Chapter 7
Geomorphic response to extreme events: Modelling the 1686 Starbotton flood

7.1 Introduction

As discussed in section 2.5, there is some confusion as to the role of large, infrequent floods relative to the cumulative effects of more frequent floods of a lower magnitude in shaping channel form and valley floor morphology. Recent large flood events would appear to have a major impact upon the landscape, but how important are these events on the long term history and evolution of a catchment? Furthermore, due to the relative infrequency of large events, there are many unanswered questions surrounding the sediment dynamics during the flood itself and the effects of vegetation and sediment supply.

In chapter 6 the response of Cam Gill Beck to long term changes in flood magnitude, frequency and vegetation cover were modelled. However, deposits from a large flood event found in Cam Gill Beck suggest that extreme floods have had a major impact on the catchment's morphology and evolution. In this chapter, the impact of a single large storm is simulated over a range of scenarios representing different levels of vegetation and sediment supply. These will be compared to simulations from chapter 6 to establish the relative importance of different flood frequencies and magnitudes. Sediment dynamics during this flood will be examined and the results validated against deposits found in Cam Gill Beck.

7.2 Field evidence.

As described in chapter 5, an extreme flood event happened in Cam Gill Beck in 1686. This left several large flood deposits in the region outlined in Figure 7.1, the largest of which is described in Figure 5.6 and detailed here as **B** in Figure 7.2.1. Other smaller berm deposits are recorded at locations **A** and **C** (Figure 7.2.1). However, the absence of prominent boulders with lichens at **A** and **C** has prevented them from being dated.

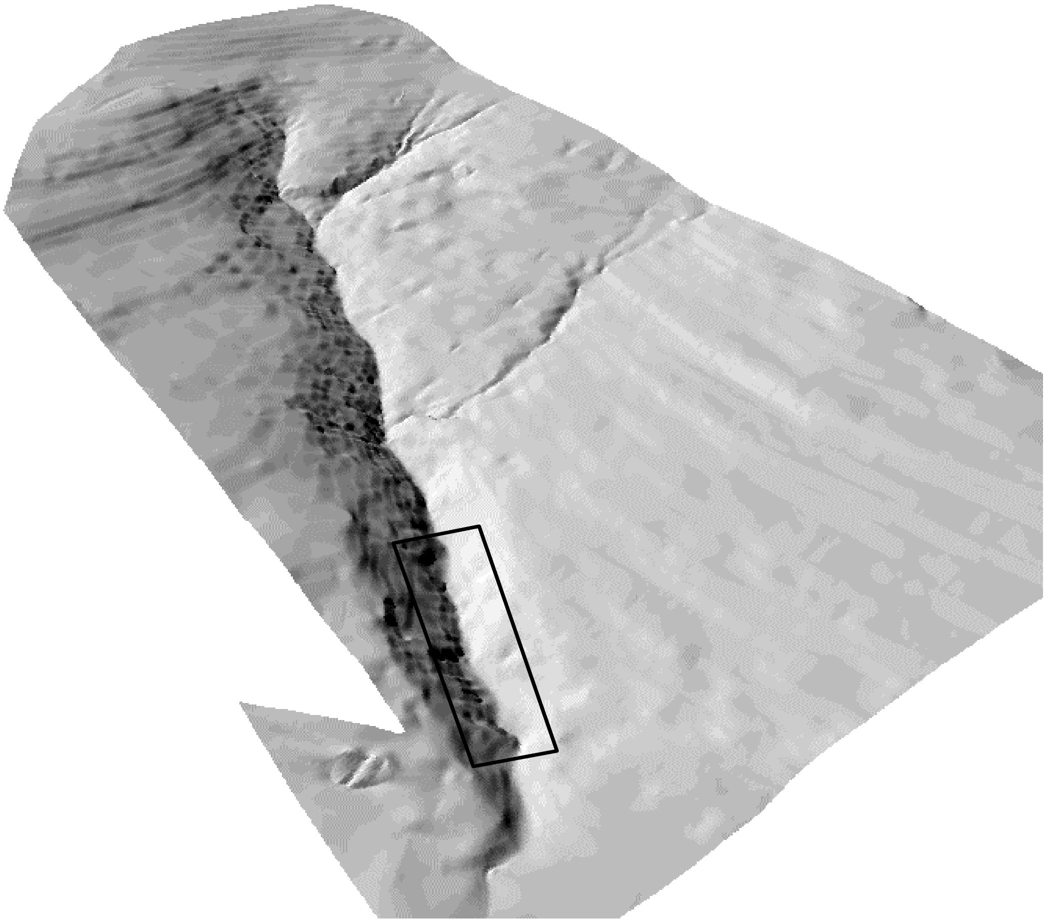

Figure 7.1. 3d projection of Cam Gill Beck DEM, viewed from south.Scale 1400 by 2800m, showing sections detailed in figures 7.2 and 7.4.

7.3 Method

The 1686 flood was simulated by using a ten year hourly rainfall data set from Church Fenton, which was edited to include two hours of extreme rainfall of 100 and 80 mm/hr each. These amounts were chosen as they are similar to those recorded by Evans (1996) of 192 mm in 2 hours in the severe flood of Wycoller Beck in the central Pennines.

Three simulations were carried out with the initial conditions taken after 500, 1000 and 1500 years of simulation of a forested catchment identical to run *dense1* (6.2.1), thus allowing different periods of sediment accumulation. Hydrological parameters were then altered to represent no tree cover as is assumed for 1686. The elevations before, after and during the storm run were saved, to show areas of erosion and deposition. A fourth run was also carried out after 1000 years but retaining a fully forested catchment. The grid scale was set at $2m^2$ and all other parameters were as described in section 6.2.

7.4 Results

Figure 7.3 shows the hydrograph from the simulated flood, peaking at $81.5m^3s^{-1}$. Figure 7.2.1 illustrates the present morphology, showing three major flood deposits / berms (**A**, **B** and **C**). Figures 7.2.2 and 7.2.3 are after the flood simulation, showing shaded plan views of the same section, with the flood deposits highlighted in white on 7.2.3. Table 7.1 shows the volumes of the corresponding deposits from the surveyed sections and all four simulations along with the amounts eroded and deposited.

Initial Conditions	**Field.**	**500yr**	**1000yr**	**1500yr**	**1000+forest**
Volume eroded	N/A	5064	5357	3760	4867
Volume deposited	N/A	2385	2285	1740	1799
Balance (E-D)	N/A	2679	3071	2020	3068
Volume Berm A	100	54.83	233.06	86.28	N/A
Volume Berm B	250	31.03	96.66	41.28	N/A

Table 7.1.Sediment discharges (All units in m^3).

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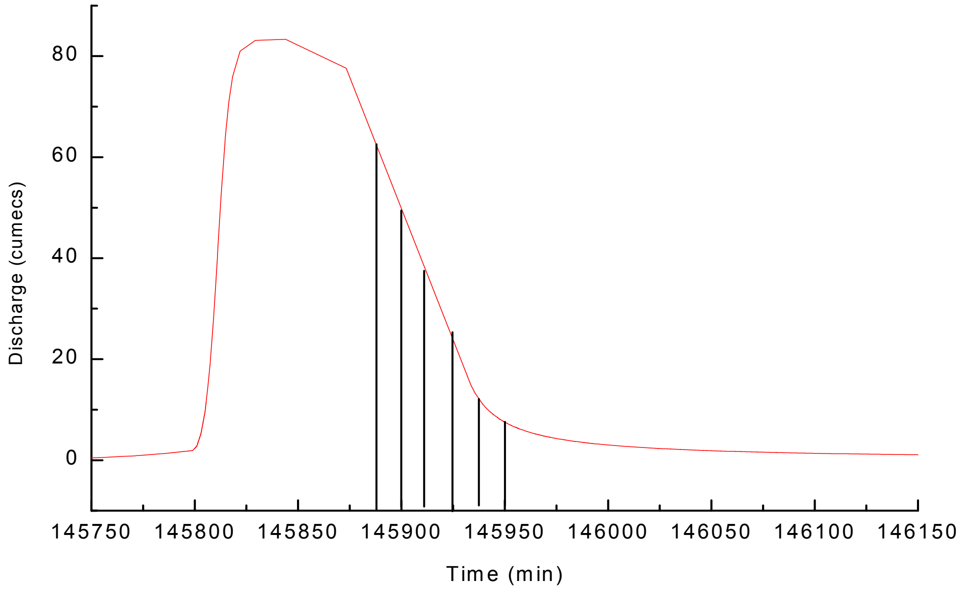

Figure 7.3. Hydrograph from the simulated extreme flood. The vertical black lines indicate the times of figure 7.4 pictures 1-6.

Figures 7.4 pictures 1-6 detail the movement of sediment down the channel during the flood with the white areas indicating deposition. The timing during these floods is represented by the lines on the hydrograph on Figure 7.3. From Figure 7.4.1 to 7.4.3 at section **D**, there is a build up of sediment which moves downstream and is re-deposited at **E**. From 7.4.4 to 7.4.6 this is again moved downstream, the deposit **E** thinning at the top and thickening at the base. By the end of the flood the deposit at **D** is almost completely removed. Figure 7.5 shows the long profile of Figures 7.4.1, 7.4.3 and 7.4.6, showing how there is erosion at point **D** with deposition and re-working at **E**.

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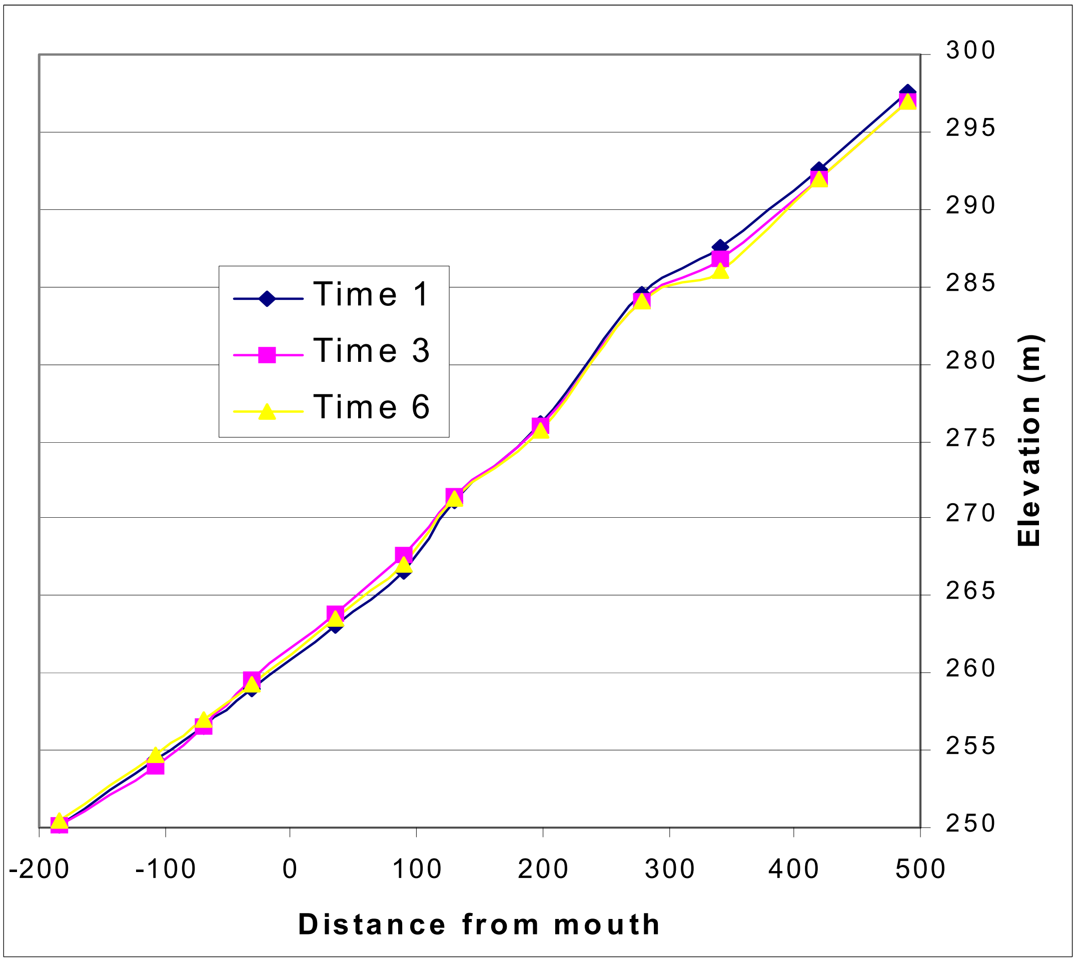

Figure 7.5. Long profile of sections from Figure 7.4.

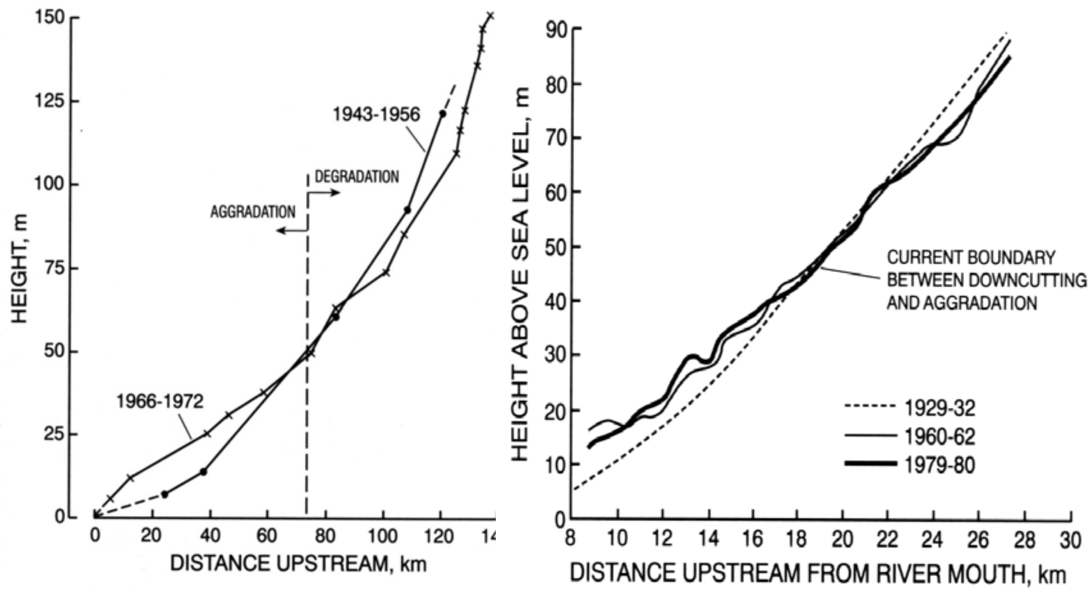

Figure 7.6. Long profile adjustment after a large flood in the Eel River, California, and changes in bed height, Waimakariri River, New Zealand (from Knighton 1998).

7.5 Discussion

The simulation of an extreme flood event produced depositional features that closely resemble those found in the field generated by a catastrophic event in 1686. Some differences exist in the size of the features (Table 7.1, Figure 7.2), namely the upstream deposit **A** is larger in the simulation than berm **B**. This is because the resolution of the contour data used for the DEM fails to pick up the valley floor features in great detail. Consequently the valley floor is wider at **A** and narrower at **B** than in the field, allowing more material to be held at **A** and not transported down to **B**. Furthermore, as less material is trapped at **B,** more is transported down to **C**. However, the total volume of the deposits (350 m^3 field versus 331 m^3 simulated) and their location does closely match those observed in the field. The comparison to the Wycoller Beck flood (Evans 1996; Table 7.2) shows Cam Gill Beck to have a greater bedload discharge for the given area. However Cam Gill Beck is steeper than Wycoller Beck, with fewer low gradient reaches allowing deposition. It may therefore be expected to flush more sediment out from the basin.

	Wycoller Beck	**Cam Gill Beck Simulation.**
Volume eroded (m^3)	2177	5357 (4000)
Volume deposited (m^3)	1826	2285 (2200)
Sediment discharge (m^3)	351	3071 (1800)
Catchment area	10km^2	4.5km^2
Slope	0.01 – 0.15	0.1 – 0.3

Table 7.2.Comparison of sediment volumes eroded.

Unfortunately, further validation is restricted by two factors.

1. As the model is attempting to simulate the past, we have no records of previous landforms or morphologies so the initial conditions for the model have to be estimated.
2. The use of the Wycoller Beck rainfall data is again only an estimate of the 1686 flood. There is every possibility that the deposits in Cam Gill Beck were formed by a flood of different magnitude.
3. There are not enough dated deposits to validate the model. As only one date is recorded, all other validations are qualitative or based upon observation.

> Ironically, the model gives us far more information about the catchment morphology and grainsize than we are capable of measuring in the field.

However, these simulations give us new insights into the roles of extreme floods and periods of lower magnitude flood events in valley floor development. McEwan and Werritty (1988) examining the effects of flash floods in the Cairngorms stated that '*The long term evolution of boulder bed mountain torrents in upland Scotland must be regarded as being primarily controlled by the operation of catastrophic processes*'. However, the model shows the bedload yield from the extreme flood is 3000 m^3 compared to 3277, 1443 and 996 m^3 per 10 years for the more moderate floods (runs *medium 2*, *medium 1.5* and *medium 1* from chapter 6) . Therefore, in the terms of work done removing sediment from the basin, the extreme flood is equivalent to 20 years erosion at present day rainfall levels, 10 years at 150% greater rainfall magnitude and 30 years at 75%. If extrapolated over 100 years, the more moderate storm regimes cause 350, 500 and 1000% more bedload discharge than the single extreme event. It could be argued that the ten year data set used is unrepresentative and may contain extreme floods itself. Indeed, the sequence runs from 1985 to 1995, capturing a full spectrum of storms including Hurricane Charley, August 1986, the wettest day in the UK's record (Institute of Hydrology, 1988). However, the hydrographs (Figure 6.12) show the peak discharges from runs *medium 1*, *medium 1.5* and *medium 2* range from 2.5, 5 and 8.5 $m^3 s^{-1}$ respectively, compared to 82 $m^3 s^{-1}$for the extreme flood. Thus, a ten year storm sequence giving a maximum flood of 2.5 $m^3 s^{-1}$ (*medium 1*) evacuates more sediment in 30 years than one massive flood. Furthermore, the storms producing extreme events, especially those resulting from thunderstorms, are often very localised. For example, Evans (1996) estimates that the Wycoller Beck flood was caused by a small cell of rain approximately 500m wide. The frontal weather systems associated with periods of sustained rainfall operate over regional scales of hundreds of square kilometres (Longfield and Macklin, 1999).

Therefore considering this and results from the model, long term periods of more moderate storm events will have a far greater impact on basin sediment yield and lowering. Notwithstanding these results, it must be remembered that this is only one catchment and different basins will be affected in different ways by extreme events. Larger catchments have the capacity to absorb or buffer extreme rainfall events and coupled with the small ‘footprint’ of large storms will show less effect than smaller basins.

Despite these indications that an extreme event is not as effective compared to long periods of moderate flooding, the model shows they have a large impact upon the valley floor morphology, leaving deposits **A B** and **C** (Figure 7.2.3) standing up to 2m above the main channel. It was expected that these deposits would be left exposed by the gradual incision of smaller flood events. However the model showed that towards the end of the falling limb, a channel rapidly incised next to the main deposit **B**. Furthermore, other simulations showed that for up to two years after the extreme flood, large sections of this deposit **B** were removed by smaller floods of up to $6m^3s^{-1}$. But, this feature was preserved if these smaller floods were held back allowing a channel to incise next to the deposit and vegetation re-growth to stabilise it. Therefore the timing and magnitude of consequent flood events is vital for the preservation of such units. This leaves a potentially confusing situation for field geomorphologists, adding a further dimension of uncertainty when trying to interpret previous events from present morphologies.

However, it must be remembered that these large floods are important in the evolution of a catchment. One may be equivalent to ten years of moderate flooding, but if three events of an extreme magnitude occur within these ten years then three times more erosion is carried out. Therefore when interpreting past regimes or climates from large flood deposits as per Macklin *et al.*(1992b) and Merett and Macklin (1998) we should be wary of inferences drawn from single or small clusters of floods. But where there are large groups of large floods at for example a decadal resolution, this can be taken as a good proxy for periods of increased flood magnitude and thus catchment sediment mobility.

The changes in sediment discharge in response to different periods of sediment accumulation were insignificant (Table 7.1). Some authors have indicated that the cold and wet early phases of the Little Ice Age were periods of accelerated accumulation (Ballantyne 1991, Harvey 1987). Thus it was expected that the model would show an increase in sediment discharge with accumulation time, as material collects by the channel. However, the simulations show that there is an increase in sediment discharge up to a peak after 1000 years accumulation time, followed by a decline, possibly as material from the slopes to supply these channel margins expires. This may well be the case in Cam Gill Beck where the steep hillslopes are presently only covered with a thin veneer of soil.

Chapter 6 concluded that vegetation removal *combined* with increased storm magnitude can massively increase sediment discharge. Here, the model suggests that upland catchments such as Cam Gill Beck are well buffered against a single high magnitude storm, since even moderate vegetation cover is sufficient to protect the slopes. The hydrograph from the forested catchment was only slightly smaller than from a deforested basin, with a peak of 74 m^3s^{-1} and similar sediment discharges. Even reducing the effectiveness of the protective surface vegetation mat had little added effect on the sediment discharge. However, close examination from the forested catchment simulations showed reduced erosion at stream heads and limited formation of flood deposits.

During the flood, there appears to be the downstream movement of a pulse, wave or slug (Nicholas *et al.* 1995) of sediment, depositing in the early stages of the flood, then re-working and moving down the channel (Figure 7.4). As the long profile in Figure 7.5 shows, this results in incision at higher points of the basin and deposition at lower. This compares well with other measurements of long profile change caused by floods (Knighton 1998; Figure 7.6). This ‘slug’ appears to be moving rapidly, travelling through the highlighted reaches in 65 minutes compared to rates varying form 0.1 to 5km a year measured by other authors (Nicholas *et al.* 1995). The high slug celerity may be driven by the steep gradient of Cam Gill Beck and the constrained valley floor, restricting substantial deposition.

During the passage of the sediment wave, the model shows zones of sediment storage and transport similar to those identified by Macklin and Lewin (1989). Depositional areas are wider and have a lower slope (Figures 7.4 **D** and **E**), whereas there is little activity in middle section as it is steeper, and narrower with the sediment flushed through. Furthermore, as the slug passes through reach **D** and **E**, there is a widening of the flood plain as the valley floor in-fills. This consequently narrows as the channel incises and removes the fill. The main sediment movement appears to occur during the falling limb of the hydrograph, suggesting that this part of the flood is most important. However, this is hard to substantiate, as the rising limb for this ‘flashy’ event is very steep and short.

The rapid speed and dynamics of the slug movement may be a function of the model parameterisation and could therefore be erroneous. However, there are few direct quantitative measurements of large scale sediment movement in upland catchments during extreme events and the results described above concur with deposits left by the 1686 flood. Therefore this modelling technique shows great potential for studying the dynamics and effects of such large floods. If the spatial and temporal resolution were increased, the detail of deposits, sediment movement even the stratigraphies of deposits could be simulated at much greater detail.

7.6 Conclusions

Simulations of an extreme flood event show a rapidly moving sediment wave which deposits large features similar in size and location to those left by a catastrophic flood in 1686. These results show that whilst this flood is important in shaping the valley floor morphology, the cumulative effect of floods an order of magnitude smaller produce more sediment over long periods. Furthermore, vegetation and different sediment supply conditions have a minimal effect.