ESTIMATING ANNUAL AVERAGE DAMAGES (AAD) FOR AGRICULTURE: A HYPOTHETICAL CASE

1. Introduction

The preceding sections estimated the damage costs to agriculture of flooding, allowing for variations in land use and the seasonality and duration of flooding. This section considers the derivation of Annual Average Damages (AAD) for a given site and a given exposure to flooding.

For the purpose here, estimation involves the following steps:

- Derivation of agricultural flood damage costs (£/ha) by type of land use, seasonality and duration of event (as explained in earlier sections)
- Derivation of a flood probability: flood area relationship that, for a specified area exposure to flooding, shows areas inundated for given return period events, where the latter are described in terms of yearly intervals between floods of a given magnitude.
- Specification of land use type affected for each flood of a given magnitude
- Specification of duration of flooding where this is known to vary between events
- Derivation of total damage costs (£) per flood event
- Derivation of a flood damage : flood probability curve
- Derivation of Average Annual Damage (AAD) costs for Agriculture
- Sensitivity Analysis

The example draws on data from the Somerset Level and Moors but it is emphasised that the case is hypothetical and illustrative only and does not provide complete or robust predictions of AAD estimates for actual or predicted flood risk in Somerset. The various steps are considered in turn.

2. Agricultural damage costs

Table 1 contains estimates of flood damage costs (£/ha) for a single flood event occurring within a year for the study area, derived from earlier sections in 2014 prices, including an estimate of floods of over 6 weeks duration that are often associated with major flood events.

Table 1: Estimates of Agricultural Damage Cost (£/ha) based on Somerset L&M (Parrett Catchment)

Duration	less than 1 week	1 to 2 weeks	2 to 4 weeks	4 to 6 weeks	over 6 weeks
	£/ha	£/ha	£/ha	£/ha	£/ha
Grassland					
seasonal weighted	55	76	246	448	943
seasonal unweighted	91	130	477	833	1,100
Arable					
seasonal weighted	240	357	437	1,138	1,535
seasonal unweighted	510	591	711	1,211	1,700

3. Flood probability: flood area relationship

Estimates of flood areas were obtained for flood events by return period and were synthetically generated (Table 2) from information on catchment hydrology and observations of flood areas during recent flood event of estimated frequency, notably the 2012 (equivalent to the 1 in 15 year event) and 2013/14 events (equivalent to the 1 in 75 year event). Area estimates were derived for these events from aerial photography and satellite imagery (Environment Agency).[1]

There is a chance that some years will contain two or more floods, particularly for highly frequent events. To allow for this, it is assumed that for the 1 in 2 year return period event, there is a 35% chance of a single flood occurring in a given year and a 15% chance of more than one flood occurring in the same year, assumed here to be two floods for simplicity (Hess and Morris, 1988)[2]. Assuming the damage costs of multiple flooding are additive, (which is reasonable considering the use of weighted monthly costs) an uplift factor of 15% is applied to the initial estimate of 50% probability of flooding for the 1 in 2 year event. This gives, for the purpose of estimating damage costs, an equivalent 65% probability of a single flood for the 1 in 2 year event occurring in a given year ((0.35 x 1) + (0.15 x 2) = 0.65)). To allow for this, an uplift factor of +15% is applied to the estimates of costs for the 1 in 2 year event as explained below. The likelihood of multiple flooding for less frequent events is small and can be ignored for the purposes here.

[1] Estimates of flood frequency and areas were derived with the assistance of Jack Mason, Principal Engineer, Black and Veatch, Ltd

[2] For a discussion and example of deriving the probability of multiple flooding for the agricultural case see Hess, T.M. and Morris, J (1988). Estimating the Value of Flood Alleviation on Agricultural Grassland, Agricultural Water Management, 15, 141-153

Table 2: Flood areas by return period of flood event and land use

Return period (years)	total area flooded (ha)	% grass	% arable
2	400	100%	0%
5	800	100%	0%
10	1400	100%	0%
15	1750	97%	3%
25	6500	95%	5%
50	13000	90%	10%
75	16750	87%	13%
100	18500	85%	15%

4. Specification of land use type for each flood of a given magnitude

The types of land use, classified into grassland and arable, were derived for flood events and areas affected by overlaying satellite imagery of flooded areas with Land Cover Data (Countryside Survey, 2010), supported by Agricultural Area Statistics, Google Earth Maps and information from farm surveys (Table 2 above). The majority of the area is grassland. The proportion of arable within the flood area tends to increase for less frequent, larger magnitude flood events.

5. Duration of flooding

Estimates of duration of flooding were obtained for flood events from observations of the 2012 and 2013/14 flood events. Less frequent floods of greater magnitude in terms of area flooded tend to be associated with longer duration flooding.

Table 3: Duration of Flooding by Flood Event

Return period (years)	Percentage of flood area by flood period in weeks				
	less than 1 week	1 to 2 weeks	2 to 4 weeks	4 to 6 weeks	over 6 weeks
2	50	50	0	0	0
5	40	60	0	0	0
10	20	40	40	0	0
15	0	25	75	0	0
25	0	40	40	20	0
50	0	0	40	60	0
75	0	0	30	60	10
100	0	0	10	60	30

6. Derivation of total damage costs (£) per flood event

Estimates of damage costs for each return period event were derived for grassland and arable areas by multiplying areas flooded by average damage costs (£/ha), weighted by duration of flooding for each event. An uplift factor of +15% is applied to the estimates of costs for the 1 in 2 year event to allow for multiple flooding as explained above.

Table 4: Estimated Average Damage costs £/ha and Total Costs by flood event

Return period (years)	Grassland			Arable			All land
	areas (ha)	Av £/ha cost	event cost £'000	areas ha	Av £/ha cost	event cost (£'000)	Cost of flood event (£'000)
2	400	66	26	0		0	30*
5	800	68	54	0		0	54
10	1,400	140	196	0		0	196
15	1,697.5	204	345	52.5	417	22	367
25	6,175	218	1,349	325	545	177	1,526
50	11,700	367	4,296	1,300	858	1,11	5,411
75	14,572.5	437	6,367	2,177.5	967	2,10	8,473
100	15,725	576	9,062	2,775	1,187	3,29	12,356

*Includes increase of 15% to allow for multiple floods occurring in a year

7. Derivation of a flood damage: flood probability relationship

Estimates of the annual probability of flood events, expressed as a reciprocal of return period intervals, and their respective total damage costs were combined to derive a flood damage probability relationship (the first three columns of Table 5).

Table 5: Estimated flood event damage costs by return period of event

Return period (years)	Annual Probability	Event Damage costs £'000	Increment in Probability	Mean event damage (£'000)	Weighted event damage (£'000)	Cumulative damage (£'000)
1	1.000	0				
2	0.500	30	0.500	15	8	8
5	0.200	54	0.300	42	13	20
10	0.100	196	0.100	125	12	33
15	0.067	367	0.033	282	9	42
25	0.040	1,526	0.027	947	25	67
50	0.020	5,411	0.020	3,468	69	137

75	0.013	8,473	0.007	6,942	46	183
100	0.010	12,356	0.003	10,415	35	218
Sum: Average Annual Damage (AAD)				**218**		

The relationship can be expressed graphically as a damage cost: flood probability curve, drawn manually and/or derived by means of curve fitting functions in Excel (Figure 1). This type of curve is presented in Penning- Rowsell et al, (2013[3], page 61) as part of a four part diagram to assess annual average losses.

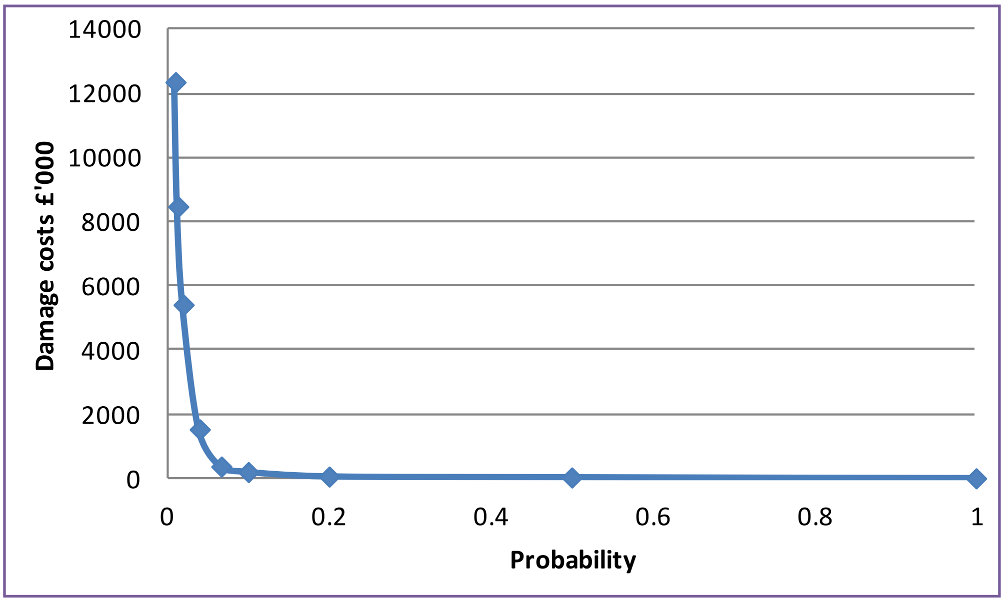

Figure 1: Flood damage: probability curve for the baseline case

8. Estimation of Average Annual Damage (AAD) costs for agriculture

If a long series of annual flood damages are available, average (or expected) annual damages can be calculated by adding up all the annual damages and dividing by the number of years. Such complete information is rarely available. In our case where flood damage costs are available for a limited number of flood events of assumed probability and magnitude (area flooded).

For practical purposes AAD can be estimated using the mid-range probability rule (Arnell, 1990)[4], applied to the points on the flood damage: probability curve and as shown in Table 5 (columns 4, 5 and 6) and Figure 2. Here:

Average Annual Damage = $\sum_{i=1}^{M-1} (p_i - p_{i+1}) ((D_{i+1} + D_i)/2)$

[3] Penning-Rowsell, E., Priest, S., Parker, D., Morris, J., Tunstall, S., Viavattene, C., Chatterton, J. and Owen D. (2013) Flood and Coastal Erosion Risk Management: A Manual for Economic Appraisal. Routledge: London.

[4] Arnell, N. (1990), Impact of hydrological uncertainties on design flood estimation and the assessment of the benefit s of flood alleviation. Report to MAFF. November 1990. Institute of Hydrology: Wallingford, UK.

where M is the number of pairs of data points, p_i is the exceedance probability for point i and D_i is the associated damage for point i. The precision of the estimate of AAD given by this method increases with the number of data points and the smoothness of the damage: probability function.

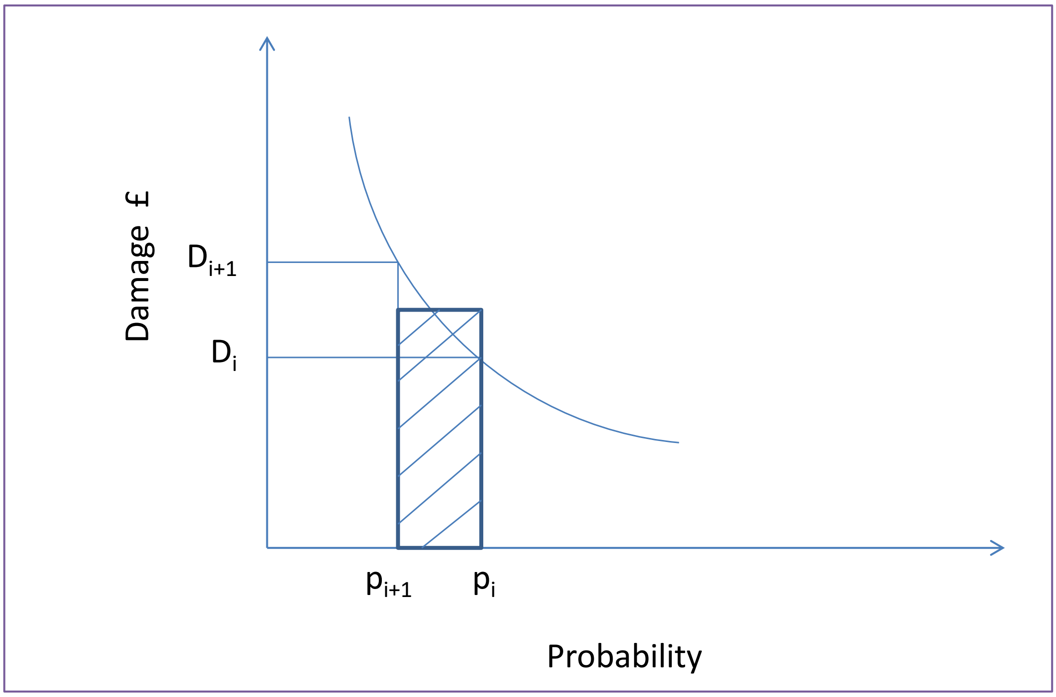

Figure 2: Estimating Average Annual Damage Costs using the mid-range probability rule (after Arnell, 1990)

AAD in Table 5, for the assumptions made for the baseline case, is £218,000 (in 2014 prices). In addition to the points made above, the estimation method here has a further possible source of error for the case concerned. There is some residual unaccounted risk associated with floods that occur less frequently than the limit of 100 years assumed here, for example associated with the 1 in 200 event and the 1 in 500 year event, and so on. These errors in estimation are not likely to exceed 10% of the initial estimate.[5] 10% has been added to the initial estimate of AAD as a default. Where these errors are likely to be important, a more detailed assessment may be required.

The estimate of AAD (Table 5) of £240,000 (£218,000 plus 10% estimation error) can be discounted at the appropriate discount rate and relevant period of years to derive a NPV. Thus, over a 50 year period at 3.5% discount rate, NPV equals £5.6 million (£240,000 x 23.5 annuity). Expressed per unit area over the whole 18,500 ha liable to flooding, AAD equate to £13/ha, with a NVP over 50 years of £304/ha.

The method can be used to explore the effect on AAD of factors such as increases in flood probability associated with climate or land use change. It can also be used to assess the reduction in AAD and associated NPV of agricultural damage costs associated with alternative flood risk management interventions, and hence the validity of investments to alleviate agricultural flood risk.

[5] Personal communication: Dr John Chatterton

9. Sensitivity analysis

The estimate of ADD is particularly sensitive to assumptions regarding the initial estimation of average annual flood damage costs (£/ha) by land use, seasonality and flood duration (as given in Table 1 and discussed earlier). If seasonally unweighted annual damage costs (£/ha) are used (from Table 1), AAD increases by about 70% to £407,000 and an NVP over 50 years at 3.5 % of £9.6 million (Table 6). Clearly assumptions about the seasonal distribution of flooding are important in the agricultural case

AAD is particularly sensitive to assumptions about flood probabilities and associated flood areas, the distribution of land use within the flooded areas, and the duration of flood events as these might vary between floods of different frequencies. The effect on AAD of uncertainties in the original estimates of damage (£/ha) and predicted changes in the flood probability: flood area relationships, perhaps attributable to climate or land use land use change, can be explored.

Everything else remaining constant, changes in the probability of flood events of a given magnitude have a proportionate effect on AAD: a doubling of flood probabilities, whereby the 100 year flood becomes 50 year flood, the 50 year flood becomes 25 year flood, and so on, doubles the estimate of AAD (everything else remaining the same). The same consideration applies to increases in the area flooded for each event of a given probability. The approach can be used to assess possible changes in flood return period and areas flooded (Table 2) attributable to changes in climate and catchment hydrology.

AAD is sensitive to assumptions about the duration of flooding for each flood event (Table 6). The estimate of AAD decreases by 40% to £91,000 if it is assumed that all floods have a duration of between 1 and 2 weeks instead of the range of durations observed. In the agricultural case, interventions that reduce the duration of flooding can have a strong effect on AAD.

AAD is sensitive to the distribution of land use in the flood areas (Table 6). In this case, given the relatively small proportion of land given to arable cropping, the absence of arable cropping in the flood area would reduce AAD only by about 6%; a 50% increase in the arable area in flood areas known to contain arable would increase AAD by about 15%. AAD would be much higher if all land were occupied by arable rather than grassland, but this is unlikely given the constraints imposed by relatively low standards of agricultural drainage in the area.

Table 6: Sensitivity analysis changes in AAD relative to the baseline estimate

Seasonal weighting of floods	**Equal monthly probability of flooding throughout the year**		
AAD £'000*	407 (+70%)		
Duration of flood events	Flooding 1 to 2 weeks only	Flooding 2 to 4 weeks only	Flooding 4 to 6 weeks
AAD £'000*	91 (-60%)	261(+15%)	490(+116%)
Proportion of arable crops	Zero arable across all flood areas	Increase in arable area by 50% in flood areas where already arable exists	All arable :100% of total area (For illustration only, arable is constrained by field drainage conditions as well as flood risk)
AAD £'000*	218 (-6%)	261 (+15%)	561 (+147%)

*AAD Baseline £240,000, figures in parenthesis show % change in AAD from baseline estimate

10. Closing remarks

The above case illustrates the derivation of AAD for the agricultural case, using a hypothetical case of mainly extensively farmed grassland. While it draws on data and evidence from the Somerset Levels and Moors, it is not intended to, nor does it, provide robust estimates of AAD that can be used beyond the purpose of illustration here.