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Plausible responses to the threat of rapid sea-level rise in the Thames Estuary

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Abstract This paper considers the perceptions and responses of selected stakeholders to a very low probability but high consequence climatic 'surprise'—a scenario of rapid collapse of the West Antarctic ice sheet, producing a global rise in sea-level of 5 m over 100 years. It uses a case study of the Thames Estuary, UK, including

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London. Through a process of dialogue involving one-to-one interviews and a 1-day policy exercise, we addressed influences on decision-making when information is uncertain and our ability to plan, prepare for and implement effective ways of coping with this extreme scenario. The interviews and policy exercise explored plausible responses to the scenario and identified weaknesses in flood management approaches to dealing with such an occurrence. The analysis shows that an extreme scenario could be highly challenging, even for an area with well-developed institutions. Participants favoured two options (a) reconfiguring London around the rising water, and (b) building a new downstream barrier which would allow London to continue as today. The lack of consensus suggests the potential for policy paralysis in response to what is a highly uncertain phenomena—this could lead to a forced, unplanned response as the rapid change overwhelmed the existing defence capability. Hence, low probability, high consequence climatic events may challenge our existing institutions. Adaptive management is presented as an approach which could address this challenge.

1 Introduction

Adaptation to climate change may require socio-economic and institutional changes beyond the framework of existing planning systems (often referred to as mainstreaming). One such case would be if climate change triggers large consequence impacts, such as the rapid release of methane hydrates, rapid decline in the North Atlantic thermohaline circulation, or the collapse of the West Antarctic Ice Sheet (WAIS). In the fourth assessment of the Intergovernmental Panel on Climate Change, such events were considered unlikely at best during the twenty-first century (IPCC 2007). However, such low probability, high consequence events may be important in planning climate policy responses (Klein et al. 2002), and may test the limits of adaptation (Adger et al. 2007; Hulme 2003; Mastrandrea and Schneider 2001). As there has been limited investigation of responses to such events, the objective of this paper is to study the perceptions and responses of selected stakeholders to this type of potential climate change impact.

Collapse of the West Antarctic ice sheet would produce a global rise in sea-level of 5 to 6 m (Mercer 1978; Schneider and Chen 1980; Vaughan and Spouge 2002; Tol et al. 2006; Tol and the ATLANTIS Team 2008). The scenario chosen to evaluate stakeholder responses represents a compromise between what is not implausible geophysically (although highly unlikely based on current knowledge) and what is still relevant for a project based on social discourse. For the Thames case study, the WAIS was assumed to begin collapsing in 2030, with 5 m SLR expected over the following 100 years (Fig. 1). The time horizon was chosen to be beyond current political processes, yet sufficiently near term to enable people to envisage the impacts. It is unlikely that stakeholders would engage in a debate on decision-making processes for events that would not occur for three or four centuries (a more plausible scenario for extreme sea level rise).

In addition to uncertainty in the sea-level rise, there is uncertainty about changes in social structure, economic development and land use in the distant future. For the purposes of exploring social responses to uncertain risks, the baseline of exposure was documented (Section 2) along with the spatial risks of the 5 m SLR scenario

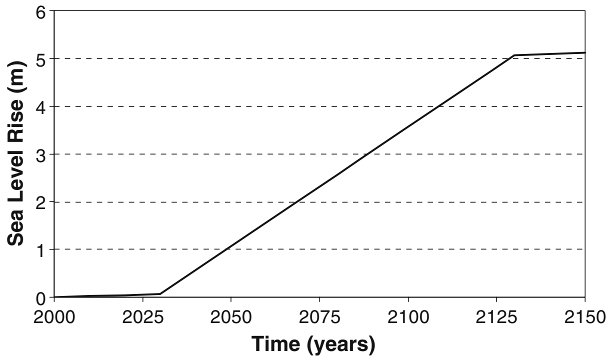

Fig. 1 The sea-level rise scenario considered in the Atlantis project

(Section 3, see Dawson et al. 2005). Projections of future vulnerability, as would be required in a scenario-impact model study, were not attempted; rather rough estimates of the changes population and development were posed (Section 3). Any impact model of a 5 m SLR would be used far outside its domain of calibration and validation, and not necessarily assist in revealing social risk responses. Thus the project explores the social dimensions of adaptive management rather than presuming that we can predict the future and should target adaptation to such uncertain futures (for example, see the discussion of robust decision making in Lempert et al. 2003).

The methodology for understanding social risk responses relied on interviews with stakeholders, followed up with a role playing policy exercise (Section 6). The results of the interviews and policy exercise are presented in Section 5. A simple method to integrate the results are qualitative 'storylines' or 'future histories' that reflect the complex implications of what a 5–6 m sea-level rise would mean to people (Section 8). Section 9 discusses broader conclusions related to climate change adaptation processes. Figure 2 summarises the approach of the project.

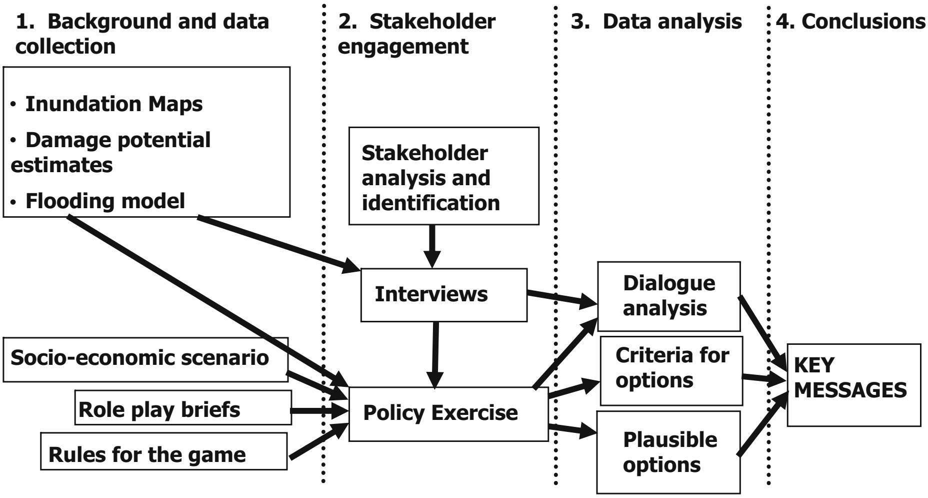

Fig. 2 The Thames Estuary case study process

2 Flood risk in the Thames Estuary

The Thames region extends from western boundary of the London metropolitan area to the tidal zones planned for development in the Thames Gateway (including Southend-on-Sea) (ODPM 2004; TGLP 2002). The region is exposed to greater flood risk than any other area of the UK because of the concentration and value of its assets. The greatest flooding threat comes from tidal surges, although inundation by river floods, local flooding when inadequate drainage systems are overwhelmed and the rise of the water table are also risks. A surge is a meteorologically-induced tide: in the southern North Sea positive surges can rise 2 m or more above normal tides. If this coincides with a spring tide then the increase in tide height can be sufficient to overtop defences. In 1953 a storm surge killed about 300 people, flooded 240,000 houses and 65,000 ha. of farmland along the East coast and the Thames Estuary (ICE, I 1954; McRobie et al. 2005). Depending on its magnitude, a tidal surge today in the Thames region could affect 1.25 million residents (a sixth of the population of London), 1.5 million commuters and property and economic activities worth £80–100 billion (Parker and Penning-Rowsell 2002). In addition, a major flood affecting the Thames region would be bound to have negative secondary impacts for almost the whole of Britain because, as the July 2007 riverine floods in England demonstrated, flood impacts spread well beyond flood prone areas.

The Thames flood plain is the site of one of the largest increases in flood loss potential in Europe. Since the 1980s there was significant regeneration of tidal flood prone land, including more or less the whole of the redeveloped docklands and riverside areas between the City and Woolwich. Despite some adaptation of buildings and developments to flooding, damage potential has tripled between 1987 and 2000 for commercial property and increased 2.5 times for residential property, partly due to ownership of technology (computers, multi-media systems etc.); new for old insurance and a reduction in salvage of flood damaged items increases insured losses (Penning-Rowsell et al. 2002). London is dependent on ageing and easily disrupted infrastructure. The underground system is especially vulnerable.

Flood management of the Thames Estuary has evolved in a piecemeal manner, often in response to major floods. The 1953 flood led to the decision to build the Thames Barrier and its associated defences, an idea first mooted in the early 1900s. The barrier, which opened in 1981, and its associated defences provide London with a high level of flood protection (currently greater than 1 in 1,000 year event) (Gilbert and Horner 1984). This is well above the normal standard of protection for flood defence in the UK, but is justifiable given the number of lives, property and infrastructure at risk. The standard of protection in outer parts of the estuary reduces to a 1 in 200 year event on the southern bank, as this is primarily agricultural land.

The design standard of protection provided by the barrier, due to be reached in 2030, may be reached sooner due to accelerated sea-level rise not accounted for in the design, although the probability of flooding will remain low (Kelly 1991). After 2030, the level of protection will continue to decline due to rising sea-levels unless the barrier is upgraded (Gilbert and Horner 1984; Kelly 1991). Mean sea-level and also extreme water levels have been rising for the last two centuries (D'Olier 1972; Bowen 1972). A long-term rising trend of 0.4 mm/year during the nineteenth century and 2.2 mm/year in the twentieth century has been observed at Sheerness (Woodworth 1990; Nicholls et al. 1999). Extreme water levels have risen more rapidly than mean sea-level, at about 1 m per century from the 1790s, and this trend was assumed to continue for the 50-year design life of the Thames Barrier (1980 to 2030). The interpretation is that tidal range/surge amplitude within the Thames Estuary has increased, probably due to reclamation of intertidal areas, and possibly deepening of the main channels. While human-induced morphological change is likely to continue through the twenty-first century, it is likely to be less significant than previously and this effect is not considered here.

Planning for the new defences up to 2100 has already begun (Lavery and Donovan 2005; Ramsbottom and Lavery 2007). In addition to the more traditional defence raising options, the managed realignment of the defence line inland of where it now stands is also being considered (Shih and Nicholls 2008). Furthermore, the government's new flood risk management policy, 'Making space for water' (DEFRA 2005, see also DEFRA 2001) recognises the importance of promoting more resistant and resilient building and development techniques. It is therefore possible that new developments in the Thames tidal floodplain will be adapted to flooding, while at least some existing ones may be retrofitted to make them less susceptible to flood damage.

3 The Thames Estuary case study scenario

The population of Greater London is projected to grow to 8.1 million by 2016, with an increase in households from 3.1 million to 3.6 million. The population is expected to continue to rise after this (DMAG 2005, Data Management and Analysis Group, part of the Greater London Authority, provides statistical information on e.g. population and disseminates it through briefings. http://www.london.gov.uk/gla/dmag/index.jsp). To sustain the growth of London, more development is planned, particularly in financial and business services. The strategy is to regenerate East London and expand eastwards in a corridor on both shores of the tidal Thames to Shellhaven which will be developed as a new 'super-port'. This expansion will take the form of a series of new towns along the Thames in the largest co-ordinated building programme in the UK for 50 years. The developments will provide around 120,000 new houses and 180,000 new jobs to relieve overcrowding in central London and provide homes at a more affordable price for people on an average income (Greater London Authority 2004). Much of the planned development is in, or bordering on, the tidal flood risk zone. The scale of this floodplain development is unprecedented and high standards of flood risk management are required as the consequences of a flood would be so great. It is assumed that defences have been upgraded for a 1-m rise in sea level by 2030—which means that significant impacts do not occur until sea levels rise more than a metre. For insurance companies, the losses from a major flood affecting central London would result in increased premiums pushing insurance out of the reach of people on low incomes making these people less able to recover in the event of future flooding. In some areas insurance cover might be withdrawn altogether, possibly leading to the collapse of the property market and urban blight and decay.

There are great uncertainties in the sea-level rise scenario and other climate change impacts that will increase the risk of severe flooding. Storm surges will be influenced by changes in the number, location and, particularly, the strength of storms (Lowe and Gregory 2005). Regionally the Thames Estuary is subsiding at

0.7 mm/year in the Thames Estuary (Shennan and Horton 2002). Regional variations in climate-induced sea-level rise may also occur because the warming of ocean water is not uniform and neither therefore is the expansion of ocean water. Changes in ocean circulation and atmospheric pressure will also affect the distribution of sea-level rise. These regional differences in climate-induced sea-level rise can be quite substantial and can vary by up to ±50% of the change in the global average (Hulme et al. 2002).

The collapse of the West Antarctic Ice sheet is a poorly understood phenomenon (Nicholls et al. 2008), so the scenario for exploring social risk responses was kept very simple: a uniform global 5 m rise over 100 years, starting in 2030 (Fig. 1). The primary source of the 5 m rise is assumed to be collapse of the West Antarctic Ice Shelf, although this does not preclude other contributions to the rise over this 100 year period (e.g., the melting of the Greenland ice sheet (e.g. Gregory et al. 2004). Following the full collapse of the West Antarctic Ice Sheet in 2130 (in the scenario), global sea-level rise slows substantially (but would continue at least due to thermal expansion of the oceans). The selected scenario deliberately represents a significant climate 'surprise' for London (and the world).

All other climate factors are presumed to remain constant, which in relative terms, is a reasonable assumption. In addition to raising ocean level, rising sea-level is assumed to raise all coastal processes that operate around sea-level and allows larger waves to reach the shore before breaking. Therefore, the immediate effect of a rise in sea-level concerns submergence and increased flooding of coastal land, and saltwater intrusion of surface waters.

The flood analysis considers both surge flooding and increased river flooding upstream of the new tidal limit. It is also assumed that all coastal ecosystems are lost, although some new habitats may develop inland.

The scenario assumes an increase in property and population at-risk, but not a significant change in flood planning in the UK. When the accelerated sea-level rise begins in 2030, there is considerable uncertainty about how long it will continue and the future rate of sea-level rise.

4 Impacts of the scenario

The 5-m sea-level rise would progressively overwhelm all the existing sea defences over a number of decades (Dawson et al. 2005), so assuming that storminess is unaffected by these changes and no new defences are constructed, the two main hazard zones are submerged land below maximum annual tides, lost to human utilisation, and the new coastal flood plain, the area below storm tides, where permanent human utilisation might continue but which would be susceptible to periodic flooding from storm surges (Fig. 3).

Due to the topography of the Thames Estuary floodplain, the area at risk from flooding increases most rapidly for the first 1 m of SLR. Each additional 1 m of SLR produces a smaller increase in the size of this area. With 5 m SLR and no further flood defences, over 900 km^2 of land would be inundated or at risk from flooding from the 1,000 year event (Dawson et al. 2005).

An experimental flood damage model developed by The Flood Hazard Research Centre (FHRC) utilising flood damage data in updated form (Penning-Rowsell et al.

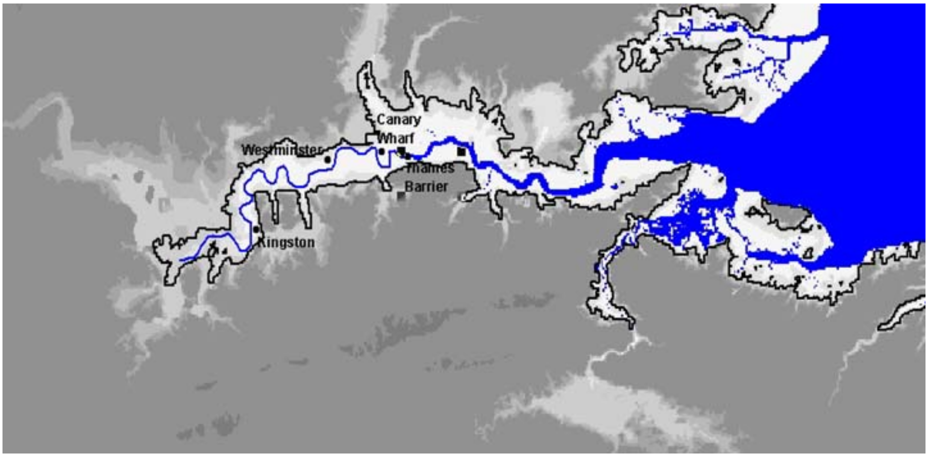

Fig. 3 Generalised flooding in the Thames Estuary with 5 m sea-level rise

1992, 2005) shows that the physical impact of flooding on property directly affected by inundation due to the 5 m sea-level rise scenario (i.e. very deep flooding in many parts of the floodplain) would be about £76 billion with about £40 billion being the residential property at 2002 prices) (Fig. 4). This would be an enormous loss given that DEFRA estimated annual average flood damage in England and Wales to be in the region of £1 billion in 2004 (ABI 2004), and the summer 2007 floods in

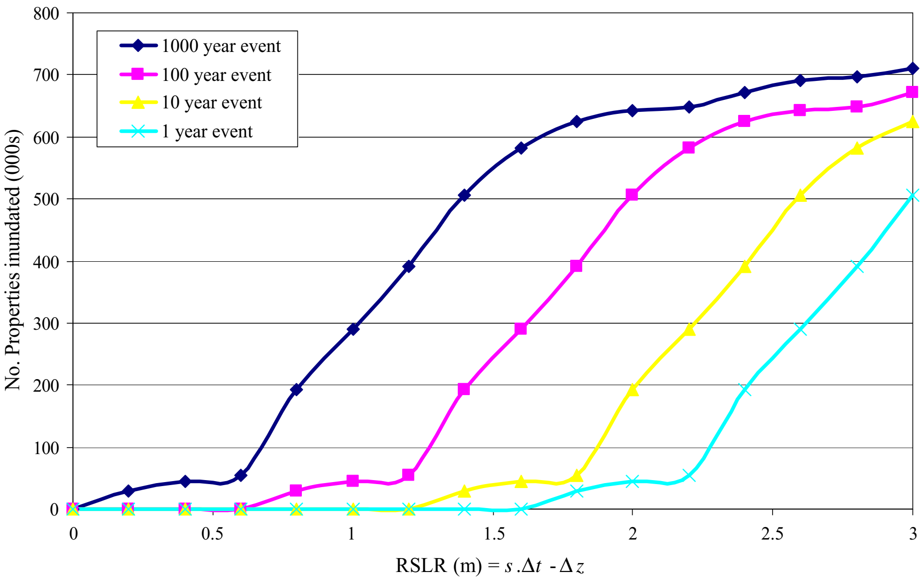

Fig. 4 Properties flooded by return period

England and Wales are believed to have generated losses of around £4–£5 billion The estimates produced by the FHRC model is for economic losses and does not take into account the indirect costs of such inundation, such as loss of working, the impact on trade, infrastructure and the insurance industry or the possible migration of people and businesses out of the area due to loss of confidence in London as a secure centre. Nor does it take account of potential secondary impacts of flooding beyond London. Although national economic loss estimates provide the basis for decisions about government investment in flood protection in the UK, they are not the whole picture. Financial losses in the commercial sector can be expected to be much larger than economic losses, and will drive the decisions about the future viability and location of businesses.

As the sea-level rises the increased risk of major flooding due to storm surges increases dramatically. The impacts of storm surges in the Thames Estuary were assessed using a computer model of flood propagation. This provides estimates of flood depth and extent for a number of sea-level rise scenarios which can be used to help quantify the economic and social impact of inundation.

The high property density in the area will result in very high primary direct damages from any flood event. Moreover, important commercial districts, such as Canary Wharf, are in the higher risk zones—being placed under threat from only a small increase in sea level. Whilst the direct damages to property and infrastructure may be large, the potential impact on the London economy through business interruption costs could be very significant (Parker 2007). The worst case scenario is perhaps illustrated by the 2005 Katrina/New Orleans disaster. Businesses in central New Orleans were totally destroyed; and small and medium size enterprises were particularly badly affected and many went bankrupt. Those whose customers were mainly in the disaster-hit area lost much of their workforces whose homes were lost causing them to move away from the city. The impact upon the UK economy in the long term might also be serious with a worst case scenario being the loss of important business to other financial districts in Europe such as Frankfurt. The global nature of many businesses in London might mean the impact of a serious flood event is felt by businesses worldwide (Dawson et al. 2005).

The population density of London means that evacuation of large areas poses a very serious problem for the emergency services, the assets of which are partly located in the flood plain. The risk of inundation of many major central London hospitals further adds to this strain. Water velocities can not be reliably extracted from the computer model used in this study; however it can be seen that large areas of land are likely to be inundated rapidly. Water levels in central London could rise at up to 2 m per hour. This rate of rise poses a very serious threat to human life if the barriers fail (as happened in New Orleans). The short timescale over which the serious flooding of central London can occur makes the Thames Estuary, and those living and working in it, very vulnerable to extreme flood events, exacerbated in the 5 m sea level rise scenario (Fig. 5).

In addition to urban impacts, valuable coastal habitats such as salt marsh and mudflats, which play an important part in coastal protection, may be progressively lost or drowned, although some coastal habitats might reform at the new shoreline. The additional housing development required by any permanent, large scale relocation of populations from inundated urban areas would increase the pressure on land and almost certainly result in significant habitat changes leading to the loss of some types.

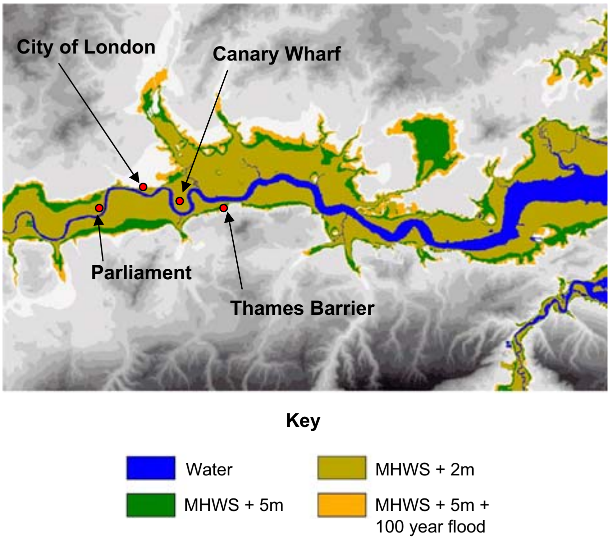

Fig. 5 Flood zones in London

5 Stakeholder interviews

Organisations to approach for interviewees were identified using the Venn diagramming technique (Pretty et al. 1995) to map out which organisations and individuals would be involved in making decisions in response to the risk and which would be involved in dealing with the impacts or representing victims of the impacts. A 'snowballing' process was used once the first round of interviews had been set up each interviewee was asked to suggest other organisations, preferably with named individuals.

Identifying appropriate people within an organisation was time-consuming. It was often difficult to persuade busy people that considering the implications of potentially catastrophic sea-level rise was something they should make time to do. People from like-minded research organisations were the easiest to engage as they were more familiar with discussing such hypothetical situations. It was very difficult to get interest from other groups, especially those who work with short planning frames, such as the financial sector, industry, port authorities and local politicians. It was impossible to achieve a full cross-section of actors: interviews were conducted with 25 individuals from 21 different organisations (22 in person and three by telephone). The interviewees came from a range of government departments and associated bodies, NGOs, trade associations, the insurance industry, emergency planning, environmental and conservation organisations, town planners, flood risk managers, flood action groups, London transport systems and local government. In large organisations such as Government departments or public bodies such as the Environment Agency individuals from different parts of the organisation were interviewed to get both strategic and operational perspectives.

The scenario was initially presented as a forecast of the form: 'A high level review panel has concluded in 2030 that the West Antarctic Ice Sheet is beginning to collapse and there is a 30% probability of a 5 m sea-level rise by 2130'. Maps illustrated the area that would be inundated with a 2 m rise and a 5 m rise in sea-level (assuming no defences) including the additional effect of a 1 in 100 year flood event. Interviewees were asked to respond as if they were in their current position but in 2030. A range of issues were raised:

- How would they and their institutions respond? What issues would arise? What would be the greatest challenges?
- Who would have power to make decisions in this scenario?
- What options are available and which are most likely?
- How would the public respond? Would there be panic or calm? How would that affect decision-making?
- What would be protected?
- How would a solution be funded? Who should pay?

6 The policy exercise

Strategy games have been used in many different situations: military strategy; corporate planning and forecasting; public policy and disaster preparedness (Toth and Hizsnyik 2008). They provide a way to integrate intangible and non-quantifiable political, societal and economic factors into the strategic planning process. They can be used to think through crisis management and assess the performance of different strategies in advance. The basic requirements for a game are a scenario, roles and rules.

For the policy exercise game, which was a day long exercise, the rules were simply to stay in role, to keep to time, and to be plausible. Material from the exercise would not be attributed to individual speakers (the Chatham House rule). The roles were written to fit the positions of the participants but adapted for 2030. For example, English Nature (now Natural England) became Natura UK, with the participant playing the same role as he currently holds at English Nature. Prior to the event each participant, including members of the research team, received a paragraph of information on their role which they were free to adapt, within the limits of plausibility, including leaving out anything they considered implausible. The participants were encouraged to be creative; with such an extreme scenario, traditional approaches might be inappropriate. Prior to the policy exercise, a scenario of sea-level rise in the Thames Estuary and a review of the effects on coastal areas and a socio-economic scenario for 2030 were sent to participants.

The aim of the exercise was to investigate possible responses to a not implausible, albeit very low probability, high consequence scenario using the collapse of the West Antarctic Ice Sheet as an example. The participants, or others in their organisations, had already been questioned as individuals but now they had the opportunity to hear and respond to others' views. Through these interactions we aimed to uncover plausible responses to the scenario and identify potential weaknesses in flood management approaches to dealing with such an occurrence. By undertaking this exploratory exercise we also explored whether this was a feasible way to look at this scenario. It was the process of finding a solution that we were interested in rather than the technical merits of one solution over another. We were not intending to conclude by making a definitive set of recommendations on how to respond, but we did hope to gain insights into the process to support the information gained from interviews and the literature. Not all stakeholder groups were represented. It would have been interesting to compare the results of several strategy games but, this was not attempted.

After a brief welcome and introduction, the participants were asked to be in their roles (2030 in the morning, and 2050 in the afternoon). A meeting of the First Advisory Group on Regional Development had been called, chaired by a representative of the Greater London Regional Development Agency (a participant, in role, informed in advance). A report had recently been released by the British Antarctic Survey presenting worrying new information on the state of the Western Antarctic Ice Sheet. The latest scientific evidence of the WAIS collapse was presented by a member of the project team (playing the role of a climate scientist from the British Antarctic Survey) along with a review of the history of flood protection and sea-level rise issues in the Thames Region 2000 to 2030. The chair asked the committee to discuss: the adequacy of the forecast; the range of potential responses; criteria for evaluating responses and further steps that should be taken at this point. Later in the morning, three groups investigated developing a communication strategy; the economics of the options, and a more in depth assessment of the different options. In plenary, criteria for assessing the best option were decided and prioritised. Five options were chosen as being the most favourable. During lunch, a control group made up of the research team and some stakeholders met and reduced the list of options to three:

- Outer barrage, protecting London to its current level of protection (see Table 1)
- Relocation of enterprises, infrastructure and people out of London (see Table 2)
- Reshaping London with some areas being inundated and others being protected (see Table 3)

The options resulting from the discussions were very simple (either 'protecting', 'abandoning' or 'reshaping' London) which suited the purpose of the exercise. Raising embankments along the Thames was discussed but not pursued as a viable option for sea level rise beyond 2 m. However, embankments can be built very high if land is available. In reality, there are many permutations of these approaches that could be applied, with, for example relocation of some eastern areas of London and protection of the centre. Indeed it is now widely recognised that effective flood management involves portfolios of measures adapted to particular localities (Evans et al. 2004). However, the freedom to adapt options to particular localities would have detracted from the clarity of the role play and would almost certainly have resulted in further prevarication. Furthermore, for a threat of the magnitude of the one considered here, there is a strong case for a coherent city-scale response.

The outcome of the 2030 committee was disagreement and procrastination, so they failed to choose a response option. The control group responded to this in the design of the afternoon proceedings. The afternoon session was (set in 2050 when sea levels are 1-m higher than 2030 and rising at 5 cm/year). An update on the WAIS collapse was given by the same climate scientist (a little older) and a second committee, a Royal Commission, was formed to review action since 2030 and agree on a response option for London. The lack of earlier response meant that the standard of protection was now 1:1,000, and declining rapidly. Without action it would diminish to only 1:100 by 2070, and continue to decline to 1:1 by 2110.

The thee key criteria for choosing a suitable response option were that it should be (a) socially acceptable, (b) preserve London's economy and (c) support national

Table 1 The outer barrage

For	Against
This could be used as an interim option to buy time for migration out of London	This option is expensive, especially if it is not the whole solution
The construction of the outer barrage presents a one-off cost that could be funded through taxes. The assets at risk are so great that such a barrage would be technically feasible. [The cost of construction was estimated during discussions to be £10–25 billion, depending on its location and length. This is roughly equivalent to the annual UK surplus on business revenue]	The cost of maintaining the barrage and its associated defences would be very high. The standard of protection provided is only as good as the weakest part of the defence system
Could be built to last many years and be designed to act as a transport link between the north and south banks of the Thames Estuary	This is not a sustainable option long term and it would have to be maintained replaced (or abandoned) and eventually
This could provide the same high level of protection as exists now	The construction process could take many years, assuming it is technically feasible as most estuaries have shifting sands and the barrage would need decent foundations and scour protection. The choice of site alone would take 2 years
This would be the least disruptive option for the city and life for most people could go on as normal	If you used the money required for the barrage on development in London it would add value and improve the environment making London a better place to live
This option creates a much bigger storage area for water if there is a storm surge	The outer barrage would have to be built as a fixed structure that could not be opened in to allow ships to pass. So, unless a ship lock system was built into the barrage the Port of London would either be lost or moved downstream of the new barrage

The barrage could protect against storm surges	It is difficult to know how high to build the barrage and its associated defences and each increment of height would significantly increase the cost, material resources and time required to construct the defences. Being seen to waste money would look very bad for the government if the flood risk did not materialise
This could be the most popular option for the insurance industry and enabling them to provide affordable insurance cover	The problem of aggregate risk remains. Would re-insurers accept the risk? 25% of people in the flood risk area do not have domestic insurance now (ABI 2004). If premiums go up only a small amount the number of people who can no longer afford insurance would increase
This option could preserve London as it is now and nothing would have to change	The area protected could be perceived by the rest of the nation to be getting favourable treatment, reinforcing the north–south divide
The outer barrage could be designed to use the tide to generate electricity and possibly provide up to 6% of the UK's future renewable energy supplies	This option would have huge operating costs and require the continuous pumping of water requiring significant power inputs, although additional upstream defences may help overcome the need to pump

Table 2 Relocation out of London

For	Against
This is the safest option if people, businesses and infrastructure can be relocated outside the flood zone	This option is socially complex and would need the use of incentives to get people to move out, unless the urgency was very great
This option is sustainable as it does not require any complex technology or maintenance of defences	To prevent the area to be inundated from being a source of contamination you would need to completely remove all potentially harmful materials such as waste and concrete. This could be time consuming and expensive
No construction materials are required for defensive structures	The evacuation process could be very time consuming, complicated and lead to conflict
The insurance system could continue as before as all new dwellings will be built outside the flooded area	Would the people who relocate be compensated? How would this work?
If this had Government support vulnerable groups could benefit from newer better housing if they relocate to a new area	Vulnerable groups might be worse off if the affluent, mobile section of the population leave early and relocate to best areas leaving only poorer areas for the most vulnerable sectors of society, creating ghettos and slums
This option would provide the opportunity to develop vibrant new towns designed to use the best new technology for communication systems, infrastructure, energy efficiency and transport and waste disposal	Decisions about where people should be relocated to will be difficult to make and could lead to tension in the host communities due to increased pressure on existing resources, perceptions of favourable treatment for the immigrants etc
Managed realignment of the coastal areas would, over time, provide new, natural coastal habitats	Many coastal ecosystems will be lost including vital breeding grounds for rare sea birds and waders
London would not be seen to be getting favourable treatment, reducing north–south tension	The alchemy that created London would be lost for ever, the heritage, the city, the culture. It would take a long time to create such a world class city elsewhere
This option provides opportunities for the rest of the nation to develop	London is the nation's financial centre. Could the nation survive without it?

Table 3 Reshaping London

For	Against
An opportunity to redesign the central part of London in a new and exciting way creating new river vistas with a vibrant, modern atmosphere	Would result in the loss of areas of historical, architectural and cultural interest. Would be unpopular with local heritage groups, fighting to protect their particular building/area and also local residents losing their personal heritage. Decision makers who have power to choose to inundate one area and save another would be unpopular although this could be mitigated through stakeholder involvement
New transportation systems would become viable, making the river the main option for the transport of people and goods avoiding unpleasant congestion on the roads and the overcrowded underground system	The underground system would almost certainly be lost due to problems associated with ground-water rise and the increased flood risk
This could be a fairly sustainable solution, assuming that there is no further significant rise in sea level	This would require the maintenance of defences on the protected sections
Some coastal and estuarine habitats would be reserved under this option and eventually there could be a net gain in habitats depending on the detailed coastal configuration	Some habitats would be lost due to the rapid rise
Vulnerable groups, including those on lower incomes, might benefit from being rehoused	Vulnerable groups might lose out by being in less vulnerable areas in the new plan evicted from their homes in flood risk areas, perhaps without compensation and little choice of where they can be rehoused. They might also be treated with prejudice in these new areas
This option requires less material for construction than the outer barrage option	Could be time consuming and disruptive to implement and much of the disruption would occur in the centre of the city, affecting productivity, quality of life and deterring tourists
Insurance companies could continue to provide flooding cover with this option	Insurance premiums might go up
The risk of flooding in Central London is significantly reduced	The risk of flooding in Central London still remains, although it is remote
There would be opportunities for new uses of the river including diving to visit submerged buildings, water sports centres, floating houses, shopping malls and entertainment venues etc	It could be costly and technically complex to decontaminate areas before submerging them. There would be a choice between removing the existing infrastructure or simply abandoning it. Both options are problematic

sustainability. The social and strategic importance of London was rated quite highly (although this may be biased by the fact that the group only considered impacts in the Thames Estuary). The cost of funding, the capital outlay and recurrent expenditure were considered less important than a scheme that maintained London as a socially and economically viable centre.

At the end of the policy exercise (but still in roles), the participants chose their preferred option. The priority scores show a balance in first choices between an outer barrage and reshaping London but the weighted scores gave the edge to the with the reshaping option slightly favoured via second choices. A further exercise rated the options according to how well they met the key criteria identified earlier. Although the outer barrage was considered to be the option most likely to be acceptable to the public, it was also recognised to be the least likely to support national sustainability. Conversely, relocating London was considered to be most publicly unacceptable but much more likely to support national sustainability. Reshaping London was seen as somewhere in between these two options for these criteria.

The role playing was debriefed (out of role) at the end of the day, along with an evaluation of the exercise.

7 Key messages

7.1 Plausible options for the Thames Estuary

Both a retreat and a protect response appear to be possible for London. The choice between these two options depends on a wide range of factors, some of which are beyond policy control e.g. an early extreme flood which triggers disinvestment from London. Much was said about the logistical and financial feasibility of the different options.

The ability to cope with a scenario of extreme sea level rise depends on the speed at which it is manifest. Once the sea-level rise was apparent in the role playing, actors began to draft specific responses and the evidence of sea level rise was confirmed as a trigger to take firm action in the debriefing. The rate of rise is very important in London although less important for some sectors as it is only the maximum height of the rise (and whether that overtops existing defences) that is of interest for them. Other sectors, such as coastal communities, nature conservation organisations and organisations dependent on or responsible for buried infrastructure, are very sensitive to any rise in the sea level.

> The coastline is already hard to defend. We are concerned with 50 cm over the next 50 years. We are struggling already
>
> A wildlife conservation officer

Although the project is not a detailed engineering or economic assessment, a protection response for London cannot be excluded. Visions of a global scale abandonment of the world's coasts under the scenario are not substantiated (Nicholls et al. 2008). However, any protection is likely to be focussed due to the large costs associated with its construction and the lower population density in parts of the Thames Estuary. It seems reasonable to expect widespread retreat and abandonment in these areas and that protection would only be found in the highest value areas, if it can be justified at all.

7.2 Paralysis in decision-making

There were many comments on the difficulty of making decisions over such long time scales.

> It is extraordinarily difficult to make these decisions. We are good over 5–10 years but terrible over 100 years.

This is also due to the short term focus of the decision makers and many other organisations.

> No government works more than 2–3 years ahead. Politically it would be difficult to see any government taking big, unpopular, decisions. There would always be questions about probability

> political agendas may be too easily prioritised to move the investment and/or incentives to take preventative action into medium term, i.e. NIMTO (Not In My Term of Office).

> If you predict this kind of eventuality and make plans for it and it doesn't materialise you get voted out of office. Would the Government sit on it then, until it is too late?

This paralysis in decision-making and the associated delay endangers the success of a protection response, increasing the likelihood of the worst-case scenario of an unplanned abandonment of large parts of London. The benefits of making long-term decisions were voiced in the policy exercise and it was generally felt that there was increasing urgency to develop this skill.

> The irony is that if we could make decisions for 100 years ahead then implementation would be much cheaper and there would be time to explore the benefits. We should look 100 years ahead and modify later—that way there would be less opposition.

A contrasting view was that, given the extreme nature of the scenario, decision-making would, in fact, be very simple, like a war or natural disaster. People would accept that this was not a typical situation and allow decisions to be taken on their behalf.

> Decision making would be easy—it would be a crisis situation and there would be a military approach to decision-making. Cold War, military thinking, Use this approach rather than adjust to probabilistic threat management.

Many voiced the opinion that in order to make decisions you had to be certain about the data, particularly where there was a huge resource commitment. As the certainty increased it was envisaged that the decision-making process would become much simpler.

> It is not possible to allocate 10 billion pounds to flood defence based on this

> If in 2030 the IPCC produced a convincing report that there was a ‘smoking gun’ then there would be an immediate decision to either build defences or evacuate. The decision would come down to spending.

Public reaction to the proposed option, which all have huge impacts for people and the economy, would raise questions about how resources are being allocated as some people will seem to benefit from the decision and others will be ‘victims’.

> Allocation of resources, this would be a key point of tension and difficult to manage. You can’t do it randomly. Losing the capital—even talk of it could lead to a huge loss of confidence. Distribution of the burden of paying for the changes could lead to huge resentments. Winners and losers again.

It was felt that certain organisations and businesses would have to give the impression that everything was fine, to cover up the scale of the problem.

> We need to be seen to manage, it doesn’t take much for people to be put off travelling to certain areas—the tourism industry would be very vulnerable to scares, like foot and mouth etc.—denial might be the best option for them.

Without a strong push from the public it might be easy to delay coming to a final decision. There was concern that such a push would not materialise as most people are preoccupied with the smaller, day to day troubles that they understand and can influence. Consideration of these bigger, less tangible issues is put off, even when their impact on peoples lives could be devastating.

> The scale of the problem is too much for people to deal with. There is a problem with denial and scaremongering—people have heard too much. People can handle small, gradual changes but not the big changes.

7.3 Need for new approaches to decision-making

Faced with ‘reality’, which is difficult to capture in role playing, a strategy might have to be imposed if there was no consensus amongst all stakeholders. However, this would take time to develop and might require a different decision-making environment (e.g., more authoritarian control due to the emergence of a ‘wartime’ mentality).

There is no easy option—tough decisions will have to be made. In the role playing, there was no agreement on the best option. All the options put forward had very large financial implications, questions of technical feasibility and would be disruptive to implement. Under each option there were groups who would be winners and groups who would be losers. The default option is for there to be no planned response and let individuals do what they can to cope on their own. This option would suit stakeholders who can relocate, but it would have large political costs, possibly significant liability exposures, and certainly not be optimal on social and economic criteria.

As with the decision to build the original Thames barrier and associated defences, the enormous consequences of a flood in London means that decisions cannot be made using simplistic cost–benefit calculations as the uncertainty associated with the sea level rise and storm surge scenarios is too great. A number of comments were made about the similarly prolonged process of building the present Thames barrier, which had eventually to be decided by the astronomer Sir Herman Bondi (Gilbert and Horner 1984).

7.4 The involvement of the public

In the role playing, the main public responses to the forecast were thought to be either denial or panic. To avoid both, clear communication of the present state of knowledge and strategies under consideration was strongly supported. Adoption of any public strategy would require a clear, transparent process that enables people to contribute and understand decisions made about their future. A few felt that involving the public in decision-making would cause delay and conflict and it was better to make a decision and present it as a *fait accompli.* This would depend on the ability to implement the decision without public support if necessary (as might be the case for an estuary barrage).

The way in which information was communicated to the public was thought to be important and this was brought up frequently in the interviews and the policy exercise. How it was actually presented (on television, an article in a newspaper etc.), who should present it (an academic, the prime minister, the King) and in how much detail would influence how the public responded and how much they could contribute to decision-making.

> there is a great risk of inaccurate reporting by the media which could lead to widespread panic and property blight

Although open consultation might lead to 'lots of reports and paralysis', the overwhelming feeling in both the interviews and the policy exercise was that public engagement was very important and should be started early, 'we have got to start talking to communities'.

7.5 Flood events as catalysts for action

Flood events are important catalysts for action (Johnson et al. 2004). In the role playing, the scenario included a flood event, between 2030 and 2050, that made the risk tangible and which provided a sense of urgency that motivated new and more radical strategies, previously not given much weight. However, if people were not aware of a trend in sea-level rise the events might not trigger new action if there was no strategy 'on the table' and ready to be implemented quickly. People have surprisingly short memories and if the opportunity is not grasped promptly the policy window for new ideas might close.

> Financial markets don't act rationally. If the only signal to the market is a report it could be easily ignored or lost. If, however it was preceded by 30 years of poor weather or if there was a devastating storm surge—that would act as confirmation

Flood events or near flood events were mentioned a number of times for their effectiveness in focussing public attention on the scenario as well as that of the policy makers. It was suggested that it would be wise to have measures ready for such events for the communication of flood risk to the public.

> The floods in 2030 would have been a powerful catalyst, but you have to channel it—the momentum soon dissipates

> Floods have helped to inject a sense of urgency into the proceedings—without them there is no incentive for action—denial [is] much easier. Floods have reminded people that the threat is real and significant.
>
> You need a disaster to force them [the government] to take action.

8 Plausible narratives

Two narratives appear to be consistent with the interviews and discussions during the policy exercise. They illustrate two alternative ways in which society might cope with the scenario of catastrophic sea-level rise. Both are hypothetical, suggesting futures that are somewhat different from present flood risk management.

Abandonment

> Presented with a forecast of extreme sea level rise of 5 m in 100 years beginning in 2030 with a 30% level of confidence based on a consensus of experts, stakeholders in the Thames region would not immediately adopt proactive action. This is partly because of the sense of protection in London established by an overhaul of the Thames flood protection scheme in the period from 2005 to 2030 for 1 m of sea level rise. However, the major impediments to action are not the uncertainty in the forecast but the scale of the threat and the need for concerted action by different stakeholders, each with conflicting views as to the best course of action. The option to protect London by raising existing defences or an outer barrier would be very expensive (a recent estimate for the cost of an outer barrier was £20 billion, without the additional defence work, have high recurring costs and present practical difficulties. It is attractive only if national or European finance would be available. A reshaping of London taking advantage of the larger estuary is an attractive vision but would also require substantial funding to decontaminate landfills and remove installations that would be inundated. Delays in responding—it might take a decade or more to design and evaluate viable alternatives—would limit the responses as the flood risk on top of the accelerated sea level rise starts to affect property insurance and reconstruction after relatively minor floods. The relocation option, essentially abandoning parts of London, is undesirable, but is likely to end up as the de facto response as enterprises and households assess the risks on an individual basis.

The unplanned response of this narrative assumes individual action to locate new investment outside of the potential risk zone, and even dis-invest from London, will dominate the attempts to define a socially desirable, public response. Even the rapid and extreme scenario posed to the stakeholders did not trigger an agreed response that protects London (physically, economically and as cultural heritage).

Civic response

> While the initial response to the forecast was confusion, with further studies of the risks and disputes over the scale of action required, the government and civic society came together to establish a viable decision making framework in which to anticipate a large-scale, planned response. Many options for financing

> the response were investigated including the extent to which London could finance its own salvation. In addition to a local tax, national and EU-wide financial support was obtained and a fund created for design studies, pilot tests and eventually direct subsidies for affected areas. The legal responsibility to protect private property from environmental threats related to climate change was shared between government and private land owners. This included a mechanism to internalise the future costs of protection, preventing companies and, to some extent, land owners from simply abandoning property that might be inundated in the future.

Although neither narrative necessarily results in successful adaptation, they illustrate how various factors are important in determining the likely response to such an extreme scenario. The extent of government control over spatial planning and risk management determines the degree to which the disparate private actions can be brought together into a public, planned response. In the absence of a strong national framework, decentralised decision making would be likely to result in an unplanned, chaotic response. A related factor is the ability to take decisions with very long time scales, helping to facilitate a concerted response. If decisions are focussed on local, short term issues this would support an inefficient, chaotic, short-sighted response.

The viability of spreading the financial burden will determine the scale of response that can be anticipated. In the absence of viable financial support from national or European (or even global) sources, the disproportionate burden on London residents might encourage abandonment and work against a concerted, public response although given London's large economy maybe the resources could be generated internally. Public engagement and cultures of conflict or cooperation in public decision making will shape debates between private actions and socially desirable responses. While these are both essential to a planned response, a chaotic response might proceed even with a high degree of public awareness and involvement in strategic decision-making due to other constraints (primarily legal and financial).

Observed trends and flood events, the risk realised, will stimulate responses, but could push actors either into or away from socially planned strategies. If a flood event occurs early in the planning cycle, this might help foster cooperation and support for ambitious responses. However, if the threat is realised in the absence of a concerted and viable action plan (at least as perceived by the actors) then the dominant response could be chaotic, private actions to minimise individual risks.

9 Conclusion: toward adaptive management

The potential paralysis in decision-making highlighted in the policy exercise could prove to be determining factor in whether society can cope with the extreme scenario considered here and has wider implications than just WAIS collapse. The prime causes of this paralysis (the lack of experience of planning over longer time frames, the large scale of the response required, the need for coordinated action between many different actors with conflicting agendas, and the uncertainty of the available information) act to prevent an effective assessment of the situation and thus the possibility of an effective response. Increasing capacity for adaptive management that could better respond to the full range of threats, including large-scale threats as considered here, requires action in several directions.

9.1 Supporting longer term decision-making

The human tendency to focus on here and now, ‘fight or flight’ responses, makes it less easy to take longer term futures into account (Ornstein and Ehrlich 1989). Decision and policy makers need tools to support long term predictions, to identify creative new approaches, to investigate the robustness of different adaptation and mitigation options to a range of future scenarios of climate and socio-economic futures. A move from solution driven approaches to processes of continual management rests on understanding the complex interactions between socio-economic, natural and technical solutions, and include people’s values and beliefs as well as scientific measurements. A portfolio of responses, including engineering options (e.g. dikes, barriers), social (e.g. early warning systems, emergency preparedness) and land use planning solutions (e.g. building codes, flood proofing), are more likely to be effective and adopted than the simple strategies evaluated in the stakeholder policy exercise.

9.2 Social learning and inclusion of the public in the process

The policy exercise and interviews emphasized the importance of public engagement in the decision-making process required for this scenario although there was some difference of opinion as to how great this should be, especially for an extreme scenario that requires an urgent response. People in the UK are not used to feeling exposed to severe threats to their existence. Respondents noted a ‘somebody ought to do something’ mentality. Raising awareness would need to jolt people out of their complacency and make it clear that although the threat is uncertain there is a real risk and that they have a role in reducing their exposure. A flood might do this; or the insurance industry threatening to reduce or withdraw cover might be effective in forcing people to take the threat seriously.

People would need formal and informal education and access to unbiased information. As there is likely to be conflicting opinions on any decision, the media would have a role in presenting information and alternative opinions. Teaching people the skills of conflict management would enhance cooperative and inclusive approaches.

9.3 Making decisions with uncertainty

Learning how to make decisions under uncertainty is essential for adaptive management (McMichael 1993; Dovers and Handmer 1992, 1995; Handmer and Dovers 1996; Ravetz 1990). In the context of climate change, it is important to distinguish between different degrees of uncertainty. Whilst there is a range of uncertainty, current sea level rise projections provide a reliable basis for some decisions. On the other hand, the sea level rise scenario addressed in this paper is surprising; an announcement that it is going to materialize would inevitably be met with some scientific skepticism, which would contribute to the inertia observed in the role play exercise. Under circumstances of severe uncertainty, new approaches to decision-making that recognise incomplete knowledge and lack of experience (Handmer and Dovers 1996; Smithson 1989), and thus do not require accurate assessment of probabilities are required. This points to methods based upon use of a wide range of scenarios (without necessarily attaching probabilities to those scenarios) and analysis of robustness to uncertainty (Dessai and Hulme 2007; Hall 2007; Lempert et al. 2003).

9.4 New social and institutional approaches

'Change at the margins' or fine tuning existing structures and institutions may be sufficient up to a point (Dovers and Handmer 1992), but coping effectively with the extreme scenario described here will require fundamental changes to institutional processes. New institutions will be needed that can react flexibly, particularly ones that have the ability to reflect on and learn from their experiences and then act on their learning to suit changing circumstances.

Flood management in such a scenario needs to move from managing nature to working with nature and managing ourselves. Addressing our role in the problem means examining our behaviour and addressing those activities that increase risks or prevent transformations to more sustainable lifestyles.

9.5 What can we learn from not implausible scenarios?

Insights into responses to forecasts of low probability, high consequence threats will be gleaned from a variety of approaches and processes. Extreme, not implausible scenarios and stakeholder role playing, open debates regarding the shift from incremental climate adaptation (in the case presented here, flood management) to institutional and policy changes at a much broader scale, (Johnson et al. 2004).

Climate change is not a remote issue for future generations. In 2001 the Intergovernmental-Panel on Climate Change report characterized the West Antarctic Ice Sheet as a 'slumbering giant' but dismissed concerns that it was disintegrating (Watson and the Core Writing Team 2001). At a recent IPCC conference (February 2005), Chris Rapley, Director of the British Antarctic Survey (BAS) said "the giant has awakened. The previous view was that WAIS would not collapse before 2100. We now have to revise that judgment. We cannot be so sanguine" (Rapley 2005).

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