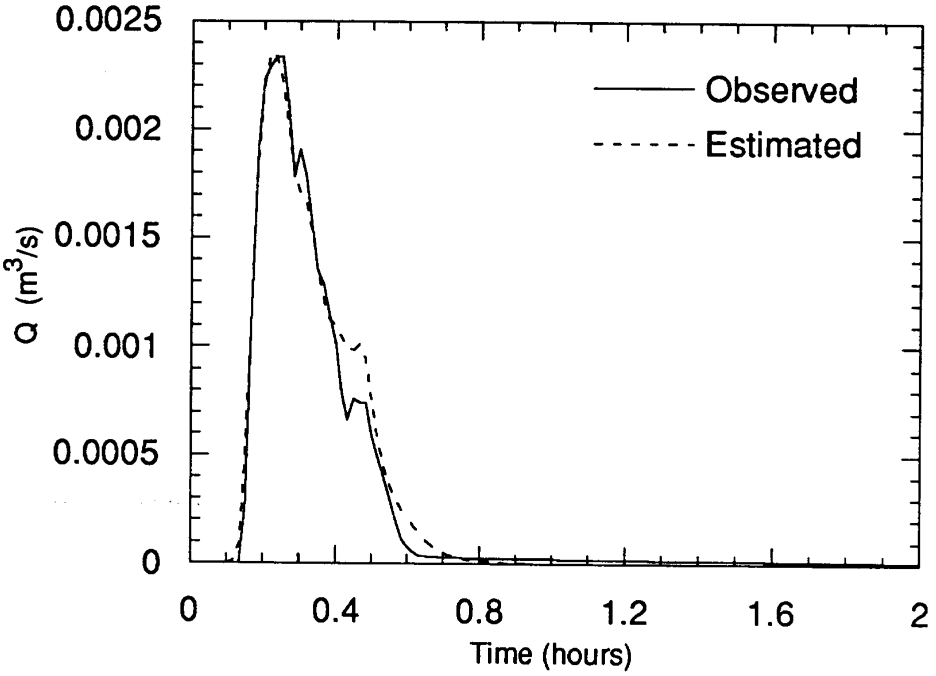

Figure 2.5 Calibration for CWT2 on 21/1/91

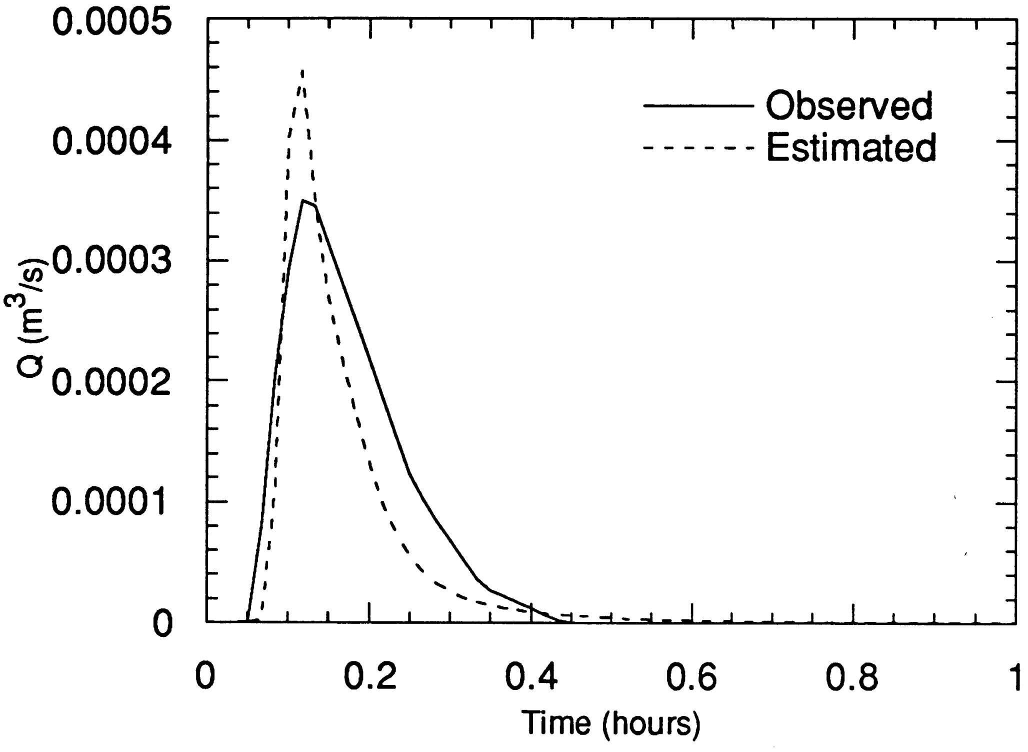

Figure 2.6 Calibration for CWT3 on 6/2/91

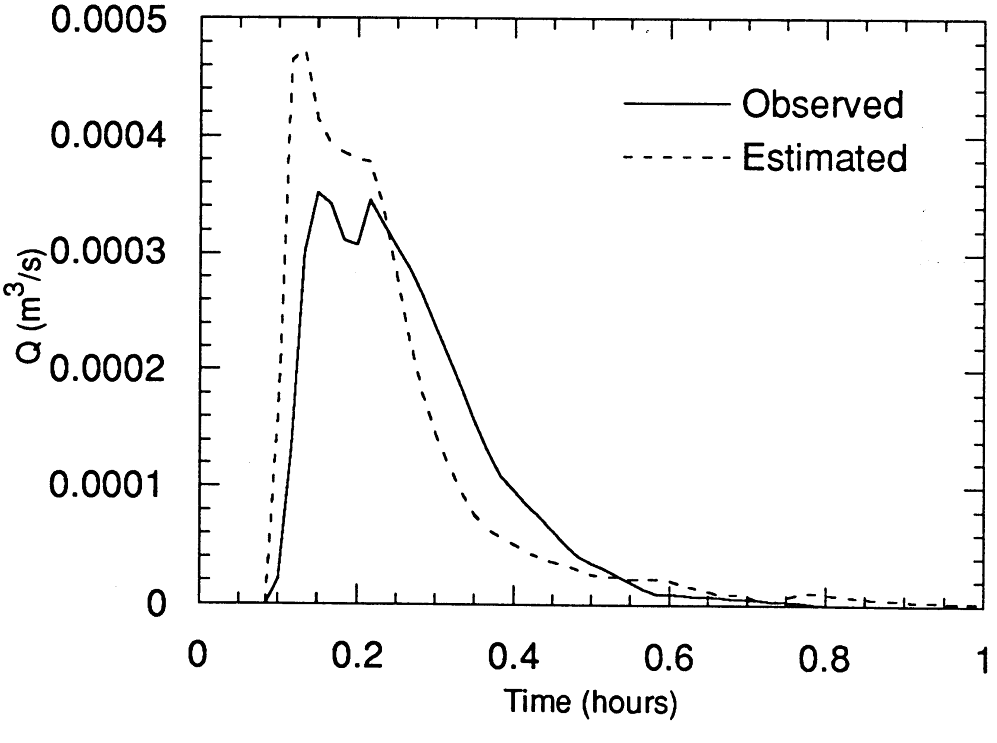

Figure 2.7 Calibration for CWT3 on 16/2/91

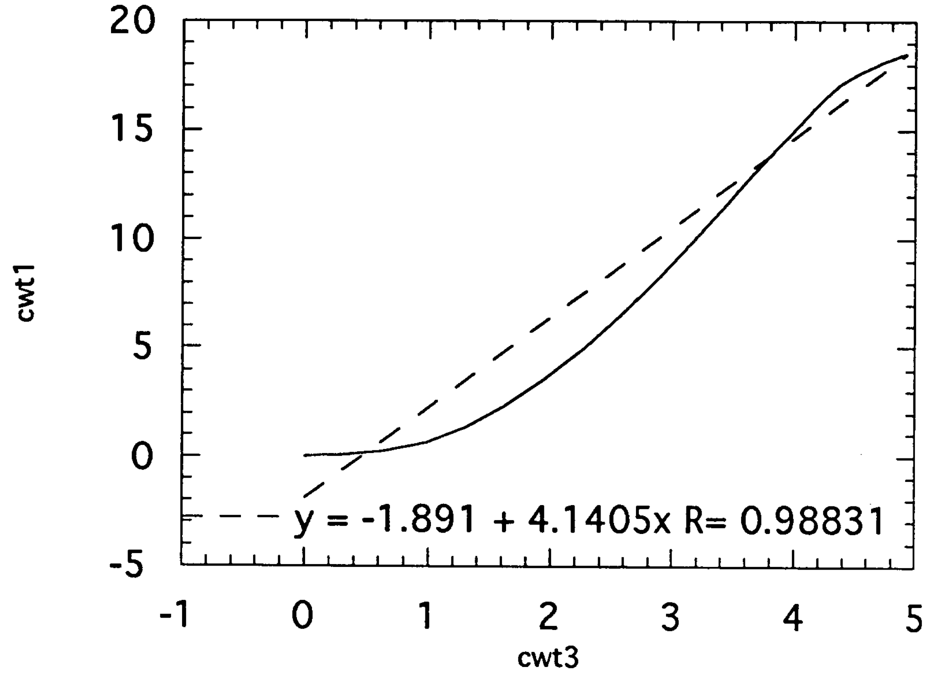

Figure 2.8 Double mass curve for CWT1 and CWT3 for event 16/2/91

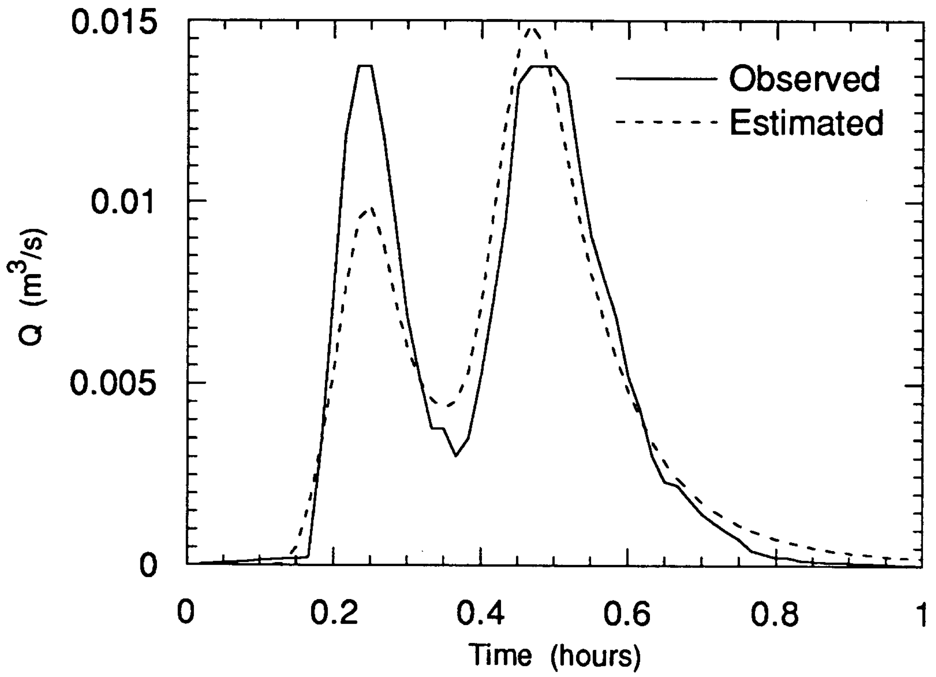

Figure 2.9 Calibration for COUT on 7/1/91

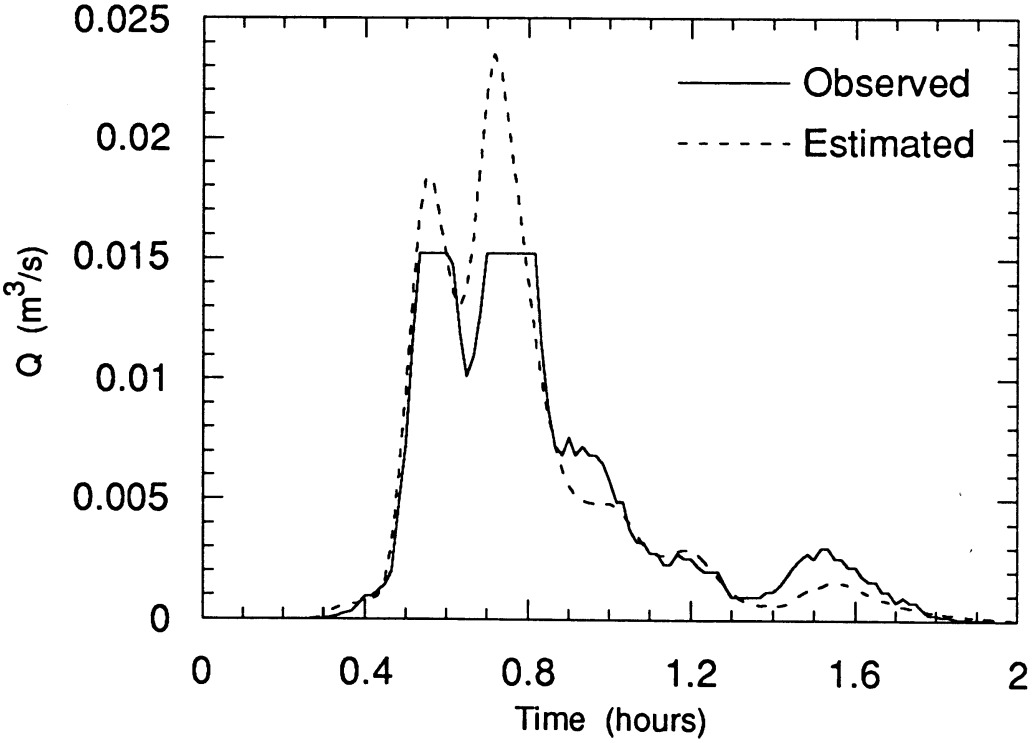

Figure 2.10 Calibration for COUT on 10/1/91

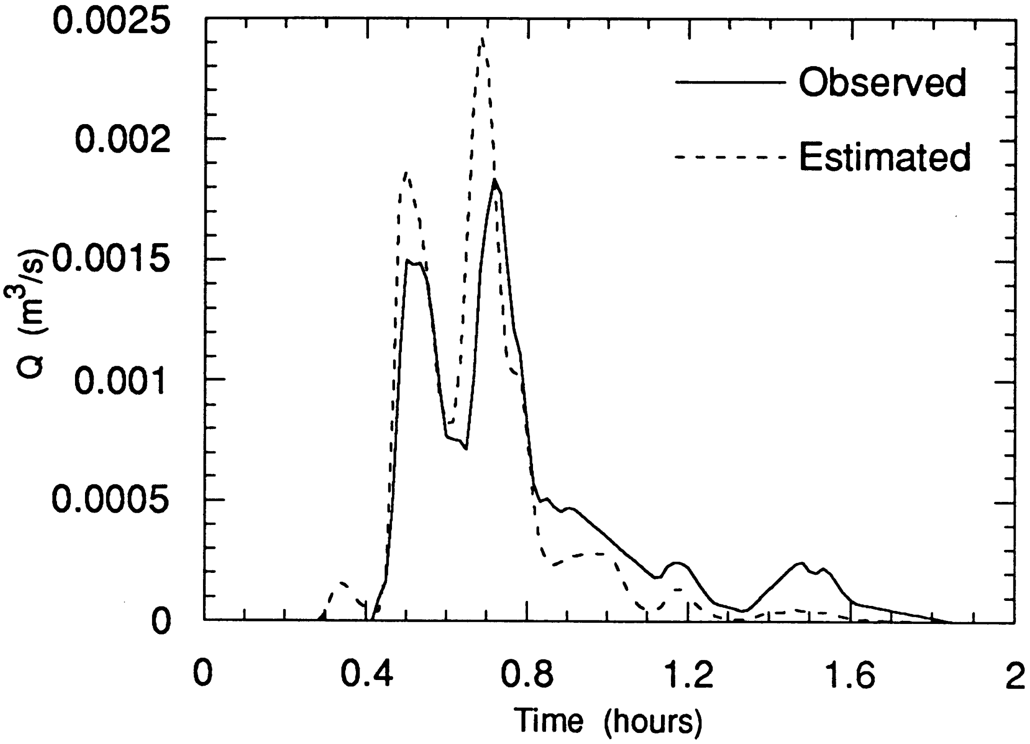

Figure 2.11 Verification for CWT1 on 10/1/91

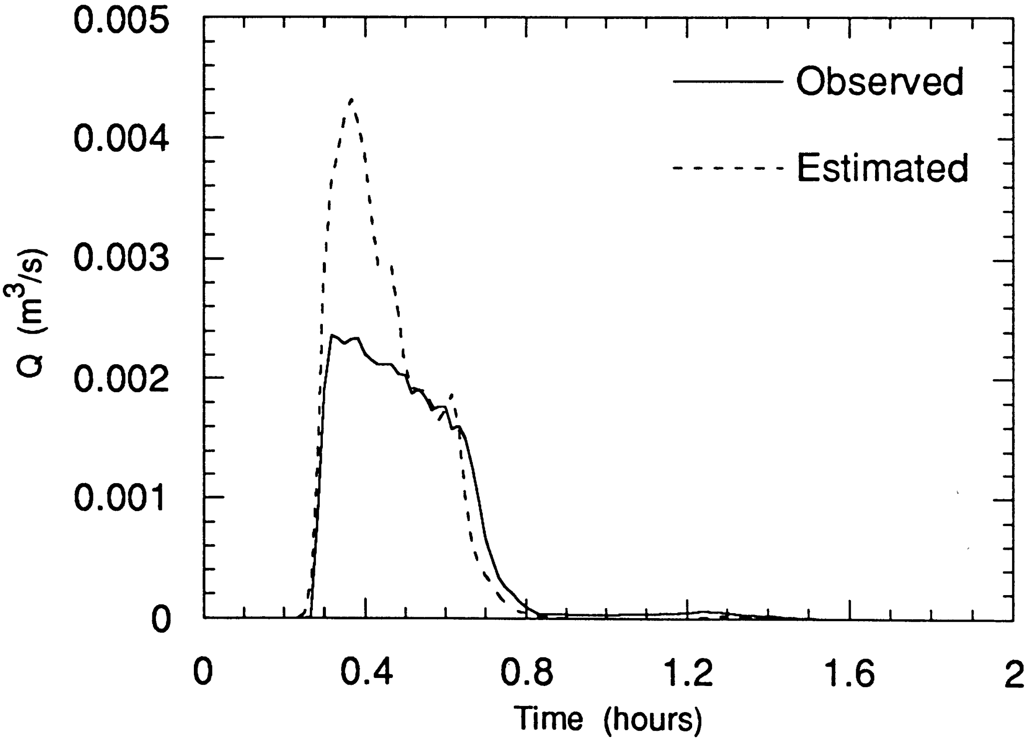

Figure 2.12 Verification for CWT1 on 21/1/91

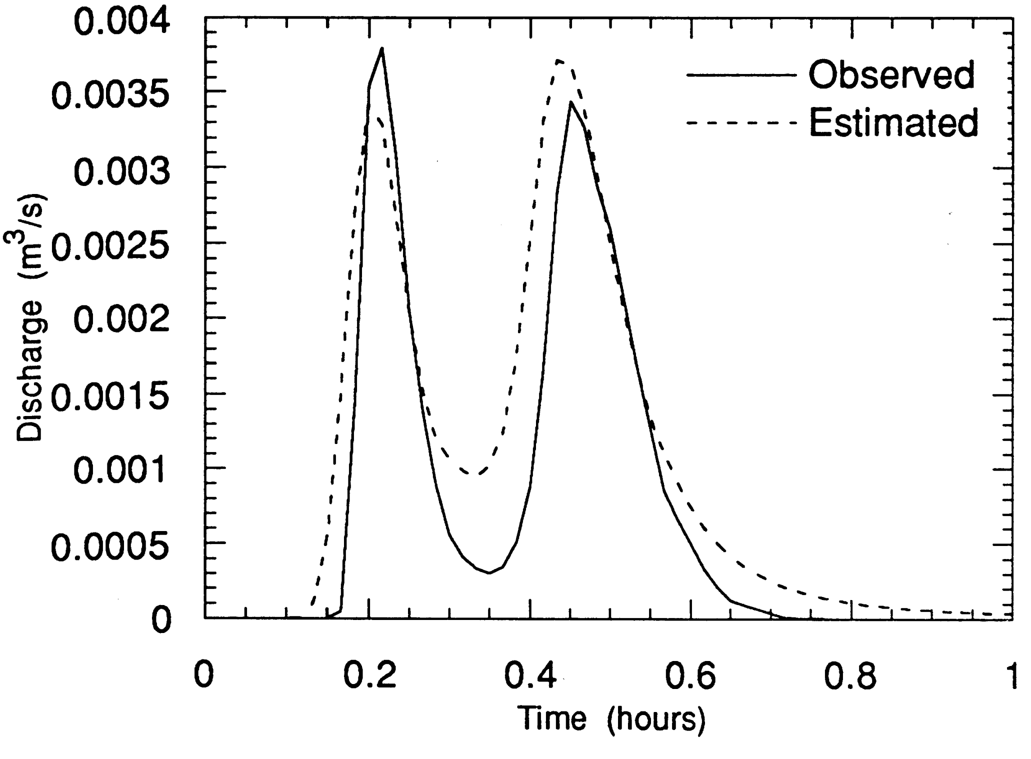

Figure 2.13 Verification for CRT1 on 7/1/91

2.3 Batter sites calibration

2.3.1 Natural rainfall data

The parameters fitted in the previous section for the caprock sites were used as the starting point for the calibration of the batter sites. Only three sites had reliable data for calibration of the hydrology. Of these two plots (BWT2 and BWT3) were discarded as being too short to be able to check the routing behaviour of the plots; the lags between peak rainfall and peak discharge were judged to be too small. The remaining site, BRT2, had 4 rainfall events of which three were considered reliable. The fourth had fluctuations in the rainfall that were not exhibited in the runoff. Two of the events, those on 6/2/91 and 22/2/91, were used for the verification of the parameters. These were a small flood (max 1.5 L/s) and a large flood (max 5 L/s) respectively, allowing the hydrology model to be verified over a range of discharges.

The fits for the 6/2/91 and 22/2/91 sites are illustrated in figures 2.14 and 2.15. The runoff volumes appear too small, particularly for the event of 22/2/91. Overall, however, the parameters as fitted for the caprock appear to be satisfactory for prediction of runoffs from the batter.

The Manning *n* used for predicting the runoff from the batters in figure 2.14 and 2.15 was the same as that for the caprock. The rising limb of the 6/2/91 event appears to be leading slightly, suggesting a higher value of Mannings *n* may be appropriate (of about 0.003), however, the rising limb for 22/2/91 appears to be satisfactory suggesting no change. The grading of the surface material on the batter appears to be similar to that on the caprock suggesting that the value of Mannings *n* should be the same as that measured/calibrated for the caprock sites. On balance, given the good overall fits, no case could be made for significant changes in Mannings *n* from the caprock to the batter.

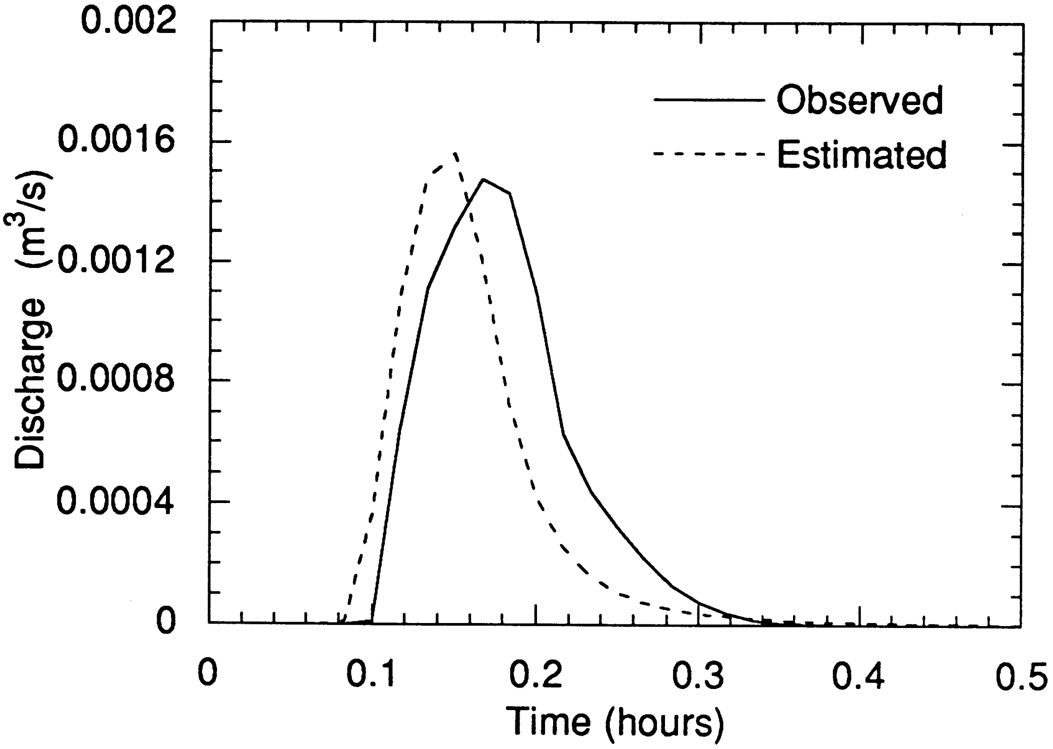

Figure 2.14 Verification of BRT2 event 6/2/91

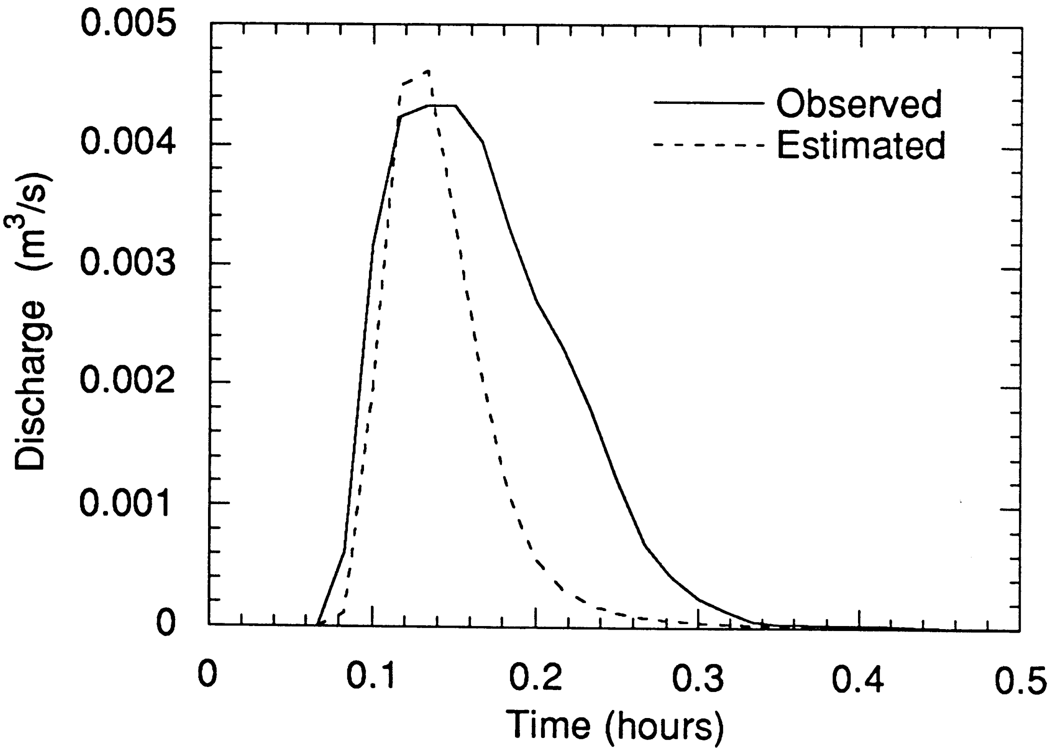

Figure 2.15 Verification of BRT2 event 22/2/91

2.3.2 Rainfall simulator data

There were a small amount of batter data available for validation of the parameters determined above. Not all the data were examined but one simulation experiment for the largest of the plots was selected. This simulation is referred to as Plot 4 Run 2 in the computer data file B1RF2QSS (see appendix B). An area of 67.8 m^2 has been adopted as the catchment area for this plot. The rainfall applied to this plot was measured by two pluviographs, both situated within the plot; the average of these two pluviographs has been adopted as the applied rainfall. Timing discrepancies in the observed runoffs and rainfalls were apparent and the data were adjusted accordingly. Figure 2.16 show the result of a simulation using the adopted parameters in table 2.4 for these data (ϕ=6.5 mm/hr). The considerable scatter of the simulated data around the observed data is due to the highly responsive plot responding to fluctuations in the applied rainfall, presumably due to random effects of wind during the simulator trials. What we need to consider is the mean trend of the simulated data averaging out these fluctuations.

The volume of this hydrograph for ϕ=6.5 mm/hr is too high by about 20%. The long-term infiltration rate, ϕ, was adjusted to 35 mm/hr and the simulation run again. This yielded a hydrograph that is marginally too low in volume by about 5%. This raises the question of what is the appropriate ϕ to adopt for this study. A value of ϕ=35 mm/hr is too high for two reasons. Firstly, the simulation data suggest it is. Secondly, a value of ϕ greater than 20 mm/hr results in no runoff occurring in the many natural storms that have been measured for both the caprock and batter. Thus it appears that the simulation data are in conflict with the data collected for the natural rainfall events. Whether this conflict is real or simply an artefact of the calibration procedure would require a statistical study of the parameter estimates from the natural and simulate rainfall experiments (eg Kuczera 1983). Until more definitive data are available, it is recommended that the value of 6.5 mm/hr fitted to the natural runoff events be adopted for the batter sites. This value is conservative and is consistent with the natural rainfall-runoff data.

No other parameters can be verified for the batters because the plot response is too quick to allow accurate calibration-verification of the plot response parameters (eg Mannings *n*). However, it is apparent in figure 2.16 that the rising and falling limb of the simulations for the observed and simulated data have similar slopes and timings, so that the parameters adopted in the simulations appear to be consistent with those observed in the field.

2.4 Conclusion

The distributed Field-Williams rainfall-runoff model (DISTFW) has been shown to provide a satisfactory fit to the data collected on the caprock and batter sites. Scatter in the infiltration parameters was observed from site to site, possibly suggesting localised porous zones in the fill. The sorptivity also exhibited small fluctuations depending on whether a rainfall event had occurred previously that day. This variation in the sorptivity appears to be important but its variation with antecedent wetness conditions could only be estimated roughly in this study because of the lack of detailed data testing specifically for this parameter. The adopted parameters are listed in table 2.4.

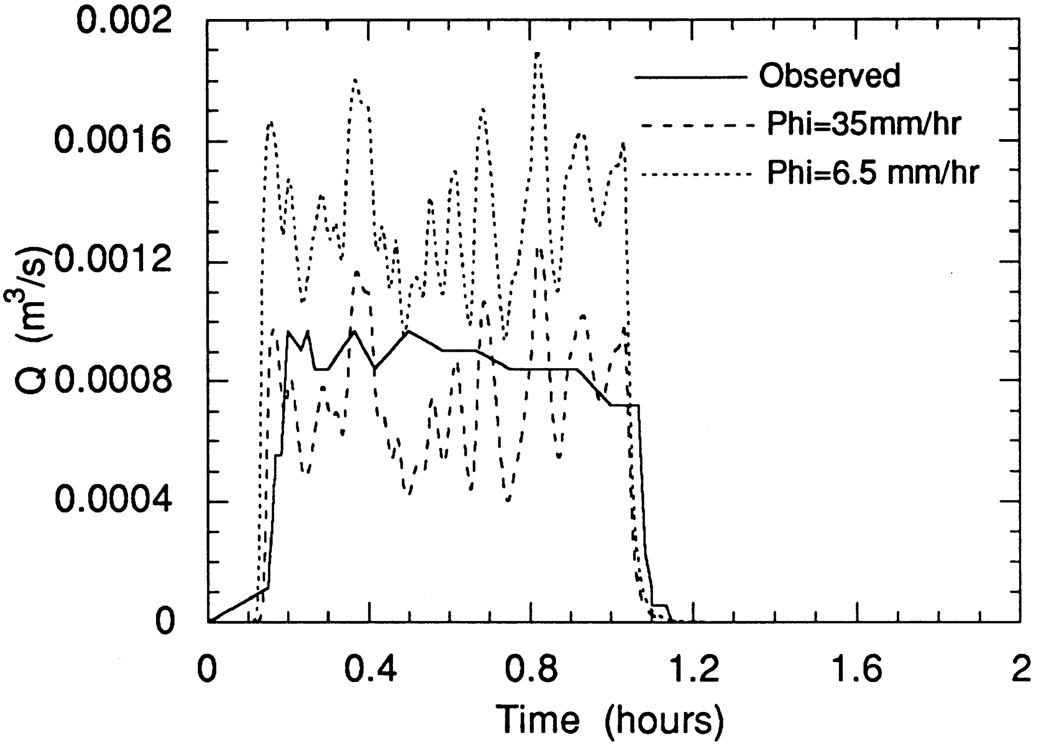

Figure 2.16 Batter Plot 4 Run 2 rainfall simulation experiment

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.