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MUDDY FLOODING ON THE SOUTH DOWNS

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Executive Summary

A post event assessment of flooding that affected parts of the South Downs, East Sussex, England in autumn 2000 is presented. The floods were of the 'muddy' variety related to soil erosion from agricultural land rather than 'clear' riverine floods. Between September and December 2000, inundation of property and infrastructure by muddy floodwater occurred several times in various suburbs of Brighton, causing damage from sediment deposition costing millions of pounds. Some inaccurate, but well publicized reports by the news media attributed blame to unprecedented autumn rainfall brought about through climatic change or 'global warming'. However, whilst climatological data shows record rainfall totals for the South Downs in autumn 2000, daily and monthly rainfall totals were unexceptional. This study aims to assess the causes and contexts under which the South Downs flooding of autumn 2000 took place and to suggest strategies for managing similar events in the future.

Strategy	Effectiveness	Possible Cost
Reversion to pasture	High	High due to subsidies to farmers
Change morphology of fields	Medium	High due to earth moving machinery
Change farming practices	High	Low
Building Controls	Medium	High but only transfers risk elsewhere

Table 1 Summary table of control strategies

From an analysis of a large body of experimental evidence of soil erosion, contemporary meteorological reports and evidence of previous muddy flooding on the South Downs it is proposed that the floods of autumn 2000 were caused and exacerbated by inappropriate land use. In particular, the growth of winter cereal crops on the Downs leaves soil without crop

cover at the wettest time of the year, leading to accelerated soil erosion and flooding. A theoretical mechanism is proposed whereby land use is the critical factor influencing sensitivity to erosion and flooding, and where initiation of severe erosion and flooding takes place against a background of heavy and prolonged rainfall. A number of mitigation strategies are proposed and evaluated (Table 1). To prevent a repeat of flooding on the scale seen in autumn 2000 it is recommended that, in conjunction with changes to floodwater management schemes outlined elsewhere, land use be reverted from winter cereal cropping to sheep pasture. This can be done using within existing mechanisms of the Common Agricultural Policy and the UK Environmentally Sensitive Area scheme.

1. Introduction

a. The South Downs

The South Downs are a dissected chalk upland in South East England, reaching heights of up to 200m and stretching from Petersfield in Hampshire to Eastbourne in East Sussex (Figure 1). They are composed of Cretaceous limestone and contain periglacial dry valleys that dissect the chalk to depths of up to 150m with slopes of 5°-25° (Boardman, 1995). The Downs receive 750-1000mm average annual rainfall with a peak in October-January. The mean annual temperature is 9.8°C, with January and July means 3.9°C and 16.3°C respectively (Potts, 1982).

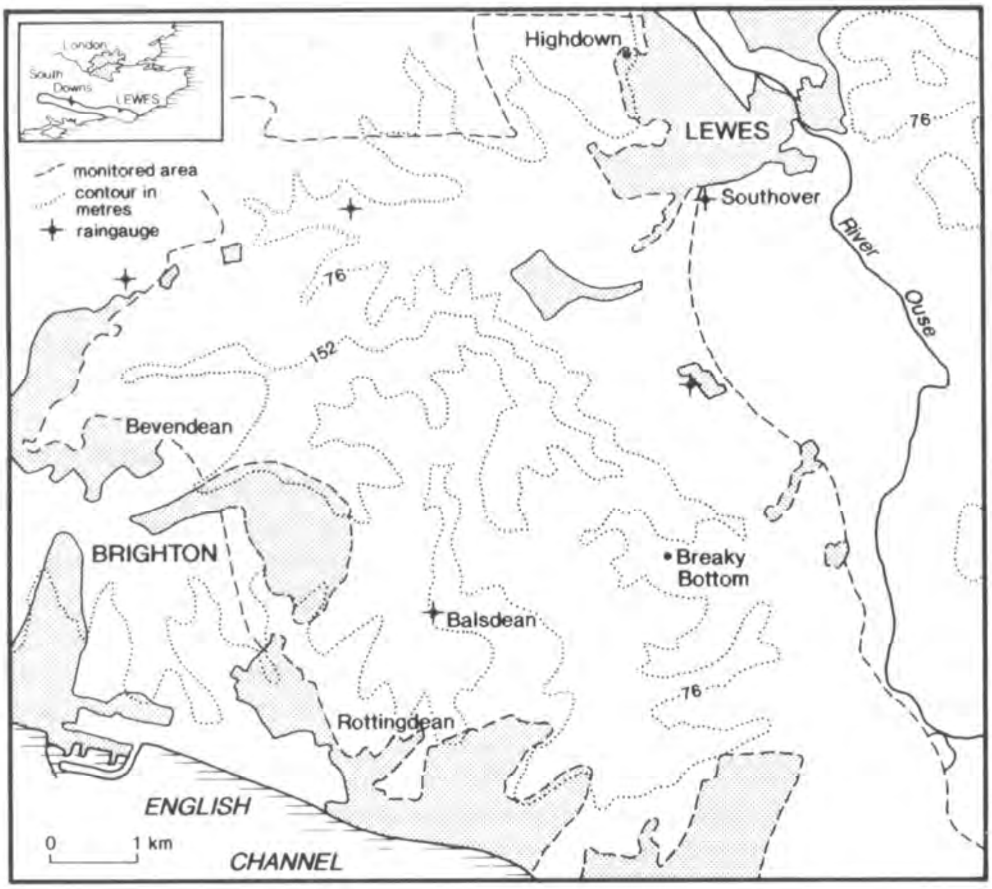

Figure 1 Map of the South Downs, England (Boardman, 1990).

The soils are Andover I Association and are mainly shallow, stony rendzinas containing silty clays and silt loams (Boardman, 2001). The soil found on the Downs today is a greatly thinned remnant of a thick loess cover that was deposited during the Devensian glaciation (Favis-Mortlock *et al*, 1997). The loss of this original loess cover has occurred over 5000 years and is related to permanent anthropogenic forest clearance and gradually intensifying agriculture (Figure 2). The history of land use on the South Downs has mostly been dominated by sheep grazing, and only in the twentieth century has the land been given over to intensive ploughed agriculture. Beginning with the Second World War, the Downs, and particularly its stepper slopes, were brought under cultivation, a practice that continued in the post-war period. The growth of winter cereal crops on all but the very steepest slopes on the Downs has been encouraged since the late 1970s by price guarantees from the EEC (Boardman, 1994), which gas led to the widespread uptake of winter wheat cultivation.

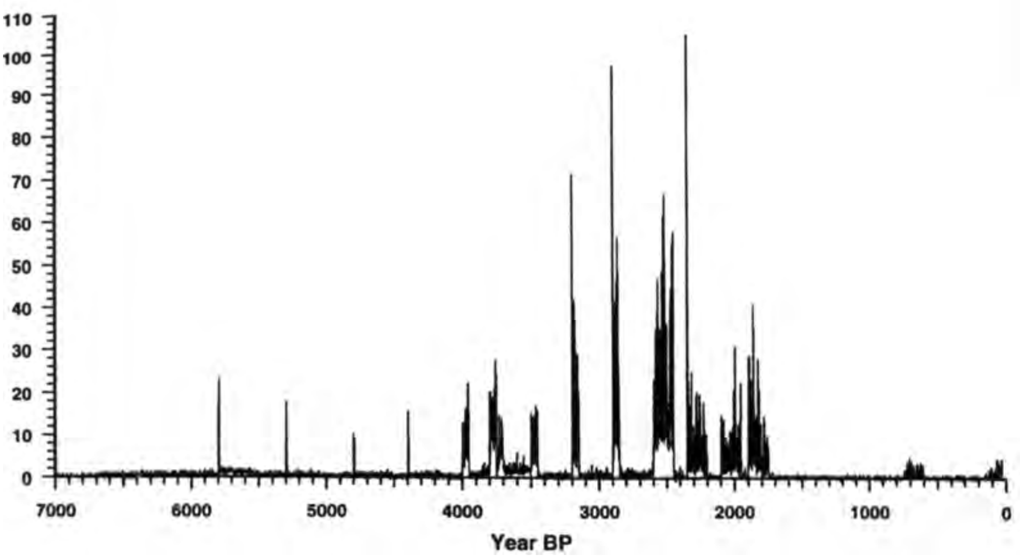

Figure 2 Simulated historical erosion rates, South Downs (Favis-Mortlock *et al*, 1997).

b. Impacts of Autumn 2000 Floods

The autumn 2000 events did not take place as a single flooding episode, but as a series of flood events related to extreme climatic phenomena. The areas affected by muddy flooding were mostly the suburbs of Brighton, including Patcham, Bevendean, Woodingdean, Ovingdean, and Westdene, which are built in the dry chalk valleys and are surrounded by winter cereal fields. An impact assessment was carried out in 2001 by the Surveyors to Brighton and Hove Council. The impacts of the flood are recorded in that report and are summarized in Table 2.

Location	Impacts
Patcham	Inundation and closure of roads and railway
	Inundation of petrol station
	Inundation and evacuation of 20 properties
	Flushing of sewage onto street
Bevendean	Inundation and evacuation of 25 properties
	Continuing flood risk 2000/1
Lewes	Inundation and closure of road
Woodingdean	Ponding of water on road and traffic disruption
	Muddy inundation of gardens
Ovingdean	Inundation of one property four times with extensive damage
Westdene	Ponding of water and mud deposition in gardens
	Fear of impeding floods for residents
Mile Oak	Inundation of 2 properties
	Inundation of roads and gardens

Table 2 Impacts of autumn 2000 floods on selected locations on the South Downs (BB&V, 2001).

Flood impacts mainly consisted of inundation of roads and infrastructure, and damage to homes and property. Muddy floodwater affected the A23 and A27 roads, necessitating removal of the muddy sediments and the closure of those roads for a period of two weeks. Muddy runoff from farmers' fields in Patcham led to the impounding of a large volume of water behind a railway embankment, that eventually broke leading to flooding of the London-Brighton railway line and disruption of rail services for 5 days (BB&V, 2001).

Method	**Alleviation options**
Reduce runoff at source	Over-pump groundwater in aquifer in summer
	Increase infiltration through use of soakaways and trenches
Temporary Storage	Retention ponds
Flood Barriers	Embankments, walls, tanks
Disposal of excess water	Install new increase capacity of existing storm drains
	Link to road drains
	Emergency pumping
Improve Flood responses	Improved monitoring
	Contingency planning

Table 3 Flooding alleviation methods and options proposed by Brighton and Hove flood assessment (BB&V, 2001).

Muddy floodwaters led to the surcharging and subsequent flushing of sewers onto streets and into homes, adding foulwater to sediment laden agricultural runoff. Homes and gardens were inundated with muddy flood water, and foul water from sewers led to extensive internal damage and abandonment of many properties pending repairs and insurance claims. Repeated flooding occurred over autumn and winter 2000 and into spring 2001, leading to further damage to properties as well as anxiety and psychological stress to homeowners afraid that their properties might again be flooded without warning (ibid.). The approximate cost of the damage to property is in the region of £1m, and clean-up costs for roads and railways, including costs incurred due to transport disruption are estimated at £5m (Boardman, 2001). The recommendations in the Brighton and Hove Flood Assessment primarily represent 'hard engineering' responses to a flood event, rather than measures that address the causes of flooding.

2. Geomorphological significance

a. Mechanisms of muddy flooding

Muddy flooding is distinct from riverine flooding in that it emerges from ephemeral, not permanent, channels on agricultural land (Boardman *et al*, 1990). It involves ephemeral flow in rills and gullies and causes soil erosion on bare fields, which leads the water to be highly turbid. Rills are ephemeral features with channels typically in the order of centimeters and are formed by the merging of sheet wash into channel flow. Gullies are more permanent, deeper channels (in the order of meters) and are formed under more intense rainfall and erosive conditions. The mechanisms of soil erosion leading to muddy flooding are well understood (Evans, 1990). Saturation of the soil surface under conditions of heavy and prolonged rainfall leads to the emergence of springs and also to Hortonian overland flow, which occurs where rainfall exceeds infiltration capacity (Morgan, 1996). The soil surface seals and slakes under such conditions, allowing incision of rills and gullies (Boardman *et al*, 1990). Runoff from rills and gullies causes sediment-laden water to be deposited away from the fields resulting in off-site impacts (Evans, 1996).

Factor	**Effect on runoff/erosion**
Surface roughness	Highest when roughness least - i.e. compacted
Surface stoniness	Highest when stoniness greatest
Soil structure	Soils become structurally unstable where organic matter <2%
Soil erodibility	Highest on sandy soils, areas of rills and soils with low organic matter
Tillage	Least on heavily tilled soils with organic matter

Table 4 Factors conditioning water erosion on agricultural land (Evans, 1996)

The Universal Soil Loss Equation (USLE) explains soil erosion as a factor of climate, soil erosivity, organisms, rainfall and temperature (Figure 3). An important precondition for soil erosion and muddy flooding is the existence of bare agricultural land, on which compaction and slaking can go on. Evans (1990) suggests that erosion is most intense when the land has less than 30% crop cover. On the South Downs, seed drilling for winter cereal crops happens in the months September-November, leaving the land with crop cover of often less than 30% at the time of greatest rainfall. Boardman (1994, 1995, 1998, 2000, 2001) has established this association between winter cereal cropping, rainfall and subsequent erosion and flooding on the South Downs for several extreme rainfall events, and has suggested a 'rainfall index' to explain rainfall thresholds beyond which erosion is initiated (Table 5). A total of 30mm rain in 48hours (corresponding to a R.I. of 1) is taken as the threshold for the initiation of erosion.

Erodibility = k R S O C

Where:

K = Soil Erodibility | *R = Rainfall Erosivity*

S = Slope length and steepness | *O = Soil Organic matter*

C = Conservation measures

Figure 3 Universal soil loss equation and factors (Morgan, 1979).

Rain Event	Index Value
30mm in 2 days	1
30mm in 1 day	2
60mm in 2 days	3
60mm in 1 day	4

Table 5 Rainfall indices (Boardman, 1990)

b. Land use, before and during Autumn 2000

Since the 1970s, UK government and European incentives have made the cultivation of winter cereal crops on the Downs an ever more attractive option for farmers. Winter cereal crops are high yielding and command a guaranteed price, making their cultivation more economically viable than sheep grazing (Boardman, 1990). The use of heavy machinery on fields on the Downs during winter cereal planting leads to surface compaction and forms wheel tracks. A compacted surface tends to cap and crust when rainfall occurs, and subsequently slake under conditions of sheet flow. The production of fine tilths using power harrows also increases the erodibility and potential for compaction of the soil. Wheeltracks act as gullies and are exacerbated by water flowing through them. A further land use change that has occurred over the last few decades is that steeper, unbroken slopes are now cultivated. In an effort to increase the total arable land available, ever steeper slopes were brought under plough, with the result that many slopes >15°, and some slopes of up to 25° are now used. Together with the removal of field boundaries such as hedges to accommodate larger machinery, and the practice of downslope rather than contour ploughing, the result has been greater potential for downslope erosion and development of gullies (ibid.). Rills and gullies are believed to form on any unvegetated surface steeper than 7°, with a continuous unbroken slope of >200m (Boardman, 1990).

Location	Volume eroded (t)
Patcham	4.5-9
Bevendean	2.4
Woodingdean	1.5
Mile Oak	6.2

Table 6 Volumes of soil eroded in selected locations around the South Downs autumn 2000 (*after* BB&V, 2001)

In September 2000, over 10,000ha of the South Downs was planted with winter cereal crops, principally wheat (Kelman, 2001). Some land previously used to grow winter cereal crops has been taken out of production since the mid 1980s under the UK's Environmentally Sensitive Area (ESA) scheme and the E.U.'s 'set aside' scheme, bringing the total land area under winter cereals to around 50% (Boardman, 1992). The soils were bare, with less than 30% cover, with tractor rollings and wheelings. A wet summer, followed by heavy autumn rainfall led to the initiation of soil redistribution, sheet wash, and eventually gully formation (Evans, 1990) with the deposition of large volumes of soil downslope in fields – 60t on the Breaky Bottom Farm (BB&V, 2001). The eroded soil blocked drains and soakaways and led to the inundation of several areas with muddy floodwater (Table 5).

3. Climatological situation

a. Perceptions of the event

The floods of Autumn 2000 were reported in the news media as being caused by extreme rainfall (Anon, 2000a, 2000b, 2000d, 2000e). Whilst it is true that autumn 2000 represented the wettest autumn since records began in 1776 (Marsh, 2001), the monthly and daily totals were not by themselves exceptional (Table 7). The October monthly rainfall average for 2000 (147mmm) did not exceed the previous highest October recorded rainfall (184mm for 1987) (Anon, 2000d). Similarly, November 2000 was not the wettest on record. What was remarkable about the conditions leading to flooding in Autumn 2000 was how widespread and prolonged the rainfall was. Exceptional rainfall and high river discharges were sustained over 14 weeks beginning in mid-September (Marsh, 2001).

	October	**November**	**December**	**January**	**February**	**March**	**April**
Long Term Mean 1960-90	93	98	92	92	59	69	54
Average 2000-1	295	230	139	139	109	133	83
Max daily 2000-1	89.8	42.7	30	29	42	22.6	16.6

Table 7 Rainfall at Southover, Lewes 2000-1 and long-term average (Boardman, 2001)

b. Synoptic conditions

Three major climatic events related to three major muddy flooding episodes can be identified. These; 10-15 October, 28 October-12 November and 8-14 December were associated with synoptic conditions that brought heavy, prolonged and localized rainfall to South East England. A slow moving deep depression appeared over the UK on the 9th October bringing heavy rainfall. A second frontal depression affected the south east on the 11th October (Figure 4) bringing heavy convective showers. A quasi-stationary position was assumed by the band of low pressure on the 11-12 October due to abnormally high Sea Surface Temperatures over the English channel (16°C). Rather than the depression moving west and bringing drier conditions, extremely wet conditions persisted for two days (Saunders *et al*, 2001). Coming on top of a month of abnormally heavy rains this was sufficient to trigger both riverine and muddy flooding in many areas.

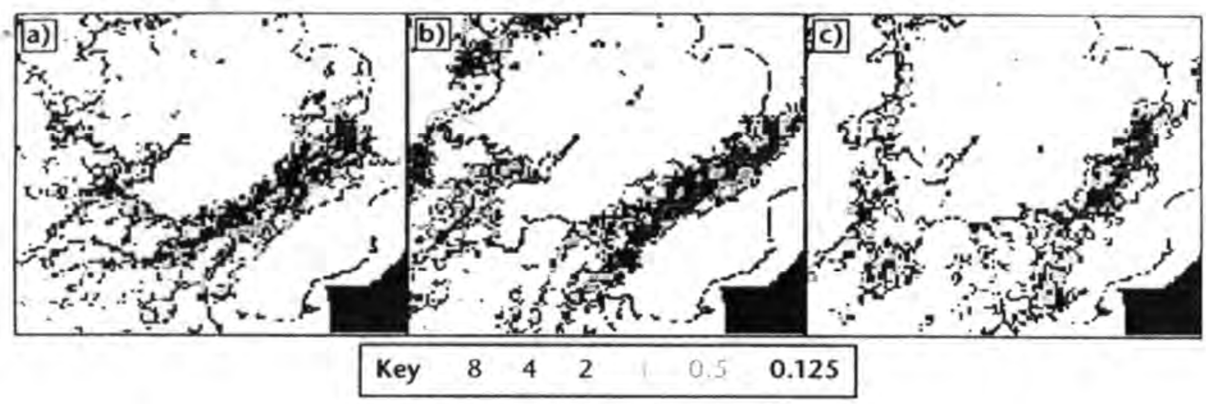

Figure 4 Composite radar images for rainfall: (a) 2000GMT 11 October; (b) 0200 12 October; (c) 0800 12 October (Kelman, 2001)

c. Prevalence of extreme events

Return periods, a function of duration and extent of rainfall, can be used to give an indication of how 'extreme' the event is, i.e. how often a similar event might be expected to occur (Table 8). Rainfall totals for the 10-12 October rainfall event were extremely high, and have long return periods - the rain gauge at Plumpton, East Sussex recorded 143.8mm rainfall in 24hrs – an event with a return period of over 300 years (Boardman, 2001), and a rainfall index of 4 – sufficient to initiate severe erosion. In the same rainfall event, 63.8mm of rain fell at Housedean farm, east Sussex, with a maximum hourly intensity of 11.4mm and a short period intensity of 3.6mm/minute (ibid.), and rainfall index of 4. For the late October/ early November flood event, the rain gauge at Southover, Lewes records 100mm of rain in 24 hours, an event with a return period of 100 years, and RI of 4.

	Return Period (years)					
	1	**5**	**10**	**20**	**50**	**100**
Duration						
5 min	4.6	7.5	9	10.4	12.1	14
10 min	6.6	10.8	13.1	15.3	17.9	20.7
15 min	7.9	12.9	15.7	18.4	21.6	25.2
30 min	10.5	16.7	20.5	24.1	28.5	33.4
1 hr	13.5	21	25.8	30.4	36.3	42.6
2 hr	17.1	25.8	31.4	36.8	44.3	51.7
6 hr	24.5	35.4	42.3	49.2	59	68.2
12 hr	30.7	43.4	50.9	58.9	70.3	80.9
24 hr	38.1	52.6	60.9	69.6	82.5	94.3
48 hr	47.2	63.6	72.7	82.5	96.7	109.2

Table 8 Relationship between rainfall (mm), return period and duration for the South Downs (Boardman, 1990 & NERC, 1975)

In the sense that the rainfall in autumn 2000 had high rainfall indices and had generally long return periods, the events were ‘extreme’. The rainfall events were high magnitude, low frequency ‘catastrophic’ events (Brunsden & Thornes, 1979) that together with anthropogenic changes in land use led to high magnitude, low frequency ‘catastrophic’ flooding. The repeated nature of the extreme rainfall in autumn 2000, occurring on at least three separate occasions, meant that rills and gullies that had developed in earlier rainfall events were reactivated generating further erosion and muddy runoff.

4. Autumn 2000 in context

a. Antecedent flood events

Although rainfall totals were high in total for autumn 2000, daily and monthly totals were not unprecedented (Table 9). The monthly totals were, with the exception of October, fairly normal for the time of year. Similarly, daily and hourly totals were not especially high compared with historical precedent. Marsh (2001) has compared the flood events in England and Wales in autumn 2000 with those of spring 1947 and found that, whilst less prolonged in spring 1947, discharges exceeded those of autumn 2000 (Figure 5). Flood events in 2000, although longer in duration, were lower in magnitude as those in autumn 1987, and spring 1980 on the South Downs (Boardman, 2001).

Location	Date	Rainfall	Return Event	Land use
Blaydon, Co Durham	June, 1941	75mm in 24hrs	20-50yrs	Young turnips
South Downs, Sussex	October, 1987	63mm in 24 hrs	10-20yrs	Prepared for winter cereals
Angus, Scotland,	March, 1992	50mm in 24 hrs	5yrs	Bare soil
South Earn, Scotland	January, 1993	440mm in month	222% of average	Ploughed winter cereals
Farringdon, Oxon	May, 1993	100mm in 4hrs	>100yrs	Maize
Ashow, Warwickshire	August, 1996	24.5mm in 30mins	20yrs	Recently planted oilseed rape
Hadspen, Somerset	May, 1998	45.6mm in 1hr	>100yrs	Maize

Table 9 Previous flooding events on the South Downs and in other downland areas (*after* Boardman *et al*, 1993 *and others*).

A severe erosion event occurred on the South Downs in October 1987, related to October rainfall that was very similar in extent and magnitude to that in autumn 2000. The difference was that in 1987, a dry September preceded heavy October rainfall – 270.9mm, previously the highest October total. On the 7th October 62.9mm was recorded in 24hrs at Balsdean (Boardman, 1988), an event with a RI of 4 and a return period of over 300 years (Boardman, 1990). The mechanism for runoff and erosion in 1987 was virtually identical to that observed in 2001 (Boardman, 1988, 2001) – bare ground was dissected by gullies in early heavy rainfall events and reactivated later by further rainfall.

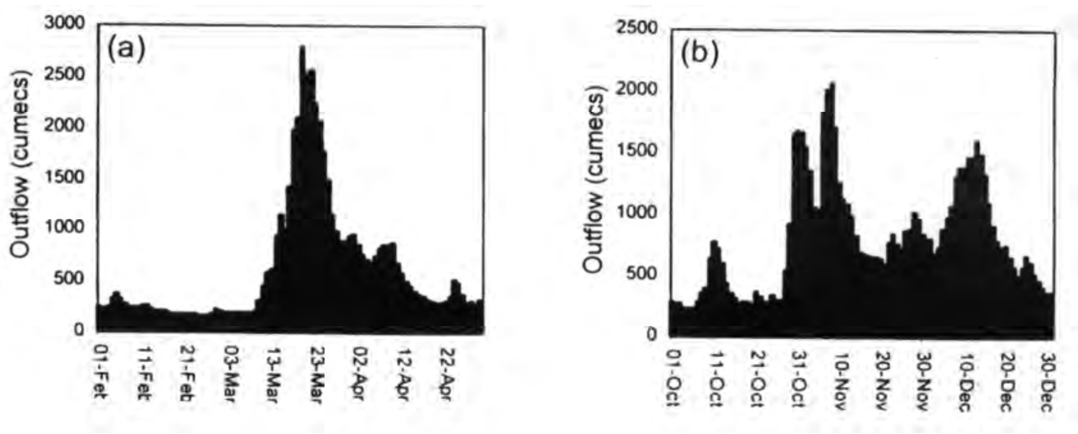

Figure 5 Comparison of (a) spring 1947 with (b) autumn 2000 flood events from daily Outflows from England and Wales (Marsh, 2001).

The 1987 event was attributed to a combination of unusually heavy rainfall and land use practices that encouraged runoff, erosion and down valley flooding. In his analysis, Boardman (1988) put the cause of the flooding squarely on management techniques that had altered field morphology. What is notable in this comparison is that although the rainfall was more severe and prolonged in the 2000 event, flooding was more extensive in 1987. This may be due to the small decline in winter cereal cropping on the Downs as a result of enforcement of ESA and Set Aside schemes (Ford, 2001). Costly damage from the 1987 event caused the local council to take remedial action to install more dams and soakaways to deal with excess flood water, and some individual farmers to take action to prevent damage to their land (BB&V, 2001).

The climatic events and flooding episodes of 1987 and 2001 can also be compared with the extreme rainfall of autumn 1980, when heavy rainfall took place but did not cause muddy flooding. Daily rainfall for Worthing, West Sussex, is recorded as exceeding 100mm per day (Potts, 1982). The events of autumn 1980 were extreme with return periods of >1000 years. Flooding in this case was of the clear variety and restricted to floodplain inundation by river water, and less damaging than muddy flooding. Similar synoptic conditions are recorded in 1980, 1987 and 2001. A deep depression and associated frontal system existed over southern Britain for several days, bringing heavy and prolonged rainfall. This was followed by a number of high magnitude, short duration events. However, none of these events led to muddy flooding in 1980 perhaps due to the relative lack of winter cereals at that time and prevalence of sheep grazing, giving fields almost total vegetation cover.

b. Muddy flooding elsewhere in the UK

Areas other than the downland of Sussex have been known to suffer from muddy flooding after extreme climatological events. These have been almost exclusively in areas where bare ground has led to rilling and gullying. In August 1996, an extreme meteorological event occurred over central England. A low pressure system traveling north east brought a high magnitude, short duration rainfall event to Ashow, Warwickshire. This event had a daily rainfall total of over 60mm and a return period of 10-30 years (Harrison & Foster, 1997). Surrounding Ashow were a number of ploughed and power harrowed fields of well drained soil that had recently been planted with oil seed rape. The effect of the storm was to erode the topsoil and develop rills and gullies causing soil deposition on nearby roads and properties amounting to over 60t (ibid.). Debris fans of over 740t were formed in farmers' fields. The storm, although severe, would not have caused soil erosion and flooding were it not for farming practices that had increased the susceptibility of the land. Hedgerow removal, ploughing, and the presence of an uncovered soil surface all had a part to play in the flood event.

An analogous event occurred in Hadspen, Somerset in May 1998, when a low pressure event brought heavy rainfall to South West England, with rainfall intensities recorded as >100mm/h (Clark, 2000). These extremely high rainfall totals have long return periods (in excess of 1000 years). Considerable erosion took pace on ploughed fields and muddy water inundated several properties and was deposited on roads. In total, approximately 150mm thickness of soil eroded from ploughed fields and deposited the road. Once again, an extreme rainfall event caused a major flooding and erosion episode from fields that were very sensitive to erosion. The literature is replete with similar examples from around Britain of extreme climatic events generating flooding on susceptible arable soil surfaces (Thomas and Allison, 1993).

5. Discussion – causes and contexts of flooding

a. Causes and contexts

Whilst there is no doubt that rainfall in autumn 2000 was unusual, (Boardman, 2000) the main cause of flooding on the Downs was not excessive autumn rainfall, but anthropogenic land use that allowed runoff, erosion and gully formation. The rainfall totals, whilst record breaking in terms of previous monthly and seasonal amounts, were unexceptional in terms of daily totals (Boardman, 2001). Previous rainfall events on the South Downs have been shown to be greater in intensity, yet result in less flooding, examples from elsewhere in the UK show that the Downs are not unique in being subject to high magnitude, short duration climatic events that generate flooding.

Since climatic events of greater magnitude than those of autumn 2000 have had less geomorphological impact in terms of soil movement and flooding (e.g. autumn 1980) and lesser magnitude storms have greater geomorphological impact (e.g. autumn 1987) seems to suggest land use, and particularly sensitivity of the land, has the greatest geomorphological influence. It is revealing that prior to the late 1970s, muddy flooding was virtually unknown on the South Downs. Breaky Bottom Farmhouse, built in 1851, did not suffer flooding until 1976, and has since been subject to inundation on more than twenty occasions (Boardman, 1995). This can be directly related to the growing of winter cereal crops in surrounding fields which increases and alterations to field morphology that lowers the erobibility of the soil.

b. Landscape sensitivity

Through an analysis of landscape sensitivity, the causes of floods on the Downs can be accounted for. A system becomes more sensitive when geomorphic thresholds are lowered and the frequency of geomorphic events increases. On the South Downs, both lowering of thresholds and increases in extreme event frequency and magnitude is happening simultaneously. Land use changes have lowered the resistance of the soil to erosion. Just as historically forest clearance led to increases in rates of geomorphic activity on the Downs (Favis-Mortlock *et al,* 1997) the switch from pasture land to arable land has led to increased erosion. In particular, the switch to winter cereals has lowered the geomorphic threshold to change (Figure 6). All of the land use changes associated with the switch to cereal crops on the South Downs appear to be taking the form of stepped incremental changes that are progressively lowering the resistance of the soil to erosion (erodibility) and concomitantly increasing the forcing mechanisms of soil erosion (erosivity) (Table 10).

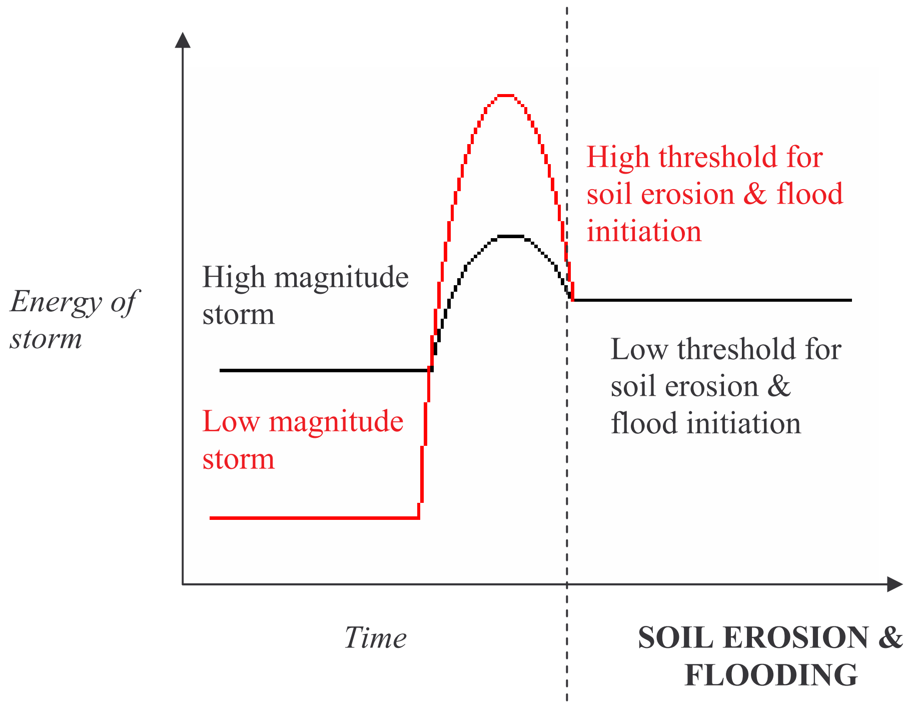

Figure 6 Geomorphic thresholds. Red line implies a low energy storm event and a high threshold for soil erosion and flooding initiation. The high threshold represents a resistant soil system, e.g. vegetated or well ploughed. The black line shows a higher magnitude storm event, capable of overcoming the threshold and initiating erosion and flooding. The threshold is also lower in this scenario – the resistance of the soil is lower due to e.g. lack of vegetation cover. Thus soil erosion and flooding is more easily initiated. For the South Downs, the black line represents the high magnitude of recent storm events combined with a lowering of the soil's resistance and thresholds to change through the growth of winter cereals (*after* Brunsden and Thornes, 1979, Schumm, 1979).

Property	Detail	Overall result
Erosivity of climate/land use	*Water, Wind & other erosive mechanisms*	Increase in magnitude and frequency of 'extreme' rainfall events - forcing agents
	Land use	Removal of vegetation cover at the wettest time of the year effectively lowers geomorphic resistance
Erodibility of soil	*Surface Roughness*	Winter cereal production has decreased roughness hence resistance to erosion, leading to a surface that is more susceptible to slaking.
	Soil structure	Compaction of soil by machinery encourages sheet wash hence erosion. The soil's internal cohesion has also been lowered by ploughing, hence is finer and more susceptible to entrainment.
	Field morphology	The morphology of fields has changed with the switch to cereal cropping, with steeper and longer fields now cultivated, resulting in greater potential for rilling and gullying.

Table 10 Result of changes to erosivity and erodibility properties of soils on the South Downs (*after* Evans, 1990)

6. Possible Management Strategies

The floods of autumn 2000 happened at a highly sensitive time for agricultural land. The complex relation between land use and climate described above shows that although climate is not the main control of runoff, it does influence the severity and frequency of runoff events (Boardman, 2001). What is perhaps most noteworthy about the events of autumn 2000 is that recent historical precedent already showed that growing of winter wheat is the prime cause of muddy flooding (Table 8), yet the practice continues largely unabated. As well as the strategies for flood mitigation in terms of flood water management and defences described in the Council Flood Assessment (BB&V, 2001), a number of more fundamental proposals for prevention and management of muddy flooding on the South Downs are proposed here which are intended to be adopted along with 'hard' hydrological engineering measures (Table 11).

Strategy	Detail	Effectiveness	Disadvantages	Possible cost
Reversion to pasture	Turn over all cropland to sheep grazing	High, soil erosion least likely to occur	Unacceptable to farmers without remuneration	High but borne by existing bodies (EU, ESA)
	Turn over erosion-prone cropland to sheep grazing	High for susceptible fields	Farmers reluctant	High but borne by existing bodies (EU, ESA)
Morphological alteration	Reinstate field boundaries (e.g. hedges) on steep slopes	High	Costly, impossible to use machinery	High
	Terracing	Medium	Costly, impossible to use machinery	High
	Flatten slopes	Medium	Costly	High
Farming practices	Plant winter cereal crops later	Medium	Still in wet time of the year, Farmers reluctant	Low
	Plant spring cereal crops	Medium	Still in wet time of the year, Farmers reluctant	Low
	Plant summer cereal crops	Medium	Still in wet time of the year, Farmers reluctant	Low
	Leave fields fallow	Medium	Erosion can still occur (bare soil)	Low
	Contour ploughing	Medium	Impossible on steep slopes	Low
Building control	Hazard mapping	High if advice on building heeded	Much existing housing stock already in flood prone areas	Medium
	Managed Retreat	Low, addresses symptoms not causes	Costly, undesirable to residents	High

Table 11 Proposed management strategies to address causes of muddy flooding on the South Downs.

7. Assessment and conclusion

The most favoured management strategy for the South Downs would be selective reversion to pasture on land most susceptible to erosion causing flooding, i.e. the steepest slopes and those that border residential properties. Alteration of field morphology is possible by abandoning steeper fields, but the re-emplacement of barriers is likely to be unacceptable to farmers using large agricultural machinery. Changes to current farming practices may go some way to alleviate problems of flooding, however contour ploughing is impossible on slopes steeper than 5° due to the risk of tractor instability, and late planting may reduce the quality of the crop. Building control is a favoured strategy of managing risk in future, but fails to address fully the problems of existing properties in the flood risk area. To alleviate that problem, the hydrological management strategies of BB&V (2001) might be adopted.

There is a large body of literature, principally the popular press that characterises the recent increase in flooding episodes as a result 'global warming'. Whilst it is true that under projected scenarios of climatic change Britain would experience greater storminess (IPCC, 2001), and perhaps more riverine flooding, anthropogenic land use exerts the major control on muddy flooding and erosion. Only by addressing land use may the risk of muddy flooding be mitigated. The muddy floods of autumn 2000 on the South Downs highlight that unless the causes and not the symptoms of muddy flooding are addressed, then high costs of disruption, cleaning up and legal proceedings will continue to be borne by insurers and by the public sector.

8. References

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