Journal of
Flood Risk Management

Impacts of the summer 2007 floods on agriculture in England

H. Posthumus[1], J. Morris[1], T.M. Hess[1], D. Neville[1], E. Phillips[1] and A. Baylis[2]

1 Natural Resources, Cranfield University, Bedfordshire, UK
2 Science department, Environment Agency, Leeds, UK

Correspondence: J. Morris, Cranfield University, Cranfield, Bedford, MK43 0AL, UK
Tel: +44 (0)1234 750111
Email j.morris@cranfield.ac.uk

DOI:10.1111/j.1753-318X.2009.01031.x

Key words
Flood risk management; rural; agriculture; England; summer 2007 floods.

Abstract

Exceptional rainfall during the summer of 2007 caused widespread flooding in parts of England. While the focus of attention has been correctly placed on the impact on densely populated urban areas, large tracts of rural land were seriously affected by flooding. Summer flooding is particularly damaging to farming. This paper presents the results from an evaluation of the impacts of the summer 2007 flood events on agriculture. High financial losses were incurred in the horticultural sector. Arable farmers incurred direct losses in the form of crop loss or yield reduction due to flooding and associated waterlogging of fields. Livestock farmers incurred indirect losses in the form of additional housing and feeding costs for livestock. Although total costs to agriculture were small compared with urban flood costs, they were typically large at the individual farm scale. Such impacts should be properly acknowledged in future strategies for flood risk management.

Introduction

Exceptional rainfall in the summer of 2007 caused extensive flooding in parts of England, especially in Yorkshire & Humberside, West Midlands (Worcestershire and Gloucestershire) and Oxfordshire. Following a sustained period of wet weather starting in early May, extreme storms in late June and mid-July resulted in flooding from heavy surface flows, overloading and surcharging of surface and subsurface drainage systems and overtopping of river flood defences (Marsh and Hannaford, 2007). As a consequence there was unprecedented flooding of properties and infrastructure in some areas. Thousands of people were evacuated from properties, and many more were in fear of evacuation. Public water and power utilities were disrupted, with the threat of power blackouts at the regional scale. An estimated 42 000 ha of farmland across England were flooded (i.e temporarily covered by surface water), predominantly from rivers (ADAS, 2008) with significant effects on yields and farm incomes. While the focus of attention has been correctly placed on the impact on life and urban property, large tracts of farmland were seriously affected by flooding, especially in floodplain areas.

As a land-based industry, agriculture is vulnerable to both surface and groundwater flooding (Morris and Wheater, 2007). Crops (including grass) are sensitive to excess water and anaerobic soil conditions during critical growth periods, with consequences for yield, quality and value. Flooding of agricultural land therefore may result in reduced crop and livestock outputs. The impact of flooding on agriculture varies considerably according to tolerance of the particular crop or land-use activity to excess water, and the frequency, duration, depth and seasonality of the event (Morris and Hess, 1988). For example, relatively short duration flooding in winter may have limited impact on grassland and cereals. A flood event in summer, however, can completely destroy a crop of grass or cereals ready for harvest.

It is possible that rural areas could face an increased incidence of flooding and a change in the nature of flood events in the future due to climate change (Wilby *et al.*, 2008). Although farming communities in floodplain areas are often well adapted to a degree of flooding, the prospect of wetter winters and increased intensity of rainfall events throughout the year, could increase their exposure to flood risk because (i) protecting the relatively 'sparse' rural space is deemed insufficiently cost-beneficial in economic terms relative to urban areas (Johnson *et al.*, 2007) and thus generally receives lower standards of flood protection, and (ii) designated rural areas are intentionally used to store flood waters in strategies that give priority to urban protection. For these reasons, it is possible that rural dimensions of flooding are inadequately understood and represented in the formulation of policy on sustainable flood risk management (Defra, 2004a) and there is a clear need to ensure that the characteristics of rural dwellers and communities that make them particularly vulnerable to flooding are fully taken into account. That is, approaches to flood risk management need to be sufficiently 'rural proofed'. As a case study, this paper reports on the findings of a survey to identify and evaluate the nature, magnitude and distribution of economic impacts of the summer 2007 flood events in rural areas on land-based activities.

Methodology

Seventy-eight farmers were interviewed in the West Midlands (Gloucestershire and Worcestershire), Oxfordshire and Yorkshire & Humberside. These three regions were most severely affected by the summer 2007 floods (Table 1).

Farms were randomly selected within the flood areas identified on flood maps provided by the Environment Agency. In this case study, flooded land is defined as farmland that was temporarily covered by surface water due to overtopping of watercourses or restrictions on arterial drainage. The area of flooded land managed by the farmers included in the survey accounted for approximately 14% of the total area of agricultural land flooded in the summer of 2007 in England. Figure 1 shows the distribution of farm types (according to the Defra (2004b) classification) of the survey sample for each region.

Most farmers participated willingly in the survey although a few declined, either because they had suffered only minor losses or, on the other extreme, their costs had been extremely high and they were still traumatised by the events. Structured questionnaires were compiled in order to collect information on the nature of the flooding, the impact on crop and livestock enterprises, the type and cost of damage and the attitude and perceptions of farmers regarding flood risk management (Table 2).

Flood loss estimation

Flood and waterlogging impacts were assessed at the farm scale and at the scale of individual 'blocks' of land, i.e. units of land, in some cases comprising multiple fields, that are managed similarly and demonstrate similar physical and hydrological characteristics, such as soils, topography and flood frequency.

Estimates of the financial losses were based on estimates of physical damage and unit prices (Morris and Hess, 1988). The methodology described by Hess and Morris (1988) was used to account for losses of grass production in terms of utilisable metabolisable energy for livestock. Losses in hay and silage crops were based on farmers' estimates. Furthermore, it was assumed that after the flood events no more grazing took place on the flooded fields. Feed barley was taken as replacement feed for the loss in grass production,

Table 1 Areas surveyed and sample of farmers interviewed

Region	Yorkshire & Humberside	West Midlands	Oxfordshire	All regions
Flood event	June 2007	July 2007	July 2007	
Rivers	Aire, Don, Hull	Avon, Severn	Thames (and tributaries)	
Total flooded area (ha)*	19 364	10 923	11 684	42 000
Flooded area in sample (ha)	1835	2175	1770	5780
Number of farmers interviewed	27	32	19	78
Probability summer flood†	0.04	0.07	0.10	0.06
Probability winter flood†	0.28	0.68	0.63	0.53

*After ADAS (2008). †As reported by farmers.

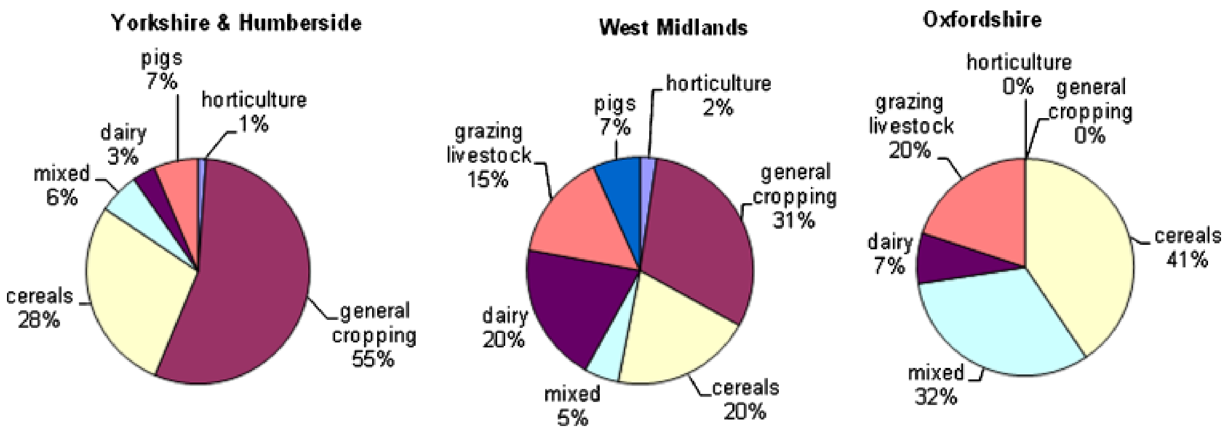

Figure 1 Sample distribution of farm types in case study regions.

Table 2 Contents of structured questionnaires for farmers

Farm characteristics
Farm size; farm enterprise; number of employees
Flood characteristics
Area flooded; duration of surface flooding and waterlogging; major impacts
Land block (and field) characteristics for flooded areas
Land use; soil type; drainage; flood frequency; area affected by summer 2007 floods
Flood damage: arable
Crop grown; expected and actual yield; impact quality crop; additional input costs (fertilisers, pesticides); additional harvesting costs; saved harvesting costs if no crop; costs for land reinstatement; changes in crop rotation following season
Flood damage: grassland
Use (grazing, silage, hay); livestock; fertiliser input; expected and actual yield grass conservation; impact forage/pasture quality
Flood damage: livestock
Duration of housing of livestock; extra costs for housing livestock (labour, feed, slurry disposal, water); diseases affecting production and treatment costs; reduction milk production or animal growth; loss of livestock due to flooding, forced sales
Flood damage: farm
Damage to buildings, contents and machinery; repair costs for fences, gates, hedges, ditches, farm tracks, debris. Impact on nonfarm income activities
Response
Warnings received; assistance received and provided during and after flood events. Perceptions on flood risk management

based on metabolisable energy values. Based on these assumptions, the cost of flood damage to grass production amounts to £0.0108/MJ.

Average market prices during the harvest season 2007 were taken for cereals, potatoes and field vegetables as reported by the Department for Environment, Food and Rural Affairs (Defra) and ABC (2007), the farming press, or the farmers' own estimates. The minimum agricultural wage rate (including employment costs) as estimated by Nix (2006) was used to account for extra labour costs caused by the flooding, with overtime rates during peak periods for emergency work. The estimates of Nix (2006) were also used to account for machinery costs and extra field operations. The total flood damage cost may not reflect actual expenditure. For example, the labour cost required to relocate livestock was often not charged for in reality, but it is a cost nevertheless and therefore taken into account in this paper.

Results and discussion

Nature and extent of floods

The farms in Yorkshire & Humberside were flooded in the last week of June 2007, when most crops were approaching the end of their growing season. The farmers that were interviewed reported that, on average, the water stayed on the farmland for 3 weeks, varying from a week to a month. After the flooding, the land remained waterlogged for another 3 weeks on average until the end of August 2007.

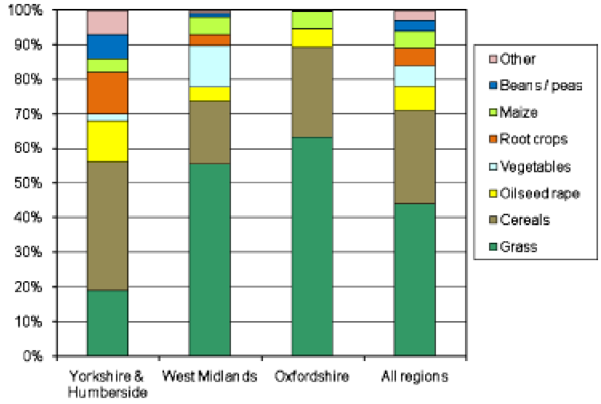

Figure 2 Distribution of land use of flooded farmland, based on survey sample.

In the West Midlands and Oxfordshire, flooding of farmland began around 21 July 2007, although a few farmers reported that they had also been flooded during early July 2007. On average, the water stayed for 2 weeks, varying from <1 day to 6 weeks according to the interviewed farmers. However, once the floodwaters disappeared, the land remained waterlogged for another month on average, until the end of August 2007.

In the West Midlands and Oxfordshire, more than half of the flooded farmland was under pasture. These farms, predominantly located along the Rivers Severn, Avon and the tributaries of the River Thames, were used to more frequent (particularly winter) flooding than their peers in Yorkshire & Humberside where over 80% of the land affected by the summer 2007 floods was arable (Figure 2).

The most frequently reported impacts of the summer 2007 floods were crop damage and associated yield loss, followed by loss of income from livestock and debris clearing (Figure 3). In addition, a minority of farmers also incurred costs due to damage to buildings, equipment, drainage and field boundaries.

Losses to arable crops included: crop yield and quality loss; additional inputs (e.g. the costs of additional agro-chemicals applied after the flooding to maintain crop performance); increased harvesting costs (adjusted for savings due to reduced yield); and land reinstatement costs. These costs were estimated for whole blocks of land, including parts that were not flooded. This was because; (a) farmers generally recorded yield and other information on the basis of whole blocks, and (b) additional costs were incurred on the nonflooded parts due to increased waterlogging and delay to activities caused by the flooding on the rest of the block. The total crop loss attributable to the flooded area was obtained by dividing

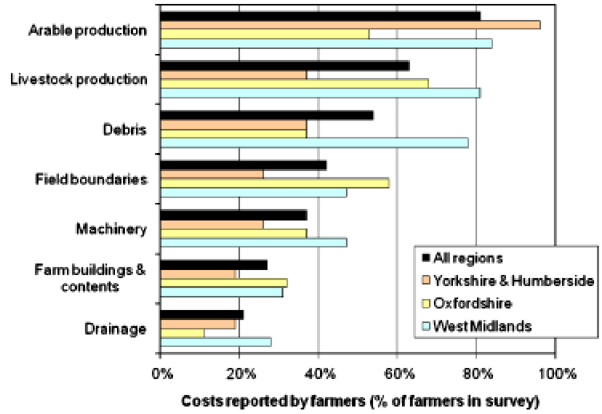

Figure 3 Source of flood damage costs as reported by farmers.

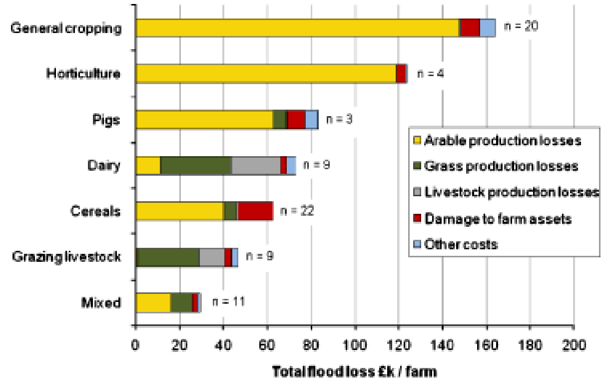

Figure 4 Damage costs on farms caused by summer 2007 floods, by farm type.

the costs at block level by the proportion of the block that was flooded.

Losses to grassland included: losses of conserved grass (hay, silage) and grazing; cost of moving livestock; and costs of reseeding pasture. Further losses to livestock production included: the cost of livestock lost due to flooding, for example by drowning; reduced milk production; additional labour; extra purchase of feed; cost of additional slurry disposal (where livestock was kept indoors due to loss of grazing); and additional treatment costs (above expected treatment costs) for animal diseases.

The damage costs to farm assets included: buildings and contents, machinery, field boundaries, field drainage, ditches and culverts and the cost of debris removal and clean-up of flooded fields. It is common for farmers to have nonfarming income activities alongside agricultural activities, such as farm shops, rental of farm buildings, tourist accommodation (camping site, or holiday cottages) or contracting businesses. Some of these nonfarming income activities were disrupted due to the flooding and these losses were also included.

Flood impacts at farm level

The average cost attributed to the summer 2007 floods varied considerably according to farm type and was heavily skewed with a few farms bearing the highest losses (Figure 4). However, the floods caused very significant losses for relatively small farm business enterprises.

At the farm level, the largest losses were incurred by 'General Cropping' farms. These losses were mainly associated with either complete crop loss or reduced crop yields. Not only did this reduce income, but also in some cases, farmers reported that they had to purchase substitute crop commodities in order to secure their contractual relationships with buyers.

The horticultural crops sector incurred the biggest losses at field level, often involving complete crop loss. Flooding of vegetable and salad crops commonly led to market rejection due to damage and/or risk of contamination. Farm level costs on horticultural farms were slightly lower than on arable farms as the area impacted by the floods on horticultural farms was typically smaller than on arable farms.

Livestock farmers incurred many indirect costs associated with the relocation and housing of livestock during the grazing season, resulting in extra costs of shelter and labour. Many bought in extra feed to replace lost summer grazing and also for subsequent winter feeding because conserved grass was lower in both quantity and quality. In some cases in the West Midlands, farmers experienced temporary disruption of potable water supplies and incurred additional costs to secure water for their livestock. Few farmers reported losses of livestock due to flooding, but there was an increase of treatment costs of diseases such as dairy mastitis and lameness. Livestock farmers incurred relatively high repair costs for fences, gates and hedges, as field boundaries are more prevalent and essential on livestock farms than arable farms.

Although the costs for repairs of farm infrastructure (farm tracks, drains, ditches and irrigation equipment) and of buildings and machinery varied considerably between the different farm types, many of these costs were farm- rather than type-specific. Costs on horticultural farms associated with damage to irrigation equipment (especially pumps) were known to be higher.

Some farmers were insured for some aspects of the losses, in particular for damage to buildings and machinery, but not all. Thirty-three farmers suffered losses related to damages to buildings and machinery, but only 13 received payments from insurance companies. Other farmers received financial support from charities such as Business Link, the Addington Fund and Yorkshire Forward. These payments were mainly made to livestock farmers to finance the purchase of extra animal feed, and typically consisted of a gift of £2000. On average, insurance and charitable

Table 3 Average agricultural damage costs due to summer 2007 floods

	Horticulture ($n=4$)	General cropping ($n=20$)	Cereals ($n=22$)	Mixed ($n=11$)	Dairy ($n=9$)	Grazing livestock ($n=9$)	Pigs ($n=3$)	All farms ($n=78$)
Flooded area per farm (ha)	18	84	76	71	70	76	88	74
Proportion total farm flooded (%)	13.2	21.6	27.5	32.4	38.3	44.5	33.3	29.4
Total cost (£ per hectare flooded, weighted averages)	6879	2028	850	411	1058	612	948	1207

donations amounted to £4720/farm compared with losses of £89 415/farm, although most farmers received nothing.

The type and extent of flood damage costs are strongly correlated with land use, although the relatively small size of the sample and the relatively large variations observed require that results are interpreted cautiously. There is a negative correlation between the proportion of flooded land under grass and the total costs of the floods ($p=0.036$)[1]. In contrast, there is a strong positive correlation between the proportion of flooded land under vegetables and the total costs of the floods ($p=0.000$). There is a positive correlation between the proportion of flooded land under grass and costs incurred by damage to fences, hedges and gates ($p=0.014$), reflecting that these field boundaries are typical for grassland and indeed essential to the management of livestock on pasture.

Average damage per hectare flooded

Table 3 shows the average flood damage costs per unit flooded area, by farm type. On average the flood damage costs was £1207/ha flooded, but the type and amount of costs vary according to farm type. Horticultural farms suffered highest losses (at £6879/ha flooded), and mixed farms had the lowest (at £411/ha flooded). Not surprisingly, the major part of the damage costs for arable farms (that is horticulture, general cropping and cereals) consisted of damage to arable crops at 96%, 87% and 62% of the total costs, respectively. Note that the majority of the losses incurred by pig farms consisted of crop losses, and are therefore not directly associated with pig production. For livestock farms, the losses in grass and livestock production were more important, especially for dairy farms (Figure 5).

On average, 82% of the total flood damage costs per hectare flooded consisted of flood damage to crops (including grass). The remaining 18% consisted of flood damage to farm assets, livestock production losses and other costs incurred at field and farm level that cannot be directly attributed to the flooded area. In Table 4 the flood damage costs are attributed to the major land-use classes (arable or grass), by region. The flood damage costs are divided into three categories: (i) arable production losses, based on flood damage to arable crops; (ii) grass production losses, based on flood damage to grass; and (iii) other flood damage costs. Again, there are clear regional differences in flood damage costs, depending on land use, farm type and flood events.

[1]The p-value gives the probability that the correlation occurred by chance. If the p-value is <0.05, the correlation is statistically significant. The more the p-value approaches zero, the stronger the statistical significance of the correlation.

Sensitivity analysis for crop prices

The estimated losses are highly dependent on crop prices as the majority of the agricultural damage consists of losses of crop output. 2007 was an exceptional year in that crop prices rapidly increased in the second half of the year, largely in response to change in world market conditions. If estimates of crop prices are reduced by 10%, the total estimated farm loss decreases within the range of 5–13% depending on the farm type (Table 5).

Farmers' perceptions of flood risk management

On-farm adaptation to flooding

The summer 2007 floods are likely to have knock-on effects on crop production for the following growing seasons. One immediate effect is a change in crop rotation. After the flood waters receded, the soils stayed waterlogged for a considerable period, in some cases until spring 2008, causing delays in harvesting and other field operations required to establish crops for the following season. As a consequence, crop rotations were changed. In most cases, this resulted in a relocation of crops, with no overall cost to the farm. In six cases, however, farmers were not able to sow winter crops or plant potatoes in spring on the flooded area as intended, resulting in income losses for the next season. Several farmers also suggested that the soil compaction (attributed by the farmers to the weight of the flood water and harvesting under wet conditions) and the reduction of the worm population is likely to suppress crop yields for the next few years. These indirect effects of flooding have been reported by others also (for example, Pivot et al., 2002).

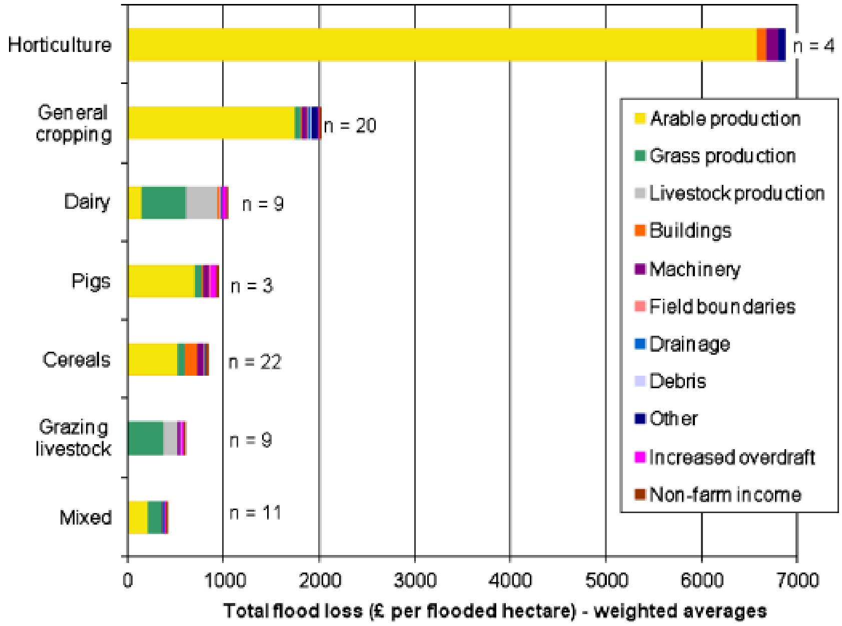

Figure 5 Damage costs (per flooded hectare) on farms caused by summer 2007 floods, by farm type.

Table 4 Flood damage costs by major land use class and region (£ per hectare flooded)

	Grassland				Arable land				All farmland			
	Y&H	WM	O	All	Y&H	WM	O	All	Y&H	WM	O	All
Arable production	0	0	0	0	1791	1844	449	1486	1456	838	165	828
Grass production	387	451	327	392	0	0	0	0	51	227	179	156
Other costs	228	371	107	250	182	341	79	204	188	356	94	222
Total	614	822	434	642	1973	2185	527	1690	1694	1421	438	1207

Y&H, Yorkshire & Humberside; WM, West Midlands; O, Oxfordshire; All, all regions.

Table 5 Sensitivity analysis of flood damage costs for crop prices

	Horticulture	General cropping	Cereals	Mixed	Dairy	Grazing livestock	Pigs	All farms
Arable production costs (£ per farm)	118 733	147 797	40 256	15 850	11 349	546	62 716	61 360
Change in arable production costs if 10% price reduction, all crops (%)	86	90	91	91	90	91	90	90
Grass production costs (£ per farm)	0	5351	5542	10 149	32 224	28 331	5939	11 582
Change in grass production costs if 10% price reduction, all crops (%)	0	90	90	90	91	90	90	91
Total costs (£ per farm)	123 891	170 256	64 538	29 225	73 576	46 741	83 140	89 414
Change in total costs if 10% price reduction, all crops (%)	87	91	93	92	95	94	92	92

Farmers were asked whether the summer 2007 flood experiences induced any permanent changes on the farm. Although many farmers thought that a repetition of these floods was very unlikely in the near future, 33 out of the 78 farmers interviewed were considering some changes on their farm. Changes under consideration included a change in land use on the floodplain (e.g. no more potatoes or winter cereals, or converting arable land into grassland), improvement of drainage and/or flood defences, securing a sufficient stock of forage for livestock (by harvesting hay or silage on fields not prone to flooding), reduction in herd size and hence need for grass or entering an environmental stewardship scheme. This group of farmers had suffered significantly higher losses related to damages to arable crops, buildings and machinery.

Farmers' perceptions on flood mitigation

During the interviews, farmers were asked what, in their view, should be done to manage floods and reduce impacts in their area in the future. Land drainage improvement was most often mentioned, in particular by farmers with arable crops. Indeed, many commented that shallow, short-duration flooding is not necessarily bad for crops, especially grass, as long as the floodwater is drained off the land quickly afterwards. Many farmers thought that the authorities could have evacuated the water sooner once river levels had gone down. However, further investigation is needed to verify whether this was indeed the case. Livestock farmers saw less need to alleviate flooding but thought increased resilience to flooding was particularly important. Those who did not have buffer stocks available in the form of 'reserve' grazing ground or fodder, suffered the highest costs. They contemplated the need to build in some sort of buffer for the future in case summer flooding becomes more frequent. Improvements in river maintenance, that is the cleaning of watercourses from obstacles and vegetation to allow faster flows, was particularly mentioned by farmers operating mixed arable and livestock systems on riparian land.

Comparing farmers' perceptions between the regions (Figure 6), farmers in Oxfordshire and Yorkshire & Humberside suggested improvements in flood defence, land drainage, river dredging and river maintenance more often than farmers in the West Midlands. Farmers in the West Midlands seem to be more resigned to the fact that their land is prone to fluvial flooding. As mentioned earlier the flood frequency faced by the West Midlands farmers is relatively high. As a result, farmers in the West Midlands put more emphasis on resilience and warning. Flood events similar to the summer 2007 floods are less common in Oxfordshire and Yorkshire & Humberside. The flood events in these two regions were mainly caused by pluvial flooding and overland flow, explaining why farmers in these regions suggested improvements of land drainage and river maintenance to reduce adverse impacts of rainfall events as experienced in 2007.

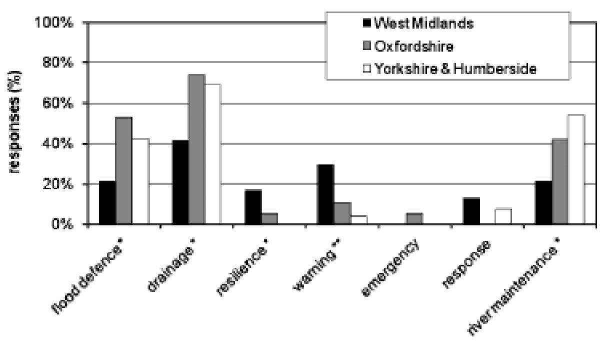

Figure 6 Farmers' perceptions on improvements for flood risk management, by region.

The impact of the summer 2007 floods at national level

ADAS (2008) estimated that a total of 42 000 ha of English farmland had been flooded, predominantly from rivers. Extrapolating the estimated average flood damage costs to national level, the present study suggests a national total flood damage cost for the agricultural sector of £50.7 million representing 1% of the gross value added of the agricultural industry in England in 2007 (Defra, 2007).

It is difficult to quantify the effect of the summer 2007 floods on the agricultural productivity and related food supply and prices at national level. The national average yield for winter wheat was 6% lower in 2007 than in 2006 (Defra, 2007), mainly due to generally wet and cold summer conditions. Overall, the summer events had a small effect on aggregate national supply. Our estimates suggest that cereal yields were down by about 40% in the flooded areas. Assuming about 1.6% of the English cereal area was affected (Defra, 2007), this suggests a reduction of about 0.6% in domestic supplies, insufficient under normal circumstances to have a major effect on aggregate supply and prices. However, 2007 witnessed a doubling of cereal prices due to shortages at the global scale and speculative commodity trading. Given the nervousness of markets at the time, the disruption to supplies caused by flooding could only exacerbate their volatility.

The summer floods and the generally unfavourable climatic conditions in 2007 affected yields and national output of important vegetable crops, notably peas, carrots and potatoes (Defra, 2007). It was estimated that 2.6% of the total potato area was written off due to flooding (BPC, 2007), however, a larger proportion of the national output was lost due to blight related to the wet weather conditions. Given the generally depressed potato yields across Europe as a whole, it is likely that flood losses led to price increases (Burrow, 2007). In such cases, paradoxically, those who lose their entire crops were unable to benefit from the 'compensation' effect of higher prices.

Conclusions

The average total flood damage cost (including production losses, damage to assets and other costs) was estimated at an average of £89 415/farm, with very large regional differences depending on the main land use type. Flood damage costs were skewed, with the majority of the farms facing lower losses than the average and a few farms incurring very high losses. On average the total flood damage costs per flooded hectare was estimated at £1207/ha. Clearly, there is a strong association between the intensity and relative profitability of farming and the cost of flooding when it occurs. The study confirmed that farmers adapt their land use to perceived flood probability; high-value crops and intensive grassland do not usually occur on flood prone land. The summer 2007 event, however, affected land not normally subject to summer flooding and therefore large areas of arable crops were flooded (especially in Yorkshire and Humberside).

Many farmers reported that damage costs were high because of long duration surface flooding and water-logging. In some cases, this was associated with a perceived deterioration in standards of drainage services in farmed areas, linked to claims of reduced maintenance of water courses (by both farmers themselves and drainage organisations) which meant that excess water could not 'get away'.

Farmers generally accept a degree of flood risk. They recognised that the summer 2007 events were extreme. Therefore, very few anticipated a change in land use as a result. However, should the probability of flooding increase, especially in summer, farmers identified the need for improved preparedness and actions to reduce vulnerability, especially regarding the care of livestock.

The results presented here provide valuable insights into how flooding affects agriculture and can inform future priorities in policy development and research in flood risk management.

Acknowledgements

This paper is based on research jointly funded by the Economic and Social Research Council, and the Environment Agency. The assistance of Dr Suresh Surendran and Mr Adam Baylis of the Environment Agency and Prof. Philip Lowe, Director, Rural Economy and Land Use Programme are gratefully acknowledged.

References

ABC. *The agricultural budgeting & costing book*, 65th edition, Agro Business Consultants, Melton Mowbray, Leicestershire, 2007.

ADAS. *Impacts of 2007 summer floods on agriculture*. Cambridge: ADAS, 2008.

BPC. Potato plantings in Great Britain 2007 by variety, provisional estimates. British Potato Council, August 31, 2007. Available at http://www.potato.org.uk (accessed on 3 April 2009), 2007.

Burrow R. A review of the GB early potato market 2007. British Potato Council. Available at http://www.potato.org.uk (accessed on 19 May 2008), 2007.

Defra. *Making space for water: Developing a government strategy for flood and coastal erosion risk management in England. July 2004*. London: Defra, 2004a.

Defra. *Agricultural and farm Classification in the United Kingdom*. London: Defra, 2004b. Available at https://statistics.defra.gov.uk/esg/asd/fbs/reference/farm_classification.pdf (accessed on 3 April 2009).

Defra. *Agriculture in the UK 2007*. London: Defra, 2007. Available at https://statistics.defra.gov.uk/esg/publications/auk/2007/default.asp (accessed on 3 April 2009).

Hess T.M. & Morris J. Estimating the value of flood alleviation on agricultural grassland. *Agric Water Manage* 1988, **15**, 141–153.

Johnson C., Penning-Rowsell E. & Tapsell S. Aspiration and reality: flood policy, economic damages and the appraisal process. *Area* 2007, **39**, (2), 214–223.

Marsh T.J. & Hannaford J. *The summer 2007 floods in England and Wales – a hydrological appraisal*. Centre for Ecology and Hydrology, Wallingford, 2007, 32pp.

Morris J. & Wheater H. Catchment land use. In: C. Thorne, E. Evans & E. Penning-Rowsell, eds. *Future flood and coastal risk*. Telford, UK: Thomas, 2007, 64–80.

Morris J. & Hess T.M. Agricultural flood alleviation benefit assessment. A case study. *J Agric Econ* 1988, **39**, 402–412.

Nix J. *Farm management pocketbook*, 37th edition, Wye: Imperial College London, 2006.

Pivot J.M., Josien E. & Martin P. Farms adaptation to changes in flood risk: a management approach. *J Hydrol* 2002, **267**, 12–25.

Wilby R.L., Beven K.J. & Reynard N.S. Climate change and fluvial flood risk in the UK: more of the same? *Hydrol Processes* 2008, **22**, 2511–2523.