River Flooding and the Grid-to-Grid Hydrological Model

Summary of Impacts

Impact	Value	
Mitigating the annual costs of damage from 'ordinary' river flooding	£24m per annum	+ £2-3m per annum under climate change scenarios
Mitigating the costs of damage from extreme river flooding events	£130m per extreme event	+ £23-39m per extreme event under climate change scenarios
Efficiency savings in constructing future flood defences over the next 25 years	Net Present Value of £19 million	

Summary of Key Points

- The Grid-to-Grid hydrological model is a tool developed by the Centre for Ecology and Hydrology (CEH) for translating rainfall into river flows to predict potential river flooding. Intensive work on the Grid-to-Grid project began in 2002 at CEH and continues today in collaboration with the Environment Agency (EA). Total NERC investment in the project (via CEH) is estimated at £1.2 million with additional funding provided by other organisations.

- Existing regional hydrological models did not have the capability to make maximum use of high-resolution rainfall forecasts since they are based on large geographical areas draining to a location where river flow is measured**. The Grid-to-Grid model is configured on a 1km^2 grid, so can take better account of the location and intensity of rainfall forecast by high-resolution weather models allowing for very targeted river flood warnings.**

- The Pitt Review on the 2007 summer floods highlighted the need for improved flood forecasting. In particular, it called for greater joint working between the Environment Agency and the Met Office to incorporate advances in high-resolution weather forecasting modelling into the EA's hydrological flood forecasting models. Work is now on-going to put the Grid-to-Grid Model into operation within the Environment Agency

- One of the immediate uses for the river flow forecasts produced by the Grid-to-Grid Model is in the 5 Day Flood Guidance Statements issued by the Flood Forecasting Centre. The Environment Agency's regional models can typically forecast up to 2 days ahead - **Grid-to-Grid will improve and extend this capability at a national level up to 5 days ahead.** Evidence shows that increased lead times for predicting flooding events reduces damages to property and infrastructure because people can move their belongings and flood defences can be erected.

- The Grid-to-Grid Model can also be used to forecast how peak river flows may change in different parts of the country due to climate change. It is still early days for this application of the Grid-to-Grid Model but it could significantly improve guidance on flood protection for new developments and help ensure that public resources for flood defences are directed to where they are most needed.

Introduction

This case study considers the impact of research at the **Centre for Ecology and Hydrology (CEH)** which has led to the development of a new national flood forecasting tool – **the Grid-to-Grid (G2G) Model**[1]. The Centre for Ecology and Hydrology is one of NERC's wholly owned research centres.

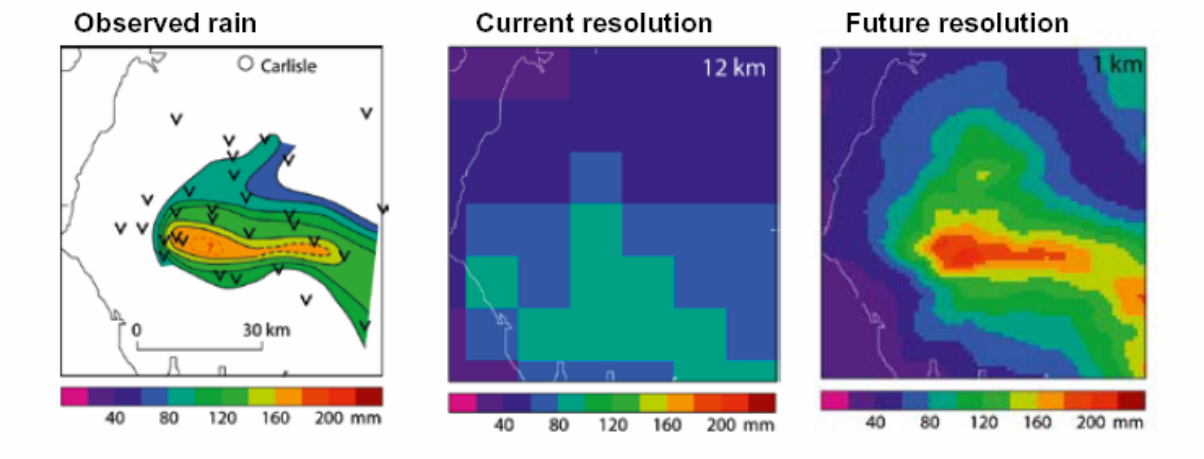
Intensive work on the Grid-to-Grid project began in 2002 at CEH. This work continues today in collaboration with the Environment Agency (EA). Total NERC investment in the project (via CEH) is estimated at £1.2 million (approximately £150,000 per annum during the development period) with additional funding provided by other organisations such as the EA, the Department for the Environment, Food and Rural Affairs (Defra) and the Met Office.

The Pitt Review: Lessons Learned from the 2007 Floods

The floods that struck much of the UK during June and July 2007 constituted the most serious inland flooding since 1947. The Government commissioned Sir Michael Pitt to undertake an independent review of lessons to be learned from the 2007 floods.[2] One of the major recommendations from the Review was the need for a step-change in the quality of flood warnings. In particular, the Pitt Review highlighted the crucial role of weather forecasting in flood forecasting. It said there must be greater joint working between the Environment Agency and the Met Office to improve national capability in modelling, forecasting and warning against flooding.

The resolution of weather models and the future period over which they predict determines the accuracy and timeliness of forecasts. At the time of the 2007 floods, the Met Office performed most of its operations at a 12.5km resolution for Europe (ie. a grid-box size of 12.5km^2), complemented by a 4km model over the UK. The Pitt Review highlighted that investment in a new high-performance super-computer at the Met Office would mean it would shortly be able to operate a high-resolution weather model (at 1.5 km^2) over the UK. The enhancement in rainfall forecasting capability with this high-resolution weather model is apparent in Figure 1. This shows how accurate this model would have been during the 2005 Carlisle floods if it had been available, compared to the 12.5km^2 model which was in use at the time.

Figure 1: Improved Resolution in Weather Models, example Carlisle (Source: The Pitt Review)



[1] This report was produced for NERC by DTZ, a private consultancy. It does not necessarily reflect NERC's opinions and policies.

[2] Sir Michael Pitt (2008), Learning Lessons from the 2007 Floods.

The Pitt Review also highlighted that a further planned upgrade of Met Office computing power in the near future would allow an ensemble of weather forecasts to be developed. Instead of running a single model with one set of initial conditions, ensemble forecasting involves running different models that start with slightly different initial conditions to reflect levels of uncertainty. If the ensemble produces a set of forecasts which are fairly similar, there can be a high degree of confidence that the forecast will reflect reality. If it produces a wide range of different weather scenarios then the forecast is less certain. The ensembles therefore give an indication of the most likely scenario and the worse-case scenario.

Also highlighted was the significant benefits that could be realised by integrating these weather forecasting developments into flood forecasting:

- **Longer Lead Times** – At the time of the 2007 flooding, the Environment's Agency's Customer Charter Standard was to provide flood warnings at least two hours ahead of potential river flooding, although prior to 2007 many places already received a flood warning service with longer lead times. Consultees told the review that considerably more warning time than this was required to allow for deployment of temporary flood protection measures and the evacuation of people and property. Evidence shows that increased lead times for predicting flooding events are directly related to reductions in the damage caused to property and infrastructure.[3]

- **Probabilistic forecasting** – The implementation of ensemble modelling should enable the most likely and the most extreme flooding scenarios to be identified and shared with emergency responders to facilitate better preparedness.

- **More accurate local-scale forecasts –** Enhancements to the resolution of weather forecasting models should enable more accurate local-scale flooding warnings in the future.

Thus, a key recommendation from the Pitt Review was that a new national Environment Agency / Met Office Flood Forecasting Centre should be established to realise these benefits. This recommendation has been implemented and on 1 April 2009 the new national **Flood Forecasting Centre (FFC)** was established.

FLOODFORECASTINGCENTRE

a working partnership between Environment Agency | Met Office

Use of the Grid-to-Grid Model to Improve National Flood Forecasting

One of the first challenges for the FFC was how to integrate advances in weather forecasting (as outlined above) into the hydrological models used within the Environment Agency for flood forecasting. The current hydrological models used by the Environment Agency do not have the capability to make effective use of high-resolution rainfall forecasts since they tend to be applied across larger geographical areas that drain to locations where river flow is measured by Environment Agency monitoring stations.

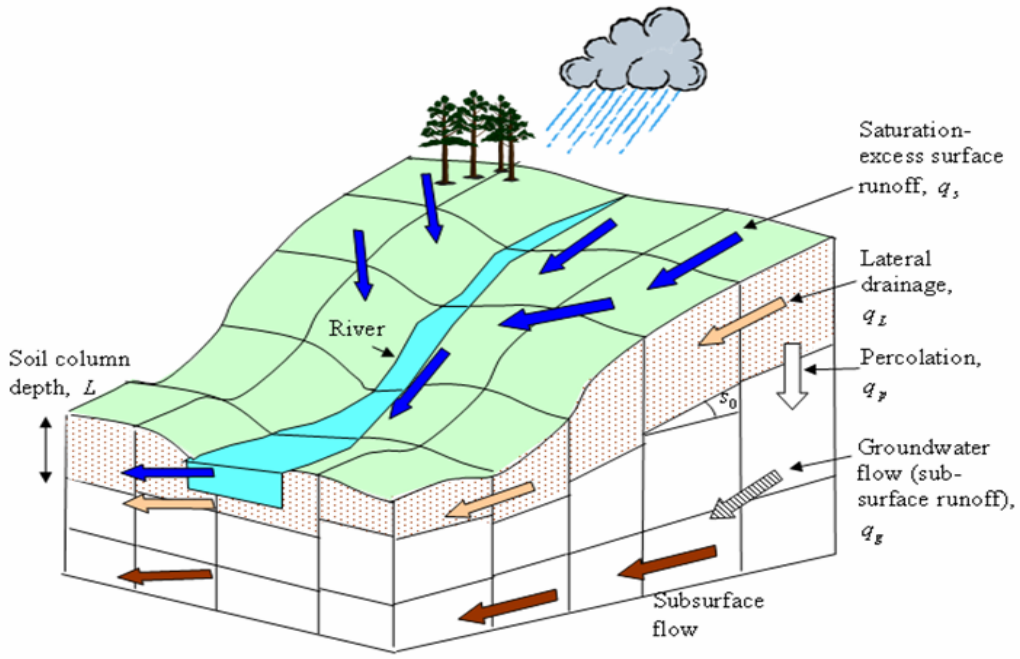
Fortunately, the scientific research programme at CEH had been exploring new approaches to area-wide flood forecasting for many years. Also, under NERC's **FREE Programme (Flood Risk from Extreme Events)**, CEH was both assessing the value of new high-resolution weather model rainfall

[3] Sir Michael Pitt (2008), Learning Lessons from the 2007 Floods.

forecasts for flood warning and developing, for the first time, methods of river flow data assimilation to improve the accuracy of the Grid-to-Grid Model flood forecasts in real-time.

Thus, at the time of the Pitt Review in 2008, CEH was at an advanced stage in developing a new 'distributed' approach to hydrological forecasting, due to the intensive work that began on the Grid-to-Grid Model in 2002. This approach uses a 1km^2 model grid with the model configuration across the country underpinned by digital spatial datasets on topography, soil/geology and land cover. In real-time, data is fed into the model from the Environment Agency's telemetry systems (rain and river flow gauges) and Met Office rainfall forecasts to provide indicative flood estimates. The Grid-to-Grid Model calculates the runoff from each grid square, which is then routed into the next downhill grid square, and so on, down to the bottom of the catchment: the model converts rainfall into river runoff and river flows. Surface and sub-surface runoff and lateral water movements in the soil are accounted for (see Figure 2).

Figure 2: The Grid-to-Grid Model Structure (Source: CEH)



As explained above, one of the immediate priorities for the Environment Agency following the Pitt Review was to find a way of incorporating high resolution weather model rainfall forecasts from the Met Office into its hydrological models to improve flood forecasting. Fortunately, an Environment Agency research contract was already underway investigating the capability of three hydrological modelling concepts to meet this brief, one of which was the CEH Grid-to-Grid Model. The project was undertaken for the Environment Agency by Deltares (who provide support to the National Flood Forecasting System operated by the Environment Agency) in collaboration with CEH.[4]

The project reported in March 2010. The conclusion was that the Grid-to-Grid Model performed well and should become part of the Flood Forecasting Centre's development programme and be incorporated into the National Flood Forecasting System, alongside current regional flood forecasting

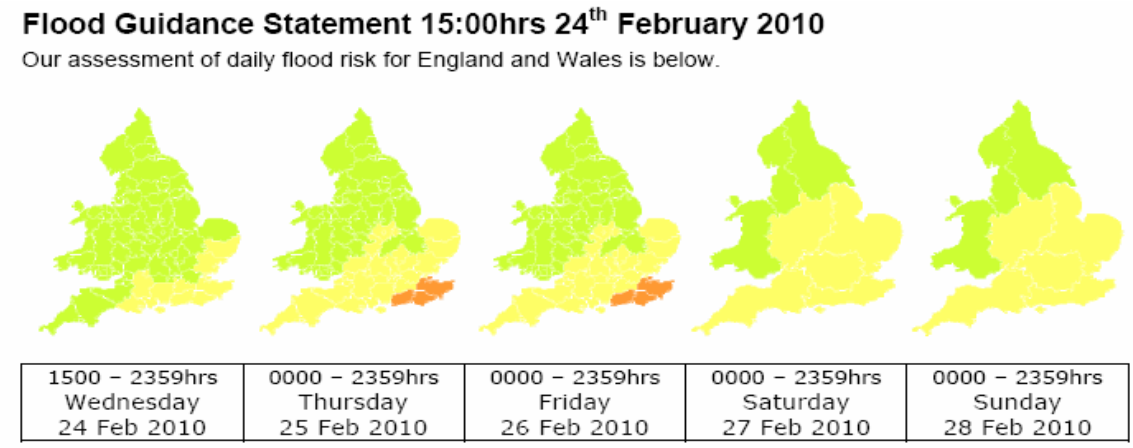
[4] http://publications.environment-agency.gov.uk/pdf/SCHO0210BRYS-e-e.pdf, http://publications.environment-agency.gov.uk/pdf/SCHO0210BRYU-e-e.pdf

models. One limitation of the model is that it does not have a tidal component and therefore cannot forecast downstream of tidal limits. This is one reason why the Grid-to-Grid Model is complementary to the Environment Agency's current regional models, not a replacement for them. The Flood Forecasting Centre expects to put the Grid-to-Grid Model into operation by August 2010, although there will be further evaluation and trials for some time.

The Environment Agency's regional models can typically forecast up to 2 days ahead. Use of the Grid-to-Grid Model can improve and extend this capability at a national level up to 5 days ahead. One of the immediate uses for the data generated through the Grid-to-Grid Model will be to inform 5 Day Flood Guidance Statements issued by the Flood Forecasting Centre. These provide an assessment of daily flood risk up to five days in advance for Category 1 and 2 responders (emergency services, local authorities, NHS bodies, transport and utilities companies) using an increasing risk of impact warning system (see below where green/yellow equates to low risk and orange/red equates to medium/high risk). Thus, agencies have more advanced notice to enable deployment of temporary flood protection measures and the evacuation of people and property.

The Grid-to-Grid Model will also spearhead the drive to implement more probabilistic forecasting so that organisations are provided with additional information on the uncertainty in a forecast. In due course, it may be possible to use Grid-to-Grid to provide even more localised information – since the model has the capability to forecast at any point down to a 1km grid square.

Figure 3: Extract from a 5 Day Flood Guidance Statement (Source: Flood Forecasting Centre)



Use of the Grid-to-Grid Model to Improve Flood Protection

The Grid-to-Grid Model is not only a tool for flood forecasting. It also has potential to be used in informing the construction of defences to protect against flooding in the future. It is still early days for this research and (unlike the work on flood forecasting) it has not reached a stage where it is being put into practice by the Environment Agency. However, it is a further interesting and potentially valuable application of the Grid-to-Grid Model.

Planning for New Development

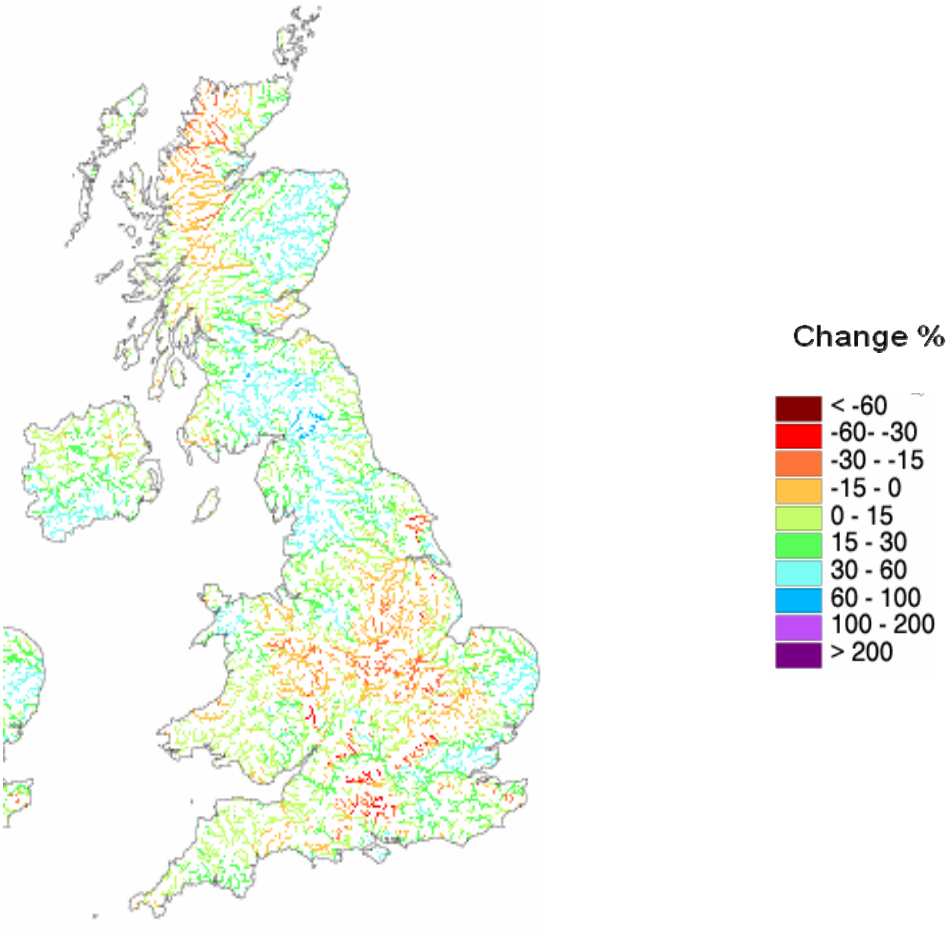
UK planning policy is to avoid development in areas of flood risk, if possible, and to protect against flooding where development in such areas is deemed to be necessary[5]. Flood defences are typically

[5] Communities and Local Government (2010), Planning Policy Statement 25 (PPS25): Development and Flood Risk.

designed to withstand an event with an annual 1 in 100 chance of occurring. However, the past is not an accurate predictor of the future when it comes to the nature and scale of flooding. As highlighted by the Pitt Review, the frequency and severity of rainstorms is expected to increase in the future due to climate change. Thus, flood defences need to be designed not only to withstand an event with an annual 1 in 100 chance of occurring but also the impacts from climate change in the future. Essentially, this means all flood defences must be designed to cope with an expected 20% increase in peak river flows at the design frequency from 2025 onwards to allow for the effects of climate change.

However, it is known that some parts of the UK are expected to have heavier rainfall than others in the future. Thus, the current blanket '20% uplift' could be leading to over-protection in some parts of the country and under-protection in other areas. The Grid-to-Grid Model represents a potential way of addressing this issue. Estimates of (hourly) rainfall and (daily) potential evaporation can be obtained from the Met Office's Regional Climate Model outputs on a 25km grid from the ensemble of 150 year projections run for the UK Climate Change Programme 2009 Scenarios. The structure of the Grid-to-Grid Model means that these estimates can be used to predict how peak river flows of a given frequency of occurrence are likely to change in the future. For example, the analysis below shows how peak river flows with a 1 in 20 year chance of occurrence are likely to change by the 2080s. It can be seen that decreases are expected in parts of Southern England and the Midlands (orange/red areas) and increases in Northern England, Wales and Scotland (green/blue areas).

Figure 4: Percentage Change in Peak River Flows by 2080s (Source: CEH)



Research on using the Grid-to-Grid Model in this way is being undertaken at CEH. It is still early days for this research but it could enable a step-change in the guidance that is provided for protecting against flooding when constructing new developments – with different precautionary sensitivity ranges for different parts of the country.

Planning National Flood Defences

The Pitt Review highlighted the need for a long-term investment strategy for flood management. In 2009, the Environment Agency published a long-term investment strategy for flood and coastal risk management in England.[6] This analysed the costs and benefits of five investment strategies. A key part of the cost-benefit analysis was taking account of the changing risk of flooding in terms of how many more properties would be at significant risk of flooding in 2035 compared to now, and the benefits that would accrue from investment to mitigate this.

The cost-benefit analysis was based on the Environment Agency's national flood risk assessment model. This is used to generate the flood risk maps on its website and can be used to model the outcomes from different types of investment projects (either at a local or more strategic level) in terms of protection of property from flooding. To take account of climate change, a 20% increase by 2035 in river flows of a given frequency of occurrence was built into the model - based on the precautionary sensitivity ranges used for development planning.

However, as highlighted above, a blanket '20% up-lift' for climate change does not reflect the geographical variation that is likely to occur in the UK. Research funded by NERC through the **Flood Risk from Extreme Events Programme (FREE)** is aiming to address this by incorporating climate change predictions into the Grid-to-Grid Model, and then incorporating the outputs into the Environment Agency's national flood risk model. This will enable more accurate cost-benefit analysis of long-term investment in flood defences, since it will take into account different levels of flooding risk likely to occur due to climate change. The Flood **Risk Under Climate Change Scenarios Project** (**FRACAS**), led by CEH, is due to end in September 2010 and work will then begin to see how this new modelling approach could be used by organisations such as the Environment Agency. Additional follow-on funding has been approved for this purpose through the NERC Knowledge Exchange Call.

Quantification of Economic Impact

Market Failure and Rationale for Grid-to-Grid Model

When assessing the economic impact of the Grid-to-Grid model, it is relevant to consider the rationale for NERC investment in the research. Public funding should not be used to undertake research that could have been undertaken by the private sector. There must be some type of 'market failure' to justify public investment in such research.

The Grid-to-Grid model is a classic piece of 'curiosity-driven' research. Scientific researchers at CEH came up with an idea for a new methodological approach to hydrological modelling prior to a need being identified by policy-makers. NERC funding enabled researchers to work on the idea and develop it into a flood forecasting tool. The private sector would not have initiated or funded such research, because there was a high level of uncertainty about final outcomes and returns from investing in this area. It is notable that two of the three models that were tested by the Environment Agency were developed at CEH; the third proved unsuitable. The Grid-to-Grid Model is an example of

[6] Environment Agency (2009), Investing for the Future.

curiosity-driven research anticipating unknown future needs which is one of the purposes of Research Council funding.

The economic impact of the Grid-to-Grid Model can be quantified in various ways outlined below:

- Mitigating the **annual costs of damage from river 'ordinary' flooding**.
- Mitigating the costs of damage from **extreme river flooding events**.
- Mitigating the increased costs of **river flooding damage in the future due to climate change**.

Each of these areas of economic impact is considered in more detail below. It is important to stress that the economic impacts reported below cannot be attributed entirely to the Grid-to-Grid Model. They reflect investment from Defra, the Environment Agency, the Met Office and NERC in developing modelling tools to improve the quality of flood forecasting.

Mitigating the Current Annual Financial Costs of Damage from River Flooding

In England, approximately 2.4 million properties are at risk from river and coastal flooding (of which around 490,000 are at significant risk). The average annual cost of damage from river and coastal flooding in England is estimated to be around £1billion.[7]

The impact of the Grid-to-Grid Model is mainly in mitigating damage from river flooding so some adjustment needs to be made to identify the annual costs of river flooding, as opposed to river *and* coastal flooding. Data from the Association of British Insurers reveals that average annual insured losses from rain-induced inland flooding across Great Britain are approximately £550 million per annum[8]. If insured losses are assumed to represent only 75% of the total financial cost of flooding events (because not everyone has contents or home insurance[9]), then the total financial cost of inland flooding in Britain is in the region of £730 million per annum.

However, inland flooding occurs from a number of sources (rivers, surface water and groundwater). The impact of the Grid-to-Grid Model is mainly in mitigating damage from river flooding. The events of 2007 were characterised by a combination of river and surface water flooding. In its interim report, the Pitt Review attributed a third of the flooding to river flooding and two thirds to surface water flooding, but in its final report it said that many of the properties included in the 'surface water category' actually flooded from a combination of factors. While it is not possible to identify precisely how much flooding was due to rivers or surface water – the implication is that the proportion relating (at least in part) to river flooding was considerably higher than that cited originally in the Pitt Review interim report. Thus, for the purpose of this exercise it is assumed that 65% of the cost of inland flooding relates to river flooding and 35% to other types of flooding. The total financial cost of river flooding in Britain is therefore estimated at around £475 million per annum.

The Grid-to-Grid Model is a key tool being used by the Flood Forecasting Centre to build Met Office high-resolution rainfall forecasting capability into Environment Agency hydrological modelling, and achieve the step-change in flood forecasting capability demanded by the Pitt Review. In particular, the Grid-to-Grid model is providing more advanced warning of flooding events (extending forecasting

[7] Environment Agency (2009), Investing for the Future: A Long Term Investment Strategy for Flood and Coastal Risk Management in England.

[8] Association of British Insurers (2009), Assessing the Risks of Climate Change: Financial Implications.

[9] Environment Agency (2010), The Costs of the Summer 2007 Floods in England.

capability out to 5 days ahead) so flood risk managers, emergency planners and responders have more time to mitigate the effects of flooding (for example by putting temporary flood defences in place). Evidence shows that increased lead times for predicting flooding events are directly related to reductions in damage caused to properties and infrastructure.[10] **If increased lead times reduced the annual costs of river flooding by 5%, this would equate to a cost saving of around £24 million per annum.** Over time, this would be reflected in lower insurance premiums and lower demands on public funds for damage that is not covered through insurance (such as damage to infrastructure).

Mitigating the Costs of Damage from Extreme River Flooding Events

The 2007 summer floods were the most severe weather-related event that the UK has experienced in decades. The total costs of the floods are estimated to be in the region of £4billion. The Pitt Review concluded that while the events of summer 2007 were very unusual, it would be wrong to dismiss them as freak events. There is evidence that the type of storms which triggered the extreme convective rainfall in 2007 will become more common and frequent in the future due to climate change.

As highlighted above, the impact of the Grid-to-Grid Model is mainly in mitigating damage from river flooding. The events of 2007 were characterised by a combination of river and surface water flooding. Thus, for the purpose of this exercise, it is again assumed that 65% of costs relate to river flooding (£2.6 billion) and 35% to other flooding (£1.4 billion).

Increased lead times for predicting extreme events such as the 2007 floods could have a significant economic impact. Using the same assumptions as above, **if increased lead times reduced the cost of river flooding from extreme events by 5%, this would equate to a cost saving of around £130 million**.

Mitigating the Costs of Increased River Flooding Damage in the Future Due to Climate Change

Today, approximately 490,000 properties are at significant risk of flooding from rivers or the sea. If investment in flood defences is kept at current levels in cash terms, there will be a further 350,000 properties at significant risk of flooding from rivers or the sea by 2035 because of climate change which is expected to lead to more frequent and severe rainstorms in the future.[11] The Environment Agency has calculated that in order to protect a similar number of properties as today (490,000) from significant risk of flooding as by 2035 (ie. no significant increase beyond the current 490,000), a steady increase in investment in flood defences will be needed from around £570 million per annum to £1 billion per annum in real prices by 2035.This equates to an increase of around £20 million in real prices each and every year. Some of this will, of course, relate to coastal defences so it has been assumed that only 50% of this annual expenditure would be deployed on defence work relating to river flooding.

As explained earlier, there is potential for the Grid-to-Grid Model to play an important role in informing investment decisions that are made under this programme by ensuring that flood defences are designed to take account of different levels of flooding risk likely to occur in different parts of the country due to climate change, rather than assuming a blanket 20% up-lift in peak river flows as is

[10] Sir Michael Pitt (2008), Learning Lessons from the 2007 Floods.

[11] Environment Agency (2009), Investing for the Future: A Long Term Investment Strategy for Flood and Coastal Risk Management in England.

assumed now. **If this helped to achieve even a 1% efficiency saving in the flood defence investment programme relating to river flooding over the next 25 years, the cost savings are estimated to have a Net Present Value (NPV)[12] of approximately £19 million.**

The Grid-to-Grid Model could also play a role in mitigating increased costs from river flooding in the future due to climate change (in terms of its role in improving flood forecasting and in informing better planning of national flood defences). Research by the Association of British Insurers (ABI) assessed the financial implications of a range of climate change scenarios on the costs of inland flooding.[13] The Inter-Governmental Panel on Climate Change (IPCC) predicts that a 2^{o}C increase in global temperature is likely by 2040 and virtually certain by 2090 regardless of any steps to reduce current or future emissions. It has also considered scenarios where the global temperature rises by 4^{0}C and 6^{0}C.

The ABI found that the most conservative scenario (a 2^{0}C temperature rise) would increase the annual cost of rain-induced inland flooding damage by 8%. If this is applied to our estimate of £475 million per annum in terms of the annual costs of river flooding, this implies an increase in costs of £38 million per annum. **If the Grid-to-Grid Model reduced these *additional* annual costs by 5%, this would equate to a cost saving of around £2 million per annum. Under the 4^{0}C temperature increase scenario, the cost savings would rise to around £3.5 million per annum.**

The increase in costs from river flooding damage due to climate change is even more marked for extreme events such as the 2007 floods which are expected to become more common in the future. The most conservative scenario (a 2^{o}C temperature rise) would increase the cost of a major 1 in 100 year event by 18%. If this is applied to our estimate of £2.6 billion in terms of the costs from river flooding for an extreme event, this implies a cost increase of £468 million. **If use of the Grid-to-Grid Model reduced this additional cost by 5%, this would equate to a cost saving of around £23 million. Under the 4^{0}C temperature increase scenario, the cost savings would rise to £39 million.**

Wider Qualitative Impacts

A range of qualitative impacts are also relevant. These can be summarised as:

- Averting the human misery from flooding
- Improving national capability in forecasting, modelling and warning against river flooding.

Averting the Human Misery from Flooding

The benefits from investment in research to improve flood forecasting capability are not purely financial. Flooding causes considerable human misery and inconvenience as illustrated by the fact that during the 2007 floods, 140,000 homes in the Tewksbury area were left without running water for up to two weeks when water flooded the Mythe Treatment Plant. Increased lead times for predicting flooding events, facilitated in part through the Grid-to-Grid Model, could help to avert this type of inconvenience in the future.

[12] Net Present Value (NPV) is the discounted value of a stream of either future costs or benefits. It is used to describe the difference between the present value of a stream of costs and a stream of benefits. A discount rate must be used when calculating a NPV in order to convert all costs and benefits to 'present values'. Using the Treasury's Green Book, the recommended discount rate is 3.5%.

[13] Association of British Insurers (2009), Assessing the Risks of Climate Change: Financial Implications.

Improving National Capability

The Grid-to-Grid Model is one of the key tools being used by the Flood Forecasting Centre to improve flood forecasting following the devastating impact of the 2007 floods. Emily Connolly, Project Manager at the Flood Forecasting Centre acknowledges the important role of NERC in funding basic environmental science:

> *"The Grid-to-Grid Model is a great piece of research which came along at just the right time for the Flood Forecasting Centre. The researchers at CEH were ahead of their time in anticipating the potential value of a new hydrological model of this kind and it demonstrates the important role that NERC plays in generating high quality science to improve the way that we manage the environment."*
>
> **Emily Connolly, Project Manager, Flood Forecasting Centre**

Consultees and Reviewers

The following people were consulted and reviewed a draft of the case study:

- Bob Moore - CEH
- Nick Reynard – CEH
- Vicky Bell – CEH
- Ben Gouldby – Hydraulics Research (FRACAS)
- Emily Connolly – Project Manager, Flood Forecasting Centre
- Tim Harrison – Flood Detection and Forecasting Senior Advisor, Environment Agency
- Steve Goring – National Capital Programme Management Service, Environment Agency