Coastal Flood Risk – does the New Orleans catastrophe hold lessons for London?

7th March 2006
Coastal Flood Risk – does the New Orleans catastrophe hold lessons for London?

Date 7th March, 2006

Location Lloyds of London
The Old Library
One Lime Street
London
EC3M 7HA

Programme

17:00 Coffee and tea

17.30 Welcome and Introduction
Dr Dougal Goodman FREng (Chair)
Vice-Chairman, Hazards Forum

Dr Robert Muir Wood
Chief Research Officer, RMS

Dr Scott Steedman FREng
Scott Steedman & Associates

Tim Reeder
Climate Change Regional Project Manager (Thames)
Environment Agency

18.30 Discussion Period

19.15 Concluding remarks

19.20 Wine and canapés

20:00 Evening Ends

Background

The 2004 and 2005 hurricane seasons have revealed the vulnerability of people and properties in the Caribbean and US coastal floodplains - most notably in the flooding of New Orleans following Hurricane Katrina. Significant coastal development during previous decades of low storm activity has placed many areas at risk under emerging conditions of increased storminess - potentially linked with climate change.

This seminar will explore how coastal flood risk is modelled within the insurance industry, reviews what has been learnt about the performance of the flood defences in New Orleans, and then considers the lessons for modelling and managing risk in the coastal floodplain in London and the Thames Gateway.
Coastal Flood Risk – does the New Orleans catastrophe hold lessons for London?

Tuesday 7th March 2006
The Old Library, Lloyd’s, London

ATTENDANCE LIST

CHAIRMAN
Dr Dougal Goodman FREng, Vice-Chairman, Hazards Forum

SPEAKERS
Dr Robert Muir-Wood, Chief Research Officer, RMS
Dr Scott Steedman FREng, Scott Steedman and Associates
Tim Reeder, Climate Change Regional Project Manager (Thames), Environment Agency

GUESTS
Mr Kevin Allchorne – Amlin
Mr Tony Bandle – Health and Safety Executive
Mr Andrew Bathurst – Benfield ReMetrics
Mr Peter Beresford – Eqecat
Dr John Bond – Individual Member
Mrs Pat Bond – Individual Member
Dr Colin Brown – Institution of Mechanical Engineers
Mr Adam Canning – Willis
Mr Andy Challoner – Aviva
Mr Chris Collier – NERC
Mr Darren Condick – University of Portsmouth
Mr Malcolm Cooper – RBS Insurance
Mr Matt Crossman – Association of British Insurers
Mr Will Curran – Wellington
Sir David Davies CBE FRS FREng – Chairman, Hazards Forum
Mr Paul Davies – Institution of Electrical Engineers
Mr Rowan Douglas – Willis
Dr Tom Eddy – Centre of Research in Social Attitudes
Dr Chris Elliot – Pitchill Consulting
Mr Matthew Foote – Willis
Dr Dougal Goodman FREng – The Foundation for Science and Technology
Dr Peter Graham – Individual Member
Dr Bob Hawley – Summerfield
Dr Celine Herijer – Lighthill Risk Network
Dr Mike Hough – The Risk Management Company
Lord Hunt of Chesterton
Mr Paddy Jago – Willis
Ms Vanessa Jones – Aspen Re
Mr Alan Just – Gerling
Mr Bob Katzaros – Broadgate
Dr Ian Lawrenson – Editor, Hazards Forum Newsletter
Mr John Lee – Secretary, Hazards Forum
Mr Adrian Lessner – Willis
Mr Will Mackay – Environment Agency
Mr Richard Marshall – Munich Re
Mr DK Matai – mi2g and ATCA
Mrs Surinda Marai – Philanthropia Trinity
Mr Yassir Menaa – Altran Technologies UK
Sir Duncan Michael – Guest
Mr Stuart Moffet – Guy Carpenter
Mr John Moore – Benfield
Sir Michael Moore – Institution of Mechanical Engineers
Dr Robert Muir-Wood – Risk Management Solutions
Ms Jennifer Müller – Risk Management Solutions
Mr Herotshi Murakami – Tokio Marine Global Ltd
Mr Brian Neale – Brian Neale Consultancy
Mr Chris O’Rourke – Chubb
Mr Patrick O’Rourke – QBE
Mr Andrew Pace – Willis
Professor Nick Pidgeon – Cardiff University
Mr Mark Platten – Zurich Re
Mr Barry Plummer – Aspen Re
Mr Jon Prichard – Institution of Civil Engineers
Mr Paul Pritchard – Royal & Sun Alliance Insurance Plc
Mr Tim Reeder – Environment Agency
Mr Brian Rofe – Individual Member
Mr Phillip Ruffles – Individual Member
Mr Richard Sanders – Willis
Mr M A Selfe – RAC Foundation
Mr Reg Sell – Ergonomics Society
Mr Gordon Senior CBE – Individual Member
Mr Roger Short – Institute of Measurement & Control
Dr Scott Steedman – Steedman & Associates
Mr Robert Stevenson – Wellington Underwriting Ltd
Mr Tanabiki – Mitsui Sumitomo
Mr Peter Taylor – Faraday Underwriting Ltd
Dr Brian Thompson – Individual Member
Mr Steve Truman – Housing Corporation
Mr Stephen Vickers – NEBOSH
Mr Simon Ward – QBE
Mr Hans Waszink – Waszink Actuarial Advisory
Mr Peter Watts – Environment Agency
Mr Simon Webber – QBE
Mr Andrew Wheeler – Willis
Mr David Whiting – Individual Member
Professor Peter Wolf – Distinguished Member
Event Report

Introduction

The Chairman, Dr Dougal Goodman, welcomed 80 guests to the first Hazards Forum event in 2005, also the first event to be held at The Old Library, Lloyd’s of London. He opened by explaining the origins of the Hazards Forum, set up to learn lessons following a number of disasters in the eighties such as Flixborough. Now here we were in 2006 meeting to discuss possible lessons to be learned from the latest natural disaster, the flooding experienced by New Orleans following the Hurricane Katrina. He thanked the sponsors, Willis, Natural Environment Research Council, Risk Management Solutions Ltd and The Lighthill Risk Network for their generous support which made the event possible. We were fortunate, he said, to have three very knowledgeable speakers whose experience in the subject under discussion was considerable and looked forward to a lively discussion at the end. He then introduced the first speaker, Dr Robert Muir-Wood.

STORM SURGE FLOOD CATASTROPHE MODELLING

Dr Robert Muir-Wood, Chief Research Officer, Risk Management Solutions Ltd.

Dr Muir-Wood’s presentation explored the current knowledge in developing and using probabilistic models to predict the likelihood and extent of a catastrophe. Such Catastrophe models are widely used by the Insurance industry for risk pricing and optimizing risk diversification.

Catastrophe models are designed to solve questions related to pricing and managing portfolios of risk within a single underlying model. For flood risk this would include what is the fair technical rate for flood insurance for a specific property, as well as how to create a portfolio of insured properties with a reduced potential for all being subject to loss within the same catastrophe event. To protect against the potential for these tail loss events the insurer may use the model to determine needs and technical costs of purchasing reinsurance. The model can also be employed for exploring the impact of alternative flood and defence failure scenarios; and the comprehensive cost benefit analyses of flood defences.

The Catastrophe model comprises four modules. The stochastic model defines the event; the hazard model predicts the likely severity of the event at every location - for example in the case of a flood the calculated maximum depth of water. The vulnerability model then calculates the impact of that depth of flooding on a specific property and the final module, the financial model, calculates the financial loss, after taking into consideration the specifics of how the insurance and reinsurance policies have been structured, and including the uncertainty in the estimations arriving from the other modules.

Catastrophe models have been developed since 1990 first for earthquake and hurricane risks and more recently for flood. As events happen the sciences within the models becomes improved and in particular the vulnerability functions that relate the hazard to the damage and loss are refined.

Looking at storm surge flood catastrophe risk he explained that the flood was likely to accompany an extreme windstorm and therefore that losses in the two classes of
catastrophes could be expected to be correlated. Similarly with a large nearshore submarine earthquake, may produce its own destruction as well as cause flooding due to any resulting tsunami. A key purpose for the model was to be able to predict the potential for many locations to be affected by the same catastrophe.

Weather conditions affecting extreme surges on the East Coast of England were graphically demonstrated by two weather maps. The first showed a deep, rapid SE-moving depression crossing the North Sea with an anticyclone W of Ireland. The storm winds caused a surge right along the Lincolnshire and East Anglian coasts, through the Thames estuary and north Kent coast and also along the Belgium Coast. The second scenario was a slow-moving deep depression in the southern North Sea with an anticyclone close to the Faeroes. In this situation the strong winds could blow over the North Sea from the east driving water onto the East Coast of England, as in a surge in 1978 which was concentrated only along the Lincolnshire and north Norfolk coasts.

To protect against extreme water levels the flood defences along the UK East Coast were developed piecemeal and in the model are represented as 917 different defence sections of different ages, construction types, heights and levels of foreshore protection. For the model these have been banded into four types: shingle ridges; earth embankments; and two qualities of concrete structure.

In considering the vulnerability module the loss as a percentage of the value of the property is strongly influenced by the height of the building, and is greatest for a bungalow and lowest for a multi storey property. Losses to the contents of a property are also strongly determined by the number of storeys and even 10-20cm of flood water can cause a total loss to the majority of the contents value of even a typical two storey house.

The Risk Management Solutions Ltd UK east coast storm surge model covers the coastal floodplain from East Yorkshire to East Kent which is divided into 374 postcode sectors within which there are 58,000 postcode units located t less than 6m above sea level. The model comprises 620 regional surge events along with a stratified sampling for combining with a full range of tide heights, and uses ‘Latin-hypercube’ sampling in order to obtain an efficient sampling of the full range of potential combinations of defence failures in the same extreme water level event. The model then provides a flood depth output for each surge-tide & defence-failure ‘combined event’ at postcode unit resolution and through preserving the probability of each modeled event facilitates calculation of flood risk costs and portfolio flood loss EPs. Comparing losses for a modeled portfolio equivalent to the total of all UK insured exposure, and comparing with results generated from two other RMS Catastrophe models of river flood and windstorm UK storm surge losses were found to be the lowest of the three at most return periods with river flood overtaking windstorm as a source of major catastrophe loss at return periods beyond 500 years.

For any model there will be uncertainties and it is important to acknowledge and where possible quantify these uncertainties within the outputs that are generated. For the storm surge flood catastrophe model, sources of uncertainty include extreme knowledge of surge-tide interactions; how wave action can be expected to accompany surge-tide; the variable spatial structure of surge-tides; flood propagation; elevation of property threshold (high uncertainty per location, uncorrelated in a portfolio); and building specific vulnerabilities. However the two principal sources of uncertainty in the model relate to defence performance, in particular around the initiation of breaching together with breach growth & inter-breach connectivities. As an example the impact of transgression model on flood depth using the topography of the Lincolnshire coast assuming a 6.8 metre storm surge where defences are just 6.5 metres revealed that breaching increases the volume of floodwater by
three orders of magnitude. Sample sensitivity tests as to the critical role of the sill height of the breach (i.e., to what depth erosion continued) were illustrated where losses vary from a predicted £1 billion loss to a £3.3 billion loss for only a 2m difference in the depth of the breach.

The remainder of the presentation featured photographic evidence from a variety of locations of defence breaches and the devastation or damage caused. The first was an older but very graphic picture of a breach in 1953 of one of the defences protecting Holland. This was followed by a slide showing the effect of the geology of breaching that took place at Røroy, Jutland on December 4th, 1999. This caused a deep scour hole inland of the defence which was also shown to be weaker than the substrate. In addition, having ingressed, the water rushing out after the surge had passed further eroded the breach site. There was also evidence of secondary breaches and sand deposition revealing inland propagation.

Finally, the hurricane Katrina storm surge damage was illustrated. Wood frame residential buildings some 50 metres from the breach were totally destroyed while brick built residential buildings at the same distance suffered badly but remained standing. Even at 150 metres from the breach wood frame residential buildings showed substantial damage although they had not been washed completely away. The satellite image of the impact of the 6-8 metre surge at Gulfport revealed total losses along the coastline. The two lower floors in blocks of flats had been washed away giving the impression that the remaining floors had been built on stilts. Even inland the destruction was considerable with buildings either destroyed or seriously damaged. Lessons have been learned for flood risk zoning in the Mississippi coastal floodplain following the experience of hurricane Katrina as its effects caused houses to be destroyed outside the previously designated flood zones.
Different Climatologies of Extreme Surges on UK East Coast

Type 1: Deep, rapid SE-moving depressions crossing North Sea with anticyclone W of Ireland

Type 2: Slow-moving deep depressions in B North Sea with anticyclone close to the Faroes

Current Sea Defences in Eastern England

- 917 defences protect insured property
- Sea defences bonded into four types

Sea Defences

Type 4

Type 3

Type 2

Type 1

Structure
Material
Condition
Foreshore

UK Flood Model: Vulnerability Module

- Loss % vs Depth above ground floor (m)
- Example locations: Bangor, Detached, Semi-Detached, Terraced, Flats

RMS UK East Coast Storm Surge Model

- Stormline from East Yorkshire to East Kent: 274 sections, 28,000 units, 6m elevation
- 620 regional surge-tides (stratified sampling for combination with fall range of tide heights)
- Latin-hypercube sampling of multiple combinations of defence failures in same surge-tide
- Flood depth output for each surge-tide & defence-failure combined event at postcode unit resolution
- Facilitates calculation of flood risk costs and portfolio flood loss IEPs


- Loss £M over return period years
- 10, 25, 50, 100, 200 years
Auditing the uncertainties in loss modeling of storm surge risk

- Sources of uncertainty in surge flood catastrophe modeling:
  - extreme surge-tide interactions
  - wave action accompanying surge-tide
  - spatial structure of surge-tides
  - defence performance & initiation of breaching
  - breach growth & inter-breach connectivities
  - flood propagation
  - elevation of property thresholds (high uncertainty per location, uncorrelated in a portfolio)
  - building specific vulnerabilities

Impact of Transgression Model on Flood Depth (Lincolnshire Coast)
6.8 m surge-tide, 6.5 m defence

Breaching increases volume of floodwater by three orders of magnitude

Example sensitivity tests: impact of breach sill height

- +3mOD sill height: £1bn loss
- +1mOD sill height: £3.2bn loss
- -1mOD sill height: £3.3bn loss

Impact of breach sill height on modelled loss

Unit-Postcode losses & overall loss

The geology of breaching: Roroy, Jutland Dec 4th 1999

1) Deep scour hole
2) Defence proves weaker than substrate
3) Reverse flow of eroded channel
4) Secondary breaches
5) Sand deposition reveals inland flood propagation

Hurricane Katrina Storm Surge Footprint (with NOLA Flood Footprint Clipped)

Surge overtopping most severe in St. Bernard Parish and New Orleans East, with waters from Lake Borgne

How far does significant damage extend from a breach?
NEW ORLEANS - FORENSIC INFORMATION

Dr Scott Steedman, Scott Steedman and Associates

In the immediate aftermath of Hurricane Katrina, the Federal Government created an Interagency Performance Evaluation Taskforce (IPET) to 'find the facts' behind the inundation of the city. The IPET investigation was divided into several tasks covering the meteorology, the surge, the pumps etc. Our task was to study the levees – to gather and analyse the evidence and to learn the lessons for the future.
One of the IPET tasks was concerned directly with gathering information on the socio-economic effects. They reported that in metropolitan New Orleans alone, the direct economic cost of the disaster was $21Bn in the five counties (parishes) that make up the city, with an additional $7Bn of damage to public structures and infrastructure. They reported 714 deaths, 70% of whom were over 70 years old.

Statistics published by Task Force Guardian state that of the 284 miles of Federal levees and floodwalls surrounding the city and 71 major pumping stations, 169 miles of levee and 34 pumping stations were damaged by the storm. Very little instrumental data could be recovered from wind or wave gauges as they were almost completely destroyed, but the collection of witness statements, surveys of high tide marks and other physical investigations were quickly set in motion to gather information. From this base, the IPET task teams worked to develop an overall picture of the disaster.

This was by no means the first time that the city had been flooded, but it was certainly the worst. In the past 60 years alone, hurricanes struck New Orleans in 1947, 1956 and 1965 (Hurricane Betsy). Over the past four decades Army Engineers have prepared detailed reports into the vulnerability of the area. A major report in 1964 contained their assessment of the critical paths of approach for a future hurricane to affect the city. Their selected path to the east of the city was very similar to the actual path taken by Hurricane Katrina, as it tracked northwards during the early morning of 29 August 2005.

The IPET teams studying the storm track and the hydrodynamics developed complex computer simulations of the sea state as the hurricane passed. They reported ‘unparalleled wave and storm surge conditions for the New Orleans vicinity’. Their simulations show graphically the passage of the storm surge from south west to north east, finally striking the coast of Mississippi near Biloxi.

Strong winds hit the city and the heavy rain, over 300 mm in parts, and the rising waters led to the massive inundation observed over tens of square kilometres of residential and commercial areas. The IPET investigation found that there were 50 breaches in total in the levee system. Four of these, associated with failures in the foundations of the levees, occurred prior to the water reaching the top or crest of the flood wall. The rest occurred as a result of water cascading over the top, called ‘overtopping’, causing scour, erosion and loss of crest.

Seawater entered the city centre through these breaches and then moved through the city along the canals and drainage system, filling the deepest low-lying areas to depths of over 3 metres within hours. Those pumping stations in the centre that had remained operational were overwhelmed, and water then entered through these pumps as well.

One of the facts the IPET sought information to understand was why so many breaches occurred, given that the height of the sea surge in the centre of the city was roughly the same as the design height of the protection system in the IHNC and less than the design height on the 17th Street and London Avenue canals.

The investigation first concentrated on the breaches that occurred prior to overtopping, when the water level had still not reached the crest. All of these cases had flood walls constructed through the old levee section, a technique used to raise the height of the protection without having to widen the levee itself.

The levees were built originally from local clay, built up in layers with a slope on either side. The oldest parts of the levees in the centre of the city date back to the original construction
of the outfall canals, over 100 years ago, when pumps were installed to drain the swampy land between the old centre of the city and Lake Pontchartrain, to the north. These old levees had very soft foundations, comprising a top layer immediately below the ground surface of a mixture of peat and clay known as ‘swampy marsh’ and a lower layer of either soft clay or sand. Below this was more clay and sand, extending to great depth – there is no natural rock anywhere in the Mississippi delta. Borings confirmed that the levee overlay clay at the location of the 17th Street breach, whereas the levee overlay sand at the locations of both the London Avenue breaches.

The IPET investigation undertook a series of model studies to identify the most likely mechanism of failure. In the case of the London Avenue breaches, the IPET study concluded that the leaning movement of the flood wall allowed the water from the canal to reach the underlying sand layer, greatly increasing the water pressures in the foundation and effectively ‘floating’ away the landward half of the levee. The study found that the case of a water-filled gap in front of the floodwall was not considered in the original design. This mechanism worked in conjunction with the weather conditions and was identified in IPET’s Draft Final Report as the most likely initiator of difficulties with the levee foundations.

The IPET study also concluded that all of the other levee breaches, many of them several hundreds of metres in length, commenced with overtopping, causing scour and erosion on the landward side of the levee, which ultimately led to loss of support and breaching. Wherever water flow was more concentrated, such as around the end of a section of wall, perhaps part of a pump station or flood gate, local scour was also found to be severe.

These mechanisms alone do not explain the number of breaches and the scale of the inundation, particularly in the centre of the city. IPET found that water levels there were typically 3-4 metres above sea level but there was little wave action and design levels of the protection system were comparable to, or higher than, the height of the surge. Within months of starting the investigation, the IPET geodetic survey team discovered that large parts of the levee system were in fact lower than was originally thought, and by a considerable margin.

Two explanations for this have been put forward. The IPET team re-surveyed all the official benchmarks in the area to check their elevation against historic records. Their first finding was that many of these were not at their anticipated elevation, largely due to subsidence within the soft clays beneath large areas of the city. Secondly, IPET found that the reference elevations of benchmarks used in the design of some floodwalls and levees were not always the correct reference elevations appropriate to that particular time period. Instead, for some projects, older out-of-date reference elevations had been used that were appropriate to a previous era. This meant that in some cases, although floodwalls were constructed to the elevation shown on the drawings, their actual elevation ‘as-built’ was below that required.

The IPET investigation found that Hurricane Katrina would have caused widespread flooding even if the levees had held, but the vulnerability of the system, which IPET concluded was “a system in name only”, contributed greatly to the scale of the disaster. The study has provided a template for other flood-susceptible areas around the world to examine the integrity of their own protection systems. They would be wise to take note: they may be next.
CLIMATE CHANGE AND FLOOD RISK, THE TE2100 PROJECT

Mr Tim Reeder, Climate Change Regional Project Manager (Thames), Environment Agency

Tim Reeder opened by outlining the Structure of his talk. First he would look at the challenges of flood risk management in the Thames Estuary, examine the climate change issues, describe the decision making framework and then explain how this had been applied to the Thames Estuary and examine the emerging results.

On a slide showing the respective water heights at intervals over the past century and a half, the various defence levels were highlighted at the time the 1879 Flood Act was introduced, again when the Act was updated in the late nineteenth century, again after the 1928 flood which led to the 1930 Flood Act and finally the interim defences built during the construction of the Thames Barrier.

Currently there are some 1.25 million people and £80bn property at risk in the area around the Thames Estuary. Although the present flood risk system is robust and to a high standard there is an ageing defence infrastructure. Add to this an increased development pressure...
for some 160,000 new homes – most of which would be built in the protected floodplain together with the impacts of climate change which is predicted to raise the sea level, increase the risk of storm surge and increase river flows and it is clear that some action is necessary.

This has culminated in the Thames Estuary 2100 Project. Its aim is to develop a flood risk management plan for London and the Thames Estuary for the next 100 years. It will address management of the estuary from a risk perspective and a ‘whole society’ approach and it is being done now because actions have long planning timescales.

Climate Change is the critical issue being addressed by the Thames Estuary 2100 Project. The main drivers of physical flood risk sources, in order of uncertainty, are waves; fluvial flow; sea level rise; surge and joint probability. The uncertainties will be addressed by applied research commissioned from the Hadley Centre and the Proudman Oceanographic laboratory.

Uncertainty in storm surge predictions was graphically illustrated on a slide showing three alternative predictions. Help with emerging uncertainties is available from the evidence, for example, of the ice melt in Greenland and the Antarctic.

To achieve the project objectives the programme of studies was based around a Decision-Making Framework that has largely been piloted by ‘espace’ (European Spatial Planning: Adapting to Climate Events).

This helps deliver policies and projects that are robust in the face of an uncertain future climate.

The decision framework is based on eight stages as shown below. Iterative loops enable the uncertainties to be reduced. For example repeating steps 3 to 5 helps to identify the option with the lowest risk.

Looking at its application to the Thames Estuary the process is currently in the loop of steps 2 to 5. This process will involve high level economic appraisal (strategic options); determining early conceptual options and selecting the high level options. This in turn will
lead to a Thames Estuary flood risk management plan. Before the plan is implemented some three iterations of steps 2 to 5 would be expected. In order to identify the options for this process the ISIS-TUFLOW broad scale flood model is being used. Four strategic options were tested using the model;

1 - Do nothing (walk away & leave barriers open)
2 - Maintenance only leading to declining standards
3 - Do ‘something’ A giving 1:1000 protection
4 - Do ‘something’ B giving 1:5000 protection

Based on the position in 2005, low, medium, high and high+ increases in sea level for the years 2050 & 2100 were tested but there was not sufficient reliable ‘detail’ to select the best strategic option and there was no information on actual interventions. However it did lead to the Exeter Paper on ‘Benefits of Stabilisation’ which demonstrated that mitigation would put off the risk of major damages to a significant extent.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Relative sea level rise (in m) in the Thames Estuary 2050 (relative to 2005)</th>
<th>Relative sea level rise (in m) in the Thames Estuary 2100 (relative to 2005)</th>
<th>PV(flood risk) (£billion)</th>
<th>Benefit of stabilisation (£billion)</th>
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<tbody>
<tr>
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<td>0.61</td>
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</tbody>
</table>

Table 1: Flood risk estimates in the Thames Estuary for different stabilisation scenarios

Communication with stakeholders in the Thames Estuary is obviously essential and to help facilitate this, computer software ‘FloodRanger’ and ‘FloodRanger Professional’ has been developed. By sending the results to FloodRanger, stakeholders are able to visualise futures and enables decision testing over a long period. The software includes differing climate and socio economic futures to be tested.

Emerging Early Conceptual Options (ECO) results indicate that the current system is robust provided that there is low climate change. It illustrates the benefits of flood storage; the issues associated with raising flood defences; identifies sea level thresholds; points to a flexible strategy allowing approach to be adapted as uncertainty reduces and highlights ‘no regrets’ issues.

Regarding non-structural responses the ECO work has shown that increased investment in managing flood events could provide a significant reduction in people at risk during an event. The key investment could be targeted at local authorities and blue light services to improve and prepare better for such rare events (Operation Triton). It also showed that the second biggest benefit would be gained from ensuring the reaction of individuals follows predefined outcomes, which could be enhanced by improved education and awareness raising. However the greatest impact on managing flood risk would be at the master planning stage for new build, where the principles of good flood compatible designs are developed by flood aware planners and architects.

Conclusions
- Climate Change Critical Factor - 4th Assessment Report Case Study
- Illustrates tangible benefit of stabilisation / mitigation - significant cost savings
- Thresholds for responses emerging - important
- Reduce uncertainty of decision making through further iterations using more data/detail essential to develop a strategy that is resilient to uncertain future
- Non structural measures essential
Climate Change & Flood Risk
The TE2100 Project

Tim Reeder
Environment Agency
creating a better place

The Thames Estuary
- 1.25 million people £60bn property at risk
- Present Flood Risk system robust / high standard
- Ageing defence infrastructure
- Increased development pressure
  - 180,000 new homes – most in protected floodplain
- Impacts of climate change include
  - Sea level, storm surge, river flows

Structure of talk
- Challenges of flood risk management in the Thames Estuary
- Climate change issues
- Decision making framework
- Application of the framework to the Thames Estuary & emerging results.

Thames Estuary 2100 Project
- Aim:
  - Develop a flood risk management plan for London and the Thames Estuary for next 100 years
- Addressing
  - Management of estuary from a risk perspective and a ‘whole society’ approach
- Timing
  - Why now - long planning timescales
Climate Change & TE 2100 Project
- Climate Change critical issue
- Main driver of physical flood risk sources in order of uncertainty:
  - Waves
  - Fluvial Flow
  - Sea Level Rise
  - Surge
  - Joint Probability

Uncertainty in storm surge predictions

Climate Change & TE 2100 Project
- Applied research commissioned from Hadley Centre & POL
- This will address these “traditional uncertainties”
  - Ice melt - Greenland, WAIS, etc

Thames Estuary 2100 Project
- To achieve the project objectives we have based our programme of studies around the a Decision-Making Framework that has largely been piloted by ESPACE...

Eight-stage decision-making framework

Application to Thames Estuary
- Currently in steps 2 to 5
Steps 2 to 5 iteration

- Expect 3 iterations:
  - High level economic appraisal (strategic options)
  - Early conceptual options
  - High level options
  - Leading to Thames Estuary Flood Risk Management Plan
  - Further work to implementation.

Findings

- 4 strategic options tested:
  - 1 - Do nothing (walk away & leave barriers open)
  - 2 - Maintenance only – declining standards
  - 3 - Do ‘something’ A giving 1:1000 protection
  - 4 - Do ‘something’ B giving 1:5000 protection
  - Current climate and Low, Medium, High, High+ at 2050 & 2100
  - But not sufficient ‘detail’:
    - Select best strategic option
    - And no information on actual interventions -
    - However!

Stakeholder engagement

- Send results to FloodRanger
- Enables stakeholders to visualise futures
- Enables decision testing over long period
- Includes differing climate and socio economic futures

Emerging ECO Results

- Current system robust given low climate change
- Benefits of Flood Storage
- Issues around raising flood defences
- Identification of level thresholds
- Points to flexible strategy - adaptable as uncertainty reduces
- Highlights no regrets issues

ISIS-TFLOW broad scale flood model

Findings

- Lead to Exeter Paper on benefits of stabilisation where we demonstrated that mitigation would put off the risk of major damages to a significant extent

| Climate | Relative risk level | Relative risk level | Stabilisation benefit | Estimated cost
|---------|--------------------|--------------------|-----------------------|-----------------|
| 2050    | 2.00               | 3.60               | 1.60                  | 1.60
| 2070    | 2.10               | 3.60               | 1.50                  | 1.50
| 2100    | 2.10               | 3.60               | 1.50                  | 1.50

Note: A risk ratio indicates the risk as 1.60 for different climatic scenarios.
The Chairman thanked the speakers for their well illustrated presentations and then invited questions from the floor.

The first questioner was concerned with the New Orleans disaster. In view of the warnings given of the approaching hurricane Katrina was there anything the US Government could have done to prevent the levees being breached or overlapped? In response it was claimed that, despite the warnings, there was absolutely nothing that could have been done to prevent the disaster. However lessons had been learned from the experience and the new defences are being designed such that preventative intervention will be possible. Further
lessons had also been learned about access. After the flood, accessibility had been very poor and this is also being addressed. In addition the pumps being used to pump out the water were found to be inadequate and failed. All these deficiencies contributed to the extent of the disaster but provided valuable information, not just for the defence of New Orleans but for all vulnerable areas worldwide.

Continuing the debate the next questioner said that, from what he had just heard, this disaster had been a combined natural/technological disaster. Although he was unaware of any had there been any modeling of climate change in the United States and if not perhaps it should start? In response it was explained that there were in fact at least three models which examined inshore surges but it was very difficult to translate this to an offshore model.

Sea levels had been rising for some time now, offered another questioner. In fact there was evidence of ice melt at the Antarctic even in Scott and Shackleton's day. He, himself, had been fortunate to visit the Antarctic and the extent of the ice melt was very considerable. In view of the inevitable effect this would have on sea levels will we be able to build defences sufficiently robust to prevent inundation? Another guest offered that a 1 metre rise out at sea was a comparatively minor problem compared with the problems of surges up rivers. One way of reducing the effect of a river surge was to permit controlled inundation over unpopulated areas thus taking the top off the surge.

Changing the subject slightly another speaker advised that the flooding and hurricane force winds which caused the loss of electricity supply in New Orleans led to huge additional problems on top of the flooding chaos. Tills in the shops did not work, no cash was available from ATMs and standby generators had to be installed in shops, banks and hospitals. With the benefit of hindsight there had been three surprises in New Orleans; the integrity of the defences, the effect on transport and the loss of electricity.

Would the best approach be to build, in vulnerable areas, a bastion and refuges to protect life? Let other areas flood and when hurricanes were forecast gather in the refuges? In response it was suggested that that may possibly be an answer but there was in fact a refuge in the form of the New Orleans Superdome and look what happened there!

With time running out the salutary fact was made that the population of New Orleans is $1/3^{rd}$ what it was before Katrina struck. This is because there is now no economy and there is therefore no point in living there.

The Chairman thanked all those who had taken part in the discussion particularly the speakers who had responded so well to the questions. He repeated his thanks to the sponsors without whom this fascinating event could not have taken place.