A NATIONAL ECONOMIC APPRAISAL OF THE IMPACTS FLOODING AND COASTAL EROSION CONSIDERING THE POTENTIAL IMPACTS OF CLIMATE CHANGE

ROBERT DEAKIN and KEVIN BURGESS
Halcrow Group Ltd
Dr PAUL SAMUELS and PAUL SAYERS
HR Wallingford Ltd
Dr JOHN CHATTERTON
JB Chatterton & Associates

ABSTRACT

Research commissioned by MAFF has examined different scenarios of defence standard provision at a national level. This work has been used to assist in policy formulation with regard to defining Government spending levels on the provision of flood and coast defence. The MAFF report "National Appraisal of Assets at Risk from Flooding and Coastal Erosion" (MAFF, 2000) details the findings of this research.

A second phase of research has now been commissioned to refine the analysis techniques employed, improve our knowledge of actual standards of service and to examine the potential influence of climate change on the economic impacts of flood and erosion damage. By being able to better spatially resolve areas susceptible to greatest economic loss the research is intended to better inform decisions taken on investment in defences. This paper sets out details of the methods introduced to assess the economic impacts under climate change scenarios and those used to examine the economic impacts on agriculture.

Preliminary results are presented for the calculated economic impacts of climate change on built property damages, and of those to agriculture in respect of foregone production under a "Do Nothing" flood defence management strategy. Further information will be made available at the conference and in the succeeding paper.

1 INTRODUCTION

Research commissioned by MAFF in 1999 – 2000, under the National Appraisal of Assets at Risk from Flooding and Coastal Erosion project, set out with following objectives:

- gather information on the extent of the areas at risk and the assets in those areas,
- update and improve the 1997 Comprehensive Spending Review (CSR) valuation of the risks,
- consider a range of scenarios for future investment, and
- to recommend potential future improvements to the analysis.

The summary results it produced were that:

- the value of the assets at risk is approximately £214 Billion,
- the potential annual average damages (without defences) are about £2.8 Billion,
- the current annual average damages are about £600 Million, and
- the current capital expenditure on asset renewals could be about half that required to maintain current standards.

(Burgess K A, et al 2000)

Recommendations for further research made at the conclusion of that first phase of study were that:

- the research be extended into the area covered by the Welsh Region of the Environment Agency, so as to provide full national coverage of the research within England and Wales,
- additional research be undertaken within the English EA regions to try to improve our knowledge of current flood defence standards,
- the effects of climate change on flood frequency and economic damages be incorporated into tidal and fluvial flood scenarios,
- methodologies formulated for examining the economic impacts of flooding on agricultural production and road traffic disruption be put into practice to enable additional components of economic damages to be brought into the national benefit / cost assessment.

Though at the time of writing the above research is not yet fully concluded preliminary results can be reported for the climate change impacts and the potential agricultural losses through foregone production.

2 CLIMATE CHANGE SCENARIOS

The main basis for establishing the potential impacts of predicted future climate change on flood frequency and flood damage has been to assume deterioration in current standards of service relative to increases in peak river flow, tidal water levels and predicted changes in wave characteristics. Combined with these effective reductions in standard of service (SOS), work has also been undertaken to re-evaluate increases in typical flood damage cost estimates associated with given return period events.

Establishing the future climate

Of key influence to the study findings has been the choice of climate change scenario and Global Climate Model (GCM) used to predict the associated changes in the fluvial and tidal environments. There are a large number of different GCM's and also Regional Climate Models. The main purpose of developing and using such models has been to investigate the effects of global warming by introducing increased 'greenhouse gas' concentrations.

The Intergovernmental Panel on Climate Change (IPCC) established a Task Group on scenarios for Climate Impact Assessments. This group established criteria to identify GCM experiments whose results could be deposited at the IPCC Data Distribution Centre (DDC). The UK Hadley Centre for Climate Predictions and Research (HADCM2) and the MAX Planck Institute for Meteorology (Hamburg) (ECHAM4) are two modelling centres that meet the IPCC requirements and are commonly used in climate change studies carried out in Europe. The use of results from both of these models was considered within this project.

The Tidal Scenario

For the purposes of this study the ECHAM4 model was chosen to simulate climate change within the tidal environment as it has been shown to simulate higher wind speeds well in coastal locations. In addition, HR Wallingford is currently working on another MAFF funded project 'Coastal Defence Vulnerability 2075' that uses data from the ECHAM4 Global Climate Model and maintaining consistency in approach between the two studies was an important consideration.

The data provided by the Coastal Defence Vulnerability 2075 project consists of two, 30-year time blocks: one representing the present day, one representing the future. The data consist of wind speeds and water levels at 6-hourly intervals and is available for five different locations around the UK: offshore of Mablethorpe, Dungeness, Lyme Bay, Swansea Bay and Blackpool.

The thirty-year time series' of wind data were transformed to wave data and have then been combined with the water level data before running through HR's JOIN-SEA software. JOIN-SEA is joint probability software that uses a monte-carlo simulation technique to generate many (10,000) years worth of wave and water level data, on which extremes analyses can be carried out.

In summary, 10,000 years worth of wave and water level data have been generated based on present day conditions and 10,000 years worth of data based on future conditions, at each of the five locations around the UK.

The Fluvial Scenario

GCMs operate at spatial and temporal scales which are greater than the extent of any UK catchment or the typical duration of a flood. In addition the GCM simulations differ according to the exact model being used such as the HADCM2 or the ECHAM4 models of the Hadley Centre and the Max Plank Institute respectively.

In order to generate future scenarios of flood discharge directly, a methodology is needed to generate point rainfall and other appropriate meteorological time series for future climate scenarios based upon historic records at the site and scenario predictions from a GCM. There are several approaches possible including:

- generation of precipitation series from historic series but adjusted to match broad scenario statistics from the GCM
- the use of stochastic weather generators based upon the broad data from GCM scenarios
- statistical Expanded Downscaling (EDS) to produce future scenarios at particular weater stations, see Bürger (2000),
- the use of regional climate models (RCMs) at a substantially finer scale than the GCM

There have been many research studies over the past decade covering the potential impacts of climate change on river flood frequency in the UK see for example Naden *et al* (1996) and Calver *et al* (1999).

In determining the impacts of climate change upon flood extent and thus risk, key parts of the process are:

- the change in precipitation – by annual amount, seasonally, number of storms, intensity of rainfall etc
- the response of parts of the hydrological cycle to climate changes – vegetation, evapotranspiration, soil moisture
- the response of the river and flood plain system
- the vulnerability of land use and occupation to flood damage (and trends in these).

All of these factors contain considerable uncertainty and currently, there is no scientific consensus on the best resolution of all the technical issues in assessing the impact of climate change on the frequency of the extent of flooding. The EUROTAS project (Samuels, 2001) demonstrated the feasibility of continuous simulation hydrological modelling coupled to river modelling using a GIS framework with down-scaled GCM information at the catchment scale. However, within the context of the current project it was not appropriate to embark upon a simulation exercise of all UK catchments, or even a selection of catchments in each geographical region and an alternative approach was devised.

Rather than tying the economic assessments to specific climate simulations from a particular GCM and emission scenario, the sensitivity of the national economic assessment of flood damages was based upon broad scenarios of increases in regional flood discharge. These are expressed as percentage change from the “current” condition, without reference to a specific GCM, emission scenario or decade of assessment.

The regional information across the UK is taken from the Flood Studies Report (FSR) (NERC, 1975) and the supplementary report series. The information in the Flood Estimation Handbook (CEH, 2000), whilst being more recent is based upon flood frequency in specific catchments rather than in broad geographical regions. A particular advantage of the FSR is that the regional information is still closely aligned with the Environment Agency regional boundaries, which form the basis of the regional assessment in the current economic appraisal.

The following assumptions are made
- that flood peak discharge is an appropriate measure of the hazard
- that peak flood discharge increases proportionately for all return periods (that is the shape of the regional growth curve is unaffected by climate change)
- that there are no large-scale river changes which affect the stage-discharge relationship at the catchment scale
- that the performance of flood defence infrastructure, and hence damage, is related to the value of peak discharge

The information used in the flood damage assessments relates flood damage to the current return period of the flood. Thus to simplify the use of the tabulated of damages, the future frequency of current flood return periods was assessed, for example, by determining the future return period of the current 100 year flow in the Anglian region. A methodology was developed to provide a future return period for any current return period in any FSR region, for percentage changes in flood flow from –10% to + 25%.

Results for Annual Average Damage (AAD) to built property within the fluvial floodplain were calculated under 10% and 20% increases in flood flow. This has allowed a comparison of the sensitivity to increases in flows to AAD in each of the EA Regions.

3 CHANGES TO STANDARDS OF SERVICE

Coastal response function and standard of service

For the purposes of this project the SOS has been directly related to the change in the return period of specified overtopping rates. This rate has been chosen as the coastal response variable most appropriate to characterise SOS, as it is closely linked to breach probability, is relatively well understood and is influenced by both water levels and wave conditions.

Overtopping performance however, is dependent on structure type. Therefore, three ‘typical’ structure types have been identified that can be readily incorporated at a national scale using the existing EA data. These types are:

- Vertical sea walls
- Embankments

- Shingle beaches

Overtopping rates have been calculated for the three structure types using well-established empirical methods developed by HR and described in EA (1999). These empirical methods require wave conditions at the toe of the structure to be specified. The formulae are based on the maximum wave height 'allowable' in a specified water depth. The wave height is then calculated as a function of water depth. This simplified approach has been adopted for use in this study, where many thousands of wave transformation calculations are required.

Use of the simplified approach requires the water depth at the structure toe to be specified. This decision is critical when assessing the coastal defence response to future climate.
A consistent, but arbitrary, method has been devised for specifying the toe and crest levels for the three different structure types. 'Typical' structure type/ toe level combinations have been considered when defining these levels, however, it is acknowledged that many and wide variations on the specified 'typical' structures will exist around the coast of the UK. This kind of broad assumption is necessary and consistent with the methodology adopted in other aspects of this project.

Tables 3.1 to 3.3 describe the calculated reductions in Current Standard of Service for the three typical structure types defined within the study.

Vertical Wall	**2075 Standard**				
Present Standard	**East Coast**	**South East Coast**	**South West Coast**	**Bristol Channel**	**North West**
2	<2	<2	<2	<2	<2
5	<2	<2	<2	<2	<2
10	2	<2	<2	<2	2
20	3	<2	5	<2	3
50	10	2	15	2	10
100	15	4	40	3	20
200	40	10	100	10	30

Table 3.1 Reduced SOS for vertical walls

Embankment	**2075 Standard**				
Present Standard	**East Coast**	**South East Coast**	**South West Coast**	**Bristol Channel**	**North West**
2	<2	<2	<2	<2	<2
5	2	<2	<2	<2	<2
10	3	<2	<2	2	2
20	5	<2	3	3	3
50	10	2	15	5	10
100	25	3	40	10	20
200	70	5	80	15	60

Table 3.2 Reduced SOS for embankments

Shingle Beach	2075 Standard				
Present Standard	East Coast	South East Coast	South West Coast	Bristol Channel	North West
2	<2	<2	<2	<2	<2
5	2	<2	<2	<2	<2
10	3	<2	<2	2	2
20	5	<2	3	3	3
50	10	2	15	5	10
100	30	3	40	15	20
200	80	5	80	20	50

Table 3.3 Reduced SOS for shingle beaches

Regional Changes to Fluvial Standards of Service
The future return period associated with the current 100-year flood for a uniform 20% increase in peak discharge is shown in Figure 3.1. Considerable regional variation is evident with the influence being least in Anglian region and greatest in Ireland.

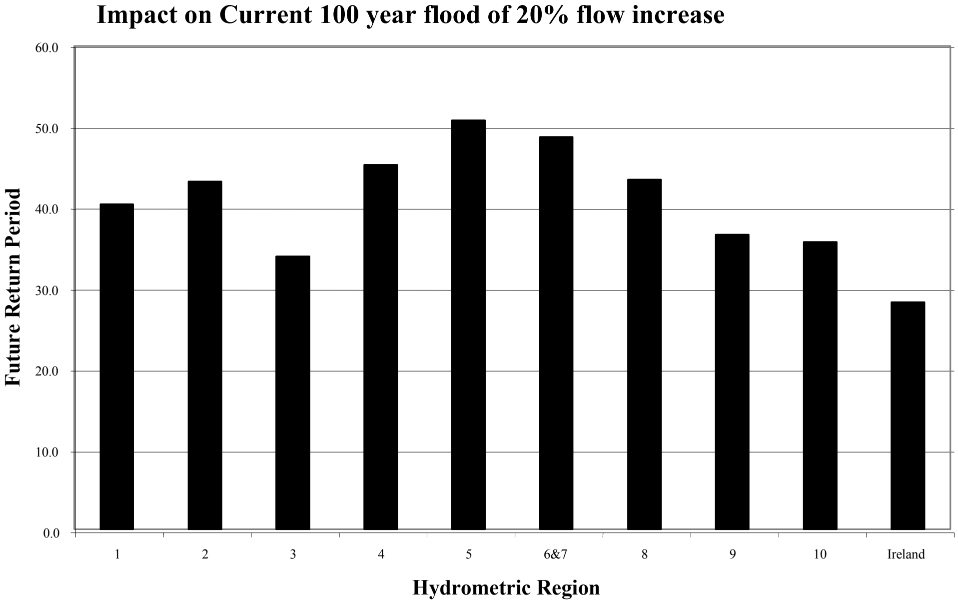

Figure 3.1 Illustration of the effect of climate change on river flow

These results were used in each region with 10% and 20% flood discharge increase scenarios. The figure of 20% is broadly in line with the scenarios of increase in winter precipitation by the 2080's for the current UKCIP studies (Hulme & Jenkins, 1998) and appears as an illustrative assessment scenario in the new PPG 25 on development and flood risk (DETR, 2001). The study reported by Naden *et al* (1996) indicated increases of about 10% for the Rivers Severn, Thames and Trent for the 50-year flood by the 2050's, based upon one of the earlier 1992 Hadley Centre GCM scenarios.

Interpreting these flood flow increases in terms of regional reductions in SOS the following results have been obtained:

	Reduced SOS						
Current SOS	Anglian	Midlands	North East	North West	Southern & Thames	South West	Wales
5	3.9	3.5	3.3	3.2	3.8	3.4	3.4
10	7.6	6.8	6.3	6.2	7.4	6.7	6.5
25	18	17	15	15	18	16	15
50	36	33	29	29	35	32	30
100	70	65	56	57	68	64	58
200	137	130	109	113	133	126	114

Table 3.4 Region reduction in SOS under 10% fluvial flood flow increase

	Reduced SOS						
Current SOS	Anglian	Midlands	North East	North West	Southern & Thames	South West	Wales
5	3.2	2.6	2.5	2.3	3.1	2.6	2.5
10	5.9	4.9	4.3	4.2	5.7	4.8	4.5
25	14	12	9.6	9.6	13	11	10
50	26	23	18	18	25	22	19
100	50	44	33	35	48	43	36
200	96	87	63	68	91.65	83	69

Table 3.5 Region reduction in SOS under 20% fluvial flood flow increase

4 BUILT PROPERTY DAMAGE INCREASE

By applying the reduced standards of service outlined in tables 3.1 to 3.5 to the asset database built-up during the previous phase of the study it was possible re-calculate the Annual Average Damages. The results provide an estimation of AAD for tidal flooding under the 2075 climate change scenario, and for fluvial flooding under 10% and 20% flood flow increases.

The AAD values calculated assume that defence structures remain physically unchanged e.g. where crest levels are currently sufficient to defend against 1 in 50 years events now, that same crest height may in 2075 only represent adequate defence against a 1 in 25 year event. Tables 4.1 and 4.2 show the comparison of AAD values. (All £ values are in millions.). It should be emphasised that in practice it is likely to be well worthwhile to mitigate such increases in damage through additional defence works or other flood management activities. Some of this mitigation is already recommended in MAFF guidance and this amply illustrates the potential benefits of adopting such a precautionary approach.

Tidal AAD (£m)	Current AAD	2075 AAD	% of current AAD
Region			
Anglian	£21.49	£71.41	332
Midlands	£4.05	£31.39	775
North East	£60.64	£252.23	416
North West	£18.78	£76.16	405
Lower Thames	£36.94	£163.67	443
Southern	£43.79	£285.00	651
South West	£10.30	£59.45	577

Table 4.1 Predicted increase in AAD for tidal flood areas

Fluvial AAD	Current AAD	Predicted AAD		% of current AAD	
Region	(£ million)	10% Flood Flow Increase	20% Flood Flow Increase	10% flood flow increase	20% flood flow increase
Anglian	£55.02	£78.16	£111.70	142	203
Midlands	£50.23	£69.04	£98.52	137	196
North East	£47.29	£90.81	£111.70	192	236
North West	£19.22	£34.03	£45.05	177	234
Thames	£201.26	£213.83	£227.18	106	113
Southern	£15.51	£19.65	£25.71	127	166
South West	£28.90	£35.49	£44.06	123	152

Table 4.2 Predicted increase in AAD for fluvial flood areas

5 FOREGONE AGRICULTURAL PRODUCTION

Separate to the work on damages to built property the study has also examined the potential economic impacts caused by flooding through foregone opportunities to agriculture. The approach taken was to establish a model of deterioration in the gross margin of production. This decline in gross margin is associated with a change in the agricultural production system from one of high to lower yields brought about through the abandonment of drainage and flood defence maintenance. Four basic management systems have been modelled, and these are detailed in table 5.1.

Unimproved/ rough permanent pasture	**Improved pasture**	**Arable system**	**Root System**	**Land use as reflected by current SoS**
n/a	n/a	n/a	n/a	Improved System
Beef system	Dairy	Arable	Roots	Current system
Reduced stocking	Reduced stocking	Lower yield arable	Arable	Intermediate deterioration
Rough grazing of store cattle	Rough grazing of store cattle	Rough grazing of Store cattle	Lower yield arable	Deterioration complete

Table 5.1 Decline path for 4 main land management systems associated with a “Do Nothing” management policy.

The model effectively represents the losses accrued through a “Do Nothing” management scenario, and the losses have been calculated as Mean Annual Average Damages incurred over a 10 and 20 year period of decline in land management systems. The model has been applied initially to both coastal and fluvial floodplains

Typical Land Management Systems and Gross Margins for the selected scenarios

In discussion with agricultural economists, the following land management scenarios have been deduced as representative of English/Welsh agriculture with respect to existing and deteriorating standards of service. It is fairly assumed that the existing land use within flood plains, as ascertained from the York/Cardiff MAFF June 4th agricultural statistics reflects the SOS currently provided. Any deterioration of this SOS will result in commensurate changes in land management systems. Table 5.2 summarises the adjusted gross margins for each land management system. Adjusted gross margins (i.e. gross margins adjusted by the appropriate factors to be applied to gross output to allow for domestic support costs) are calculated in line with the FCDPAG3 Scenario 3 – Partial loss of agricultural output.

However, for simplicity the gross margins are not converted to net margins by deducting changes in fixed costs at farm level through changes in the land management system. The fixed costs structures of farms are assumed not to be affected, though this would certainly not be the case in particularly large fenland farms, where cereal production deteriorates to extensive pasture. It is difficult to isolate differential fixed costs at this level of generality, and using Nix whole farm fixed costs and applying these to the changed management systems assumed distorts the analysis. In any case, as domestic subsidy has been subtracted from the gross output to simulate economic gross margins as against farm gate prices, fixed costs would have to be adjusted to give their equivalent economic values.

Unimproved/ rough permanent pasture	**Improved pasture**	**Arable system**	**Root System**	**Land use as reflected by current SoS**
As current	As current	As current	As current	Improved System
Single lowland sucklers (£210)	Dairy (£876) or 18 month beef (£338) (1a)	Arable rotation (2) (£448) Fens (£725)	Potatoes (£1,833) (3)	Current system
Single lowland sucklers (£135)	Dairy (£786) or 18 month beef (£172) (1b)	Arable rotation (£282) Fens (£348)	Arable rotation (2) (£448) Fens (£725)	Intermediate deterioration
Beef Stores summer finishing (£60)	Beef Stores summer finishing (£60)	Beef Stores summer finishing (£60)	Arable rotation (£282) Fens (£348)	Deterioration complete

Notes: (1a) Mean value £607; (1b) Mean value £479. (2) Arable default is 4 years Winter Wheat (£ 446); 1 Winter Oilseed Rape (£456). If East Anglia 4 years WW (£446); 1 Spring barley (£361); 1 potatoes (£,2205)
(3) Mean of average and high yields

Table 5.2 Land use management systems and gross margins (£/hectare) (Nix 1999)

Resultant Loses

Using production statistic from MAFF's 1999 agricultural census it was possible combine current production values, gross margins and SOS values within the study GIS database. Using this information to calculate declining productivity over 10 and 20 year periods of decline the following economic losses have been calculated as Mean AAD values.

	Foregone Agricultural Production		
Region	**10 year decay**	**20 year decay**	**Built Property AAD**
Anglian	£247.7	£215.4	£364.6
Midlands	£67.9	£59.2	£367.7
North East	£82.7	£72.3	£484.3
North West	£29.6	£26.1	£195.5
South West	£32.4	£28.5	£152.1

Table 5.3 Foregone agricultural production as Mean AAD value (£ million).

6 CONCLUSIONS

This research project has yet to run its full course, though at the time of the conference final results will be reported. Results remain outstanding for the Welsh EA Region and for some aspects of the agricultural and traffic disruption analysis. Further refinements also have to be put into place in the reporting of AAD to built property. However even with these final details outstanding it is possible to gauge the order of magnitude that the impacts of climate change could have on the increased potential for flood damage.

Within tidal floodplains, using the assumptions that have been made in typifying flood defence structures into three generic types, we can observe a scenario that sees a dramatic reduction in effective standards of service associated with the 2075 climate change prediction. All regions show significant reductions in standards. Translating these to AAD values produces a 3 to 8 fold increase in all regions.

Increases in fluvial flood flows can be seen to reduce effective standards by around 75% and 50% of their current standard for a 10% increase. For a 20% increase in flood flow this reduction is greater, to around 50% to 30% of current standards. Damages also rise, but proportionally are much less than those seen for tidal areas. As examples of the two extremes in fluvial regions, Thames Region AAD increases only by between 6% and 13%, whereas the increase in the North East is between 92% and 136%.

Table 5.3 compares foregone agricultural losses with “Do Nothing” AAD’s for built property. Not surprisingly it shows Anglian Region, which contains most of the Grade 1 agricultural land in the UK, suffering damages to property and agricultural production at the same order of magnitude. For all other regions the damages sustained through foregone agriculture is one order of magnitude below that for built property.

The work undertaken in the previous phase of this study highlighted the need to increase levels of spending on the provision of flood defences in order to maintain current standards of service. Results so far generated within this follow-on study indicate that potential further losses due to climate change are indeed potentially large. From a strategic point of view this provides ample support for the current recommended system of precautionary allowances. In the longer term further consideration needs to be given to improving the basis of these allowances and determining how the significant improvements in current standards that are lilkely to be required to mitigate against increased flood risk arising from climate change can most effectively be achieved.

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