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

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1. Abstract

This paper considers the perceptions and responses of selected stakeholders to a scenarion of rapid rise in sea-level due to the collapse of the West Antarctic ice sheet, which could produce a global rise in sea-level of 5 to 6 metres. Through a process of dialogue involving one-to one interviews and a one-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.

Through these interactions we hoped to uncover plausible responses to the scenario and identify potential weaknesses in our current flood management approaches to dealing with such an occurrence. By undertaking this exploratory exercise we hoped to find out whether this was a feasible way to deal with such a low probability but high consequence scenario. It was the process of finding a solution that interested us rather than the technical merits of one solution over another. We were not intending to produce definitive set of recommendations on how to respond but to gain insights into the process of making a decision, specifically what influences it and what assumptions are made.

2. Introduction

This paper considers the implications of a rapid rise in sea-level due to the collapse of the West Antarctic ice sheet, which could produce a global rise in sea-level of 5 to 6 metres [Mercer, (1978), Vaughan and Spouge, (1992), Tol *et al*, submitted this volume]. We focus on the Thames estuary. Poumadère *et al*. (submitted, this volume) focus on the Rhone delta, and Olsthoorn *et al.* (submitted, this volume) on the Rhine delta. There is also a global analysis using the FUND impact model to develop a first estimate of the global effects (Nicholls *et al* , in review).

The collapse of the West Antarctic ice sheet has been called 'glaciology's grand unsolved problem' (Weertman 1976). It is particularly prone to collapse as much of it is below sea-level. If the entire ice sheet slips off global sea-level would rise by five metres even without

the ice melting (Mercer, 1978). This is discussed in greater depth in Tol et al, (submitted, this volume).

It should be emphasised that the 5 metre scenario is fairly implausible but not absolutely impossible. We deliberately chose a scenario that could represent 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. Our objective was to study the perceptions and responses of selected stakeholders to this type of climate change impact. The time horizon had to be sufficiently near to enable people to envisage the impacts. It is unlikely that we would be able to engage people in a debate on decision-making processes for events that would not occur for three or four centuries.

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, due to low atmospheric pressures and strong winds over shallow seas will be influenced by changes in the number, strength and location of storms. Lowe et al. (2001) modelled storm surge for both existing conditions and the climate in 2100, using a 35km resolution model of the North West continental shelf region. Both were driven by wind conditions from a Hadley Centre regional climate model. The results show an increase in 1:50 year return period events for the majority of the British coast. The increase ranged up to 0.24 m. Debernard et al (2002) conducted a similar analysis of wind, wave and storm surge climates in the northern North Sea. Present day and future (2030-2050) conditions were modelled. These were driven with output from regional climate models. The results showed relatively small changes, but rougher autumnal maritime climates.

It should also be noted that the rate of sea level rise will not be the same at all points on the globe. This is due to ground settlement (currently about 0.7mm/year in the Thames estuary (Shennan and Horton, 2002)) and regional variations in sea level rise. Regional variations in climate-induced sea-level rise 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 per cent of the change in the global average (Hulme et al, 2002). They are not well predicted by climate models.

In addition to uncertainty in the sea-level rise scenarios there is even greater uncertainty about changes in social structure and land use in the distant future. For the purposes of this work we only use rough estimates of the changes in the natural system. We do not attempt to develop precise models, as precision would be easily mistaken for accuracy. Any model would be used far outside its domain of calibration and validation. Instead, we develop dense scenarios ('storylines' or 'future histories') that are largely qualitative in nature, but do reflect, in an internally consistent manner, the complex implications of what a 5-6 metre sea-level rise would mean to people.

Using this extreme, but plausible, scenario with decision-makers and affected groups enabled us to think through our ability to cope, or not cope, what influences this and ways it might be enhanced. Through the dialogue process we were able to think through what influences decision-making when information is uncertain and to determine our ability to plan, prepare for and implement plausible solutions.

3. The Thames Estuary

3.1 Demography and current land use

The Thames region extends from western boundary of the London metropolitan area (near the Teddington weir) to the tidal zones planned for development in the Thames Gateway. The region encompasses London as well as Southend-on-Sea and the smaller communities of Essex and Kent. The region is exposed to greater flooding damage than any other area of UK because of the concentration and value of its assets. Although susceptible to inundation of flood plains by river water, local flooding when old and inadequate drainage systems are overwhelmed and the rise of the water table, tidal surges present the greatest threat. Surges occur when areas of low pressure move south or south west over the North Sea creating a hump of water that can be up to 100 miles wide. Given the right conditions this mass of water is squeezed down between the UK and the European mainland where the sea is shallow, increasing the tide height by up to 1.5m. If this coincides with a spring tide then the increase

in tide height can be sufficient to overtop defences. This was witnessed in 1953 when a storm surge killed 300 people, flooded 240,000 houses and 65,000 hectares of farmland along the East coast and the Thames Estuary (Kelman, I, 2004). Depending on its magnitude, a tidal surge today could affect an area of the Thames Estuary containing 1.25 million residents (1/6 of population of London) 1.5 million commuters and property and economic activities worth £80-100 billion (Parker, 2002).

The population of Greater London, now 7.5 million, is projected to become 8.1 million by 2016 (London Assembly, 2002). Household numbers are projected to increase from 3.1 million to 3.6 million in the same period. The population is expected to continue to rise after this, although the likely rate of rise is not yet known. To sustain the growth of London, more development is planned in the coming years, particularly in financial and business services. The strategy is to regenerate East London and expand eastwards in a linear 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 biggest co-ordinated building programme 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).

Land for development in the London area is scarce as much of it is already highly developed or subject to planning restrictions such as in the green belt. 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 very great. For insurance companies, the losses from a major flood affecting central London would be very great and push premiums out of the reach of people on low incomes. In some areas insurance cover might be withdrawn altogether[1] leading to the collapse of the property market and the associated urban decay. The new business and finance areas in Canary Wharf would be very vulnerable to increasing flood risk. The City of London, London's financial centre, would also suffer despite being above the mean sea-level after 5 m sea-level rise. Although it might have the resources to recover from a major flood, but it is questionable whether it would to stay, due to the loss of

confidence in London as a secure centre. Less vulnerable locations would become more attractive.

3.2 The existing flood management system

Flood management 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 (greater than 1 in 1000 year event) (Gilbert and Horner, 1984). This is well beyond the normal standard of protection for flood defence nationally but is justifiable given the huge number of lives, property and infrastructure at risk. The standard of protection in other 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 this, the level of protection will continue to decline due to rising sea-levels unless it is upgraded (Gilbert and Horner, 1984, Kelly, 1991). Observations in the Thames estuary show that 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/yr during the 19th Century and 2.2 mm/yr in the 20th Century has been observed at Sheerness (Woodworth, 1990; Nicholls *et al*, 1999). Extreme water levels have risen more rapidly than mean sea-levels, about 1 metre 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 21st 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. 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, 2002, Klein, et al, 2005).

3.3 The Thames Estuary case study scenario

The collapse of the West Antarctic Ice sheet is a poorly understood phenomenon so the scenario was kept very simple in order to satisfy the main goal of understanding the possible responses. Therefore, the analysis is based on a uniform 5-m rise over 100 years, starting in 2030 (Figure 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. The scenario has the following characteristics:

- A uniform rise in sea-level in the Thames estuary of 5m per century beginning in 2030;
- A global-scale phenomena due to the collapse of the West Antarctic Ice Sheet, although the scenario ignores possibly compounding effects of the melting of the Greenland ice sheet (e.g. Gregory et al., 2004)[2];
- The onset of the sea-level rise is anticipated in the scenario by a panel of experts in 2030 but had not been taken into account in earlier policies and planning (that it, in terms of flood planning in the UK it is a relatively sudden and unexpected threat);
- When the accelerated sea-level rise begins in 2030, there is considerable uncertainty about how long it will continue and the rate of sea-levels rise; and
- The end of the rapid rise is abrupt following the full collapse of the West Antarctic Ice Sheet, and global sea-level rise slows substantially beyond 2130 (but would continue at pre-2030 rates due to thermal expansion of the oceans).

Due to the extreme nature of this sea-level scenario, 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 5 m scenario is considered for the Thames Estuary, defining the worst-case impacts in 2130. 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.

Figure 1 The Sea-Level Rise Scenario Considered in the ATLANTIS Project.

3.4 Likely impacts of the scenario

Figure 2: Generalised flooding in the Thames Estuary with 5 metres rise in sea level (assuming no new defences).

Figure 3: Flood zones in London with 2 and 5 m sea-level rise. Also shows the additional impact of a 100 year flood.

The 5 metre sea level rise scenario is sufficient to overwhelm all the existing sea defences, so, assuming that storminess is unaffected by these changes and no new defences are constructed, the two main hazard zones will be:

- Submerged land - below maximum annual tides, lost to human utilisation;
- 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.

The topography of the Thames estuary floodplain is such that the area at risk from flooding increases most rapidly for the first 1m of SLR. Each additional 1m of SLR produces a smaller increase in the size of this area. In the worst case scenario of 5m SLR and no intervention, over 900km^2 of land would be at risk from flooding from the 1000 year event (Dawson et al, 2004).

The Thames flood plain is the site of one of the largest increases in flood loss potential in Europe. Damage potential has tripled between 1987 and 2000 for commercial property and increased 2.5 times for residential property due to ownership of technology (computers, multi-media systems etc.), new for old insurance and a reduction in salvage of flood damaged

items (Penning-Rowsell *et al*, 2002). London is dependent on aging and easily disrupted infrastructure. The underground system is especially vulnerable. In the 1980's there was significant development of previously uninhabited tidal flood prone land, including more or less the whole of the redeveloped docklands and riverside areas between the City and Woolwich. A flood damage model developed by The Flood Hazard Research Centre predicts that the physical impact of flooding on property directly affected by inundation due to the 5 m sea-level rise scenario is £76 billion with £40 billion being the residential property damage (Parker, 2002). This estimate 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 migration of people and businesses out of the area due to loss of confidence in London as a secure centre. As the sea-level rises the increased risk of major flooding due to storm surges increases dramatically (see Fig 4).

Figure 4: Properties flooded by return period

Storm surges in the Thames estuary were modelled for the Atlantis project using a hydrodynamic software tool. 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. However, 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 the infrastructure may be large, the potential impact on the UK economy in the long term may be disastrous 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 may mean the impact of a serious flood event is felt by businesses worldwide (Dawson *et al*, 2005).

From a social perspective, the population density of London means that evacuation of large areas of floodplain poses a serious problem for the emergency services. The risk of inundation of many major central London hospitals further adds to this strain. Water velocities can not be reliably extracted from the inundation model, 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 2m per hour and greater than 1m per hour for the 1:1000 year event after 1m net SLR. This rate of rise poses a serious threat to human life. The short timescale over which the serious flooding of central London can occur makes the Thames estuary very vulnerable to such an extreme sea level rise scenario. These values assume the current defence system, currently under review, is not upgraded.

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 large scale relocation of populations from inundated urban areas would increase the pressure on land and almost certainly result in significant habitat losses.

4. Methodology

4.1 The case study process

Figure 5 Diagram of the case study process

For the purposes of the interviews and the stakeholder policy exercise 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'. The dialogue began with discussions among a few key stakeholders who agreed to advise the project. Semi-structured interviews were followed by a policy exercise structured as a role playing, strategy game.

4.2 Interviews

In the interviews the scenario was described and maps presented to illustrate the area that would be inundated in the South East part of Britain and the area of London that would be submerged with a two metre rise and a five metre rise in sea-level (assuming no defences) including the effect of a 1 in 100 year flood event. Interviewees were asked to respond to the scenario as if they were in their current position but in 2030. The interviewee was asked for a general response to this i.e. how would they, in their role now, respond to such a scenario?

What issues it would raise? What would be the greatest challenge for them and their organisation? The discussion that followed was more or less guided (depending on the interviewee) to cover a range of issues including:

- 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?

Organisations to approach for interviewees were first identified by undertaking a stakeholder analysis using the Venn diagramming technique (Pretty et al, 1995). This enabled us to map out which organisations and individuals would be involved in making decisions in this scenario and which would be involved in dealing with the impacts or representing victims of the impacts. Once the first round of interviews had been set up each interviewee was asked to suggest other organisations, preferably with named individuals, as a recommendation greatly increased the likelihood of obtaining an interview (a process known as 'snowballing').

Identifying the appropriate organisations and more particularly, identifying appropriate people within an organisation was time-consuming. It was often difficult to persuade busy people that considering the implications of 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 City, industry, port authorities and local politicians. Thus it was impossible, given the scope and resources of the two-year project for one researcher to achieve a full cross-section of actors. In the end, interviews were conducted with 25 individuals from 21 different organisations (22 in person and 3 by telephone). The interviewees came from a range of government departments and associated bodies, the NGO and private sector representing business, 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.

4.3 The policy exercise

Strategy games have been used in many different situations: military strategy; corporate strategic planning and forecasting; public policy and disaster preparedness (Toth and Hizsnyik, submitted this volume). 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, a set of roles and some rules.

For our game, a day long exercise, we had a minimal set of rules (to stay in role, to keep to time, to be plausible, and for speakers to remain anonymous). The roles were written to fit the positions of the participants but adapted for 2030. For example, English Nature 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, leaving out anything they considered implausible. The participants were encouraged to be creative as with such an extreme scenario traditional approaches were unlikely to be appropriate. In addition to the role play briefs, 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 also sent to participants.

The aim of the day 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 hoped to uncover plausible responses to the scenario and identify potential weaknesses in our current flood management approaches to dealing with such an occurrence. By undertaking this exploratory exercise we hoped to find out 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 come out with 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. As we had only one strategy day, not all stakeholder groups were represented. It would have been interesting to compare the results of several strategy games but, within the constraints of the project, this was not possible.

After a brief welcome and introduction, the participants were asked to be in their 2030 (later 2050) roles for most of the rest of the day. 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 collapse of the West Antarctic Ice Sheet was presented by a member of the Atlantis 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. As we did not want to constrain how this was be done the chairman and the group made this decision. Later in the morning the group split into three to investigate: developing a communication strategy; the economics of the issue and; a more in depth assessment of the different options. Later, 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 which were:

- an outer barrage, protecting London to its current level of protection;
- the relocation of enterprises, infrastructure and people out of London.
- the reshaping of London with some areas being inundated and others being protected;

It should be noted that the options resulting from the discussions were very simple (either 'protecting', 'abandoning' or 'reshaping' London) and this suited the purpose of the exercise. In practice, 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 second session was set in 2050. An update on the West Antarctic Ice sheet 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 an option for London. The 2030 committee had procrastinated and had failed to choose an option for London. This delay means that the standard of protection of the defences was now 1:1000, and declining rapidly. Without action it was to diminish to only 1:100 by 2070, and continue to decline to 1:1 by 2110.

5. Results

The specific results of the policy exercise were a set of response options, criteria to be applied to response options and a rough rating of the options that had been developed in the discussions. The thee key criteria for choosing a suitable response option were that it should be socially acceptable, preserve London's economy and support national sustainability. The social and strategic importance of London was rated quite highly (although this may be biased by the fact that we asked the group to only consider impacts in the Thames Estuary). While the cost of funding the capital outlay and recurrent expenditure was important, it was 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 role), 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 reshaping option due to the weight of second choices for this option. 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[3].

The dialogue from the interviews and policy exercise was analysed to inform our understanding of participants perceptions of the risk and the way decisions should be made to respond to it. Different categories of enquiry were identified for the analysis e.g. Is it the flood events or the continuous rise that is discussed? How do participants react to the two scenarios, 2030 and 2050? What if anything causes them to take action? How do the public behave in response to this scenario?

6 Key messages

6.1 Plausible options for the Thames Estuary

Both a retreat and a protect response appear to be possible for London under this extreme scenario. 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 arguments for and against the three options (construction of a large outer barrage, mass-migration out of Central London and relocation in new, purpose-built towns) have been brought together in the following tables:

Table 1. Reshaping London

Table 2. The outer barrage

Table 3. New Cities – Migration out of London

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 this evidence of rise was confirmed as a trigger to take firm action in the debriefing. The rate of rise is 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

While we cannot claim to have conducted a detailed assessment, even under this extreme scenario a protection response for London cannot be discounted. Visions of a global scale abandonment of the world's coasts under the Atlantis scenario are not substantiated (Nicholls et al, submitted this volume). 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 (Essex and North Kent). 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.

6.2 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'*

This paralysis in decision-making and the associated delay endangers the success of a protect 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 for us to develop this skill. Over time we would need to become better at this.

> *'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. This is a crisis, 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 your 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 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.'*

In addition to the lack of certainty in the scenario, a number of other factors were suggested to explain the poor progress made in coming to a decision during the policy exercise:

- Fear of public reaction to the proposed option. Any of the options chosen would have huge impacts for people, the economy and wealth generally. There would be 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.'

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

  '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'.

- Fear of the proposed solution failing or becoming a white elephant *'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?' and*

- The NIMTO response; *'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)'*.

It was felt that 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 scare mongering - people have heard too much. People can handle small, gradual changes but not the big changes.'

6.3 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. The problem has to be looked at in a different way. 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. [4]

6.4 The involvement of the public

The overall view seemed to be that decision making process should be clear and allow opportunities for the public to have an input into the decisions made although the final decision-making power should be with the central government rather than decentralised if a protect response is desired. Public engagement is key to a planned response and requires clear communication of the risks, uncertainties and options.

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, a small 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 it was feared by one that with open consultation you get *'lots of reports and paralysis*' (in the decision-making process) 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'*

6.5 Flood events as catalysts for action

Flood events are important catalysts for action, as has been observed previously (Johnson et al, 2004). In the role playing, the scenario included a flood event that made the risk tangible and which provided a sense of urgency that motivated new and more radical strategies, previously not given much weight. The flood events were presented as part of the overall scenario of rapid sea level rise. 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 was '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 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.'*

7. Plausible narratives

Reflecting on these key messages we tried to summarise our risk assessment in the form of two narratives or storylines. Although we did not discuss these directly with the participants, they both 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.

Presented with a forecast of extreme sea level rise of 5m 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 1m 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 (quoted in Brown, P. (2005))), 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 we posed does not trigger an agreed response that protects London (physically, economically and as cultural heritage).

However, in the alternative narrative:

> *While the initial response to the forecast was confusion, 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 protection, 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.

8. Discussion

The options identified in this study to respond to the threat of 5m sea-level rise may be technically feasible but there is doubt as to whether they are realistic socially or politically. The paralysis in decision-making highlighted in the policy exercise could prove to be determining factor in whether society can cope with this extreme scenario. The delay

resulting from this paralysis would significantly reduce the possibility of implementing the most effective responses and, in the worst case, would result in an unplanned abandonment of London. The prime causes of this paralysis (the lack of experience of planning over longer timeframes, 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) all act to prevent an effective assessment of the situation and thus the possibility of an effective response.

In order to increase our capacity to cope with this scenario we need to find ways to directly address this paralysis and support the decision-making process.

8.1 Supporting longer term decision-making

It has been suggested that biological evolutionary programming encourages humans to focus on here and now, 'fight or flight' responses which make it less easy for us to take the future into account (Ornstein & Ehrlich, 1989). How do we develop the capacity for foresight to enable us to respond to more distant threats?

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. In order to move from more solution driven approaches to a process of continual management we need to understand the complex interactions between socio-economic, natural and technical solutions and include people's values and beliefs as well as scientific measurements. The parameters of this study meant that the solutions were kept very simple. In reality there would be a portfolio of solutions 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).

8.2 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 although there was some difference of opinion as to how great this should be. It was noted that there may be resistance from those with a desire to retain the

'status quo' in society as it exists today. Such people would be reluctant to accept changes that were radically different from their own or that reduced their power in the decision making process.

As most people in the South East of UK are distanced from the need for day-to-day survival they are not used to feeling exposed to severe threats to their existence and do not feel responsible for ensuring their own continued existence. The project identified this as a 'somebody ought to do something' mentality. Any awareness-raising would need to jolt people out of their complacency and make it clear that although the threat is uncertain that there is a real risk and that they have a role in reducing their exposure. One way to do this would be by creating a shock. Our policy exercise went some way to mimicking the scenario in order to get people to think through what was happening. The insurance industry threatening to reduce or withdraw cover from an area would also be effective in forcing people to take the threat seriously.

In order to be able to input into the process in a meaningful way it was recognised that people would need support through formal and informal education and access to unbiased information. As there is likely to be conflicting opinions in society to any decision discussed the media would have a role in presenting information and alternative opinions in a non-confrontational way. Teaching people the skills of conflict management would enhance cooperative and inclusive approaches.

8.3 Making decisions with uncertainty

Many others have explored the question of how improve the resilience of societies by learning how to make decisions with uncertainty (McMichael, 1993, Dovers and Handmer, 1992, 1995, Handmer 1996, Ravetz, 1990).

We have to learn to make decisions without complete certainty, just using best guesses given current knowledge and understanding. For climate change the information required for certainty in response is virtually absent, but by the time the situation has become clearer the best or even the only time for response may have passed (Dovers and Handmer, 1996). 'The

need is not to remove uncertainty (for that is impossible) but to make it open and positive rather than covert and manipulative' (Ravetz, 1990).

We need to accept that our knowledge will always be incomplete and learn to scope out the different levels of ignorance and uncertainty of an issue (Smithson, 1989) to identify what we know we don't know and what we aren't even aware we don't know due to bias, lack of experience and then be open about it, monitor it and minimize it as new information comes to light. Policy makers should learn to be open about gaps in knowledge and understanding and not try to hide them.

Most importantly decision makers have to learn how to make decisions given incomplete knowledge that address the core problems and not just maintain the *status quo.* 'Change at the margins' or fine tuning existing structures and institutions may work up to a point (Dovers and Handmer, 1992) but the scenario described here will require fundamental changes to the way processes operate if we are to cope effectively with the changes it will bring and such changes will be resisted by organisations that thrive in the current situation. New institutions will be needed that can react flexibly and adapt, particularly ones that have the ability to reflect on and learn from their experiences and then act on their learning to suit changing circumstances.

8.4 New social and institutional approaches

Traditional flood management approaches were based in the understanding that we were managing nature. Now we must let go of this notion and focus on how we work with nature and manage ourselves (McMasters, 1993). This means that we have to address our role in the problem. This means examining our behaviour and addressing those activities that are doing harm (such as over consumption of resources) and focus on ways to enhance our quality of life that do not require over-consumption. If we want to address the root causes of the problem we need structures and institutions that will support the process rather than ones which will feel threatened by it and try to hinder it. In order to do this there needs to be an investment in a process of social learning to get people to understand that things need to change, or at least that things can't continue as they are, and that we all have a role in this process.

8.5 What can we learn about less implausible scenarios?

There is a sea-level rise commitment (Wigley, 1995) that will happen regardless of what we do to reduce emissions. Even a small increase in sea-level will increase the risk of serious flooding in the Thames estuary. We need to integrate our thinking about these extreme scenarios into decisions we make about more probable flood management today.

Climate change is not a remote issue for future generations it is here with us today. It is useful to debate these worst case scenarios as such dialogues contribute to the incremental changes described by Johnson *et al*, that create the context for flood management policy change, especially that which occurs after a flood event (Johnson et al, 2004).

In 2001 the Intergovernmental-Panel on Climate Change report characterised the West Antarctic as a 'slumbering giant' but it dismissed concerns that it was disintegrating (Watson *et al*, 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 judgement. We cannot be so sanguine''. If we can make decisions that are able to cope at such extremes, then we have a "windfall" opportunity to gain when the (likely) reality of the in between scenario occurs.

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Table: 1. 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 groundwater 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 preserved under this option and eventually there could be a net gain in habitats depending on the detailed coastal configuration (Nicholls and Tapsell (1995).	Some habitats would be lost due to the rapid rise.
Vulnerable groups, including those on lower incomes, might benefit from being rehoused in less vulnerable areas in the new plan.	Vulnerable groups might lose out by being 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.

Table2. 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 and eventually replaced (or abandoned).
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 3. New Cities – Migration 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?

Figure 1: The sea-level rise considered in the Atlantis project

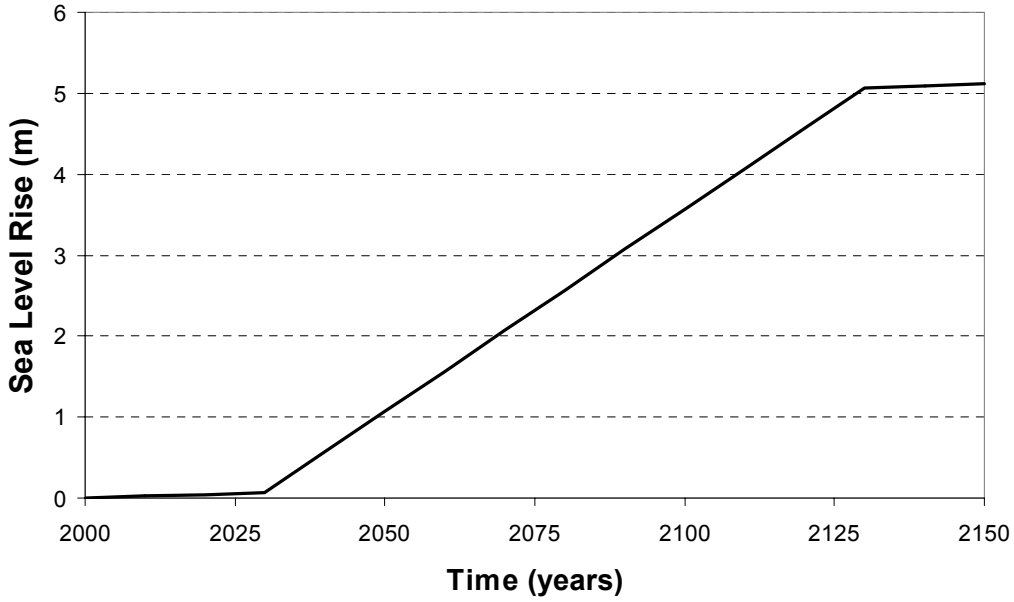


Figure 2. Generalised flooding in the Thames Estuary with 5m sea-level rise (assuming no new defences)

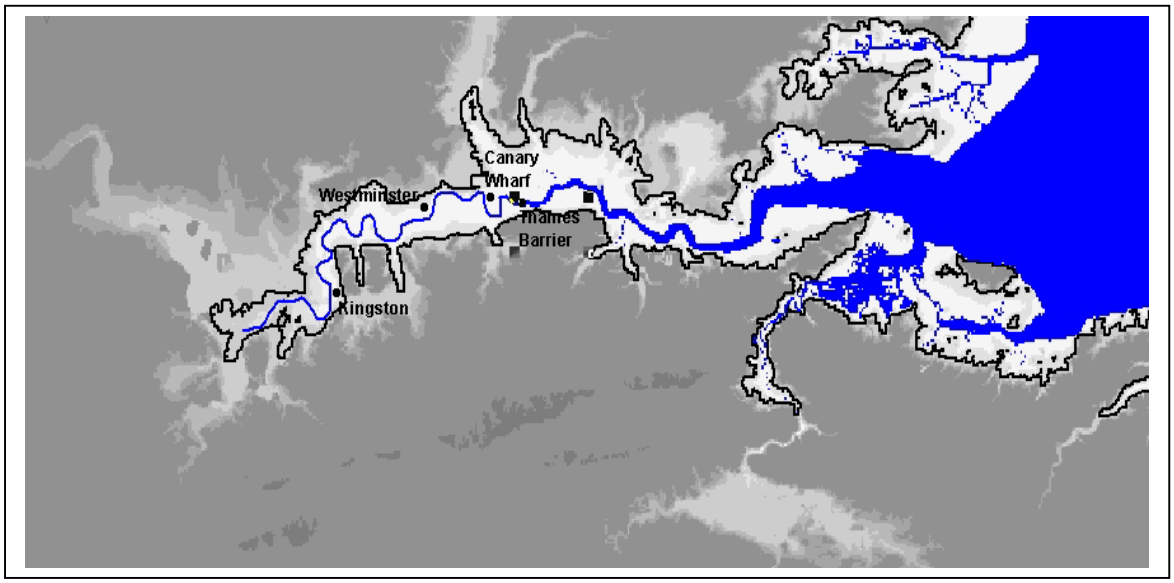


Figure 3. Flood zones in London with 2m and 5m rise in sea-level. Also shows the impact of 5m rise and a 100 year flood event.

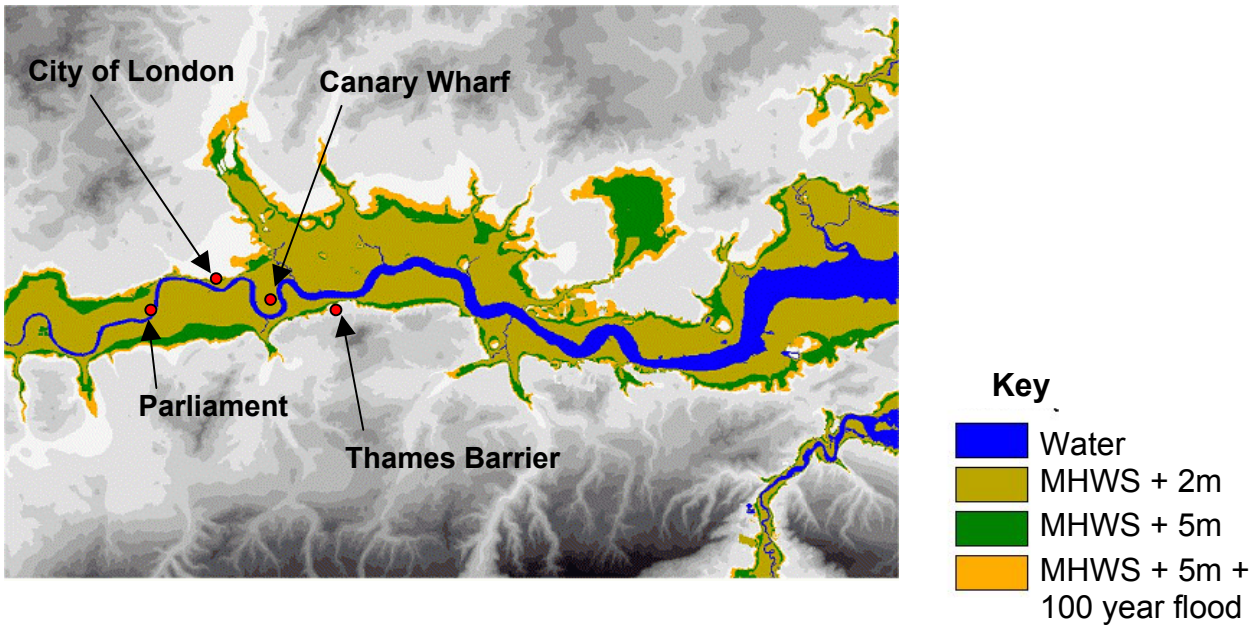


Figure 4. Properties flooded by return period

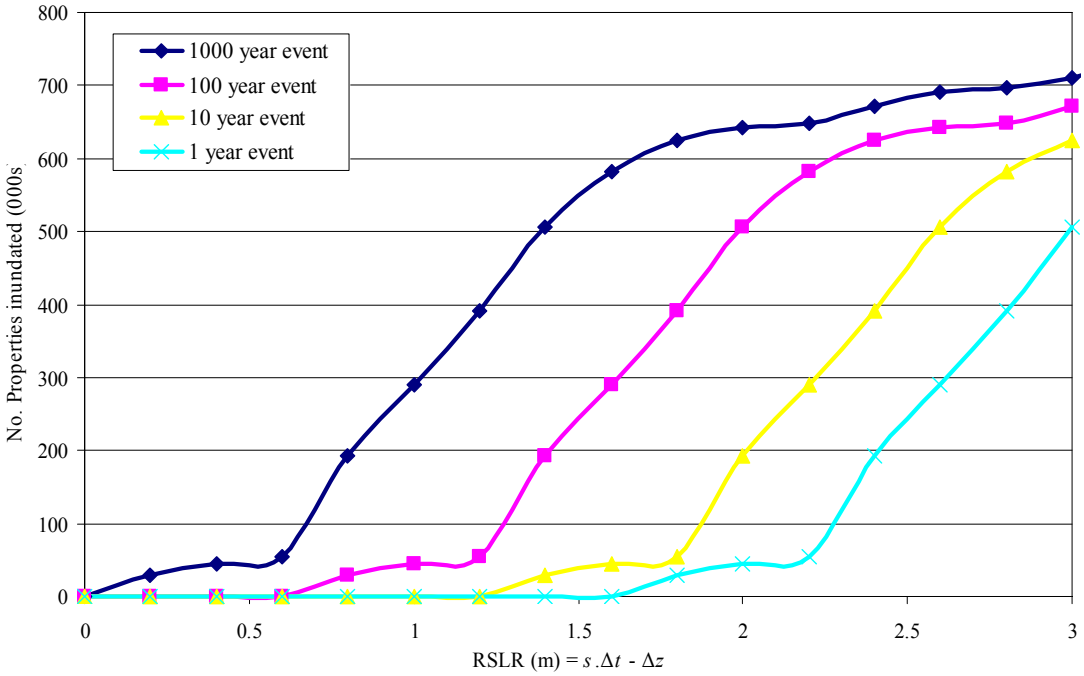
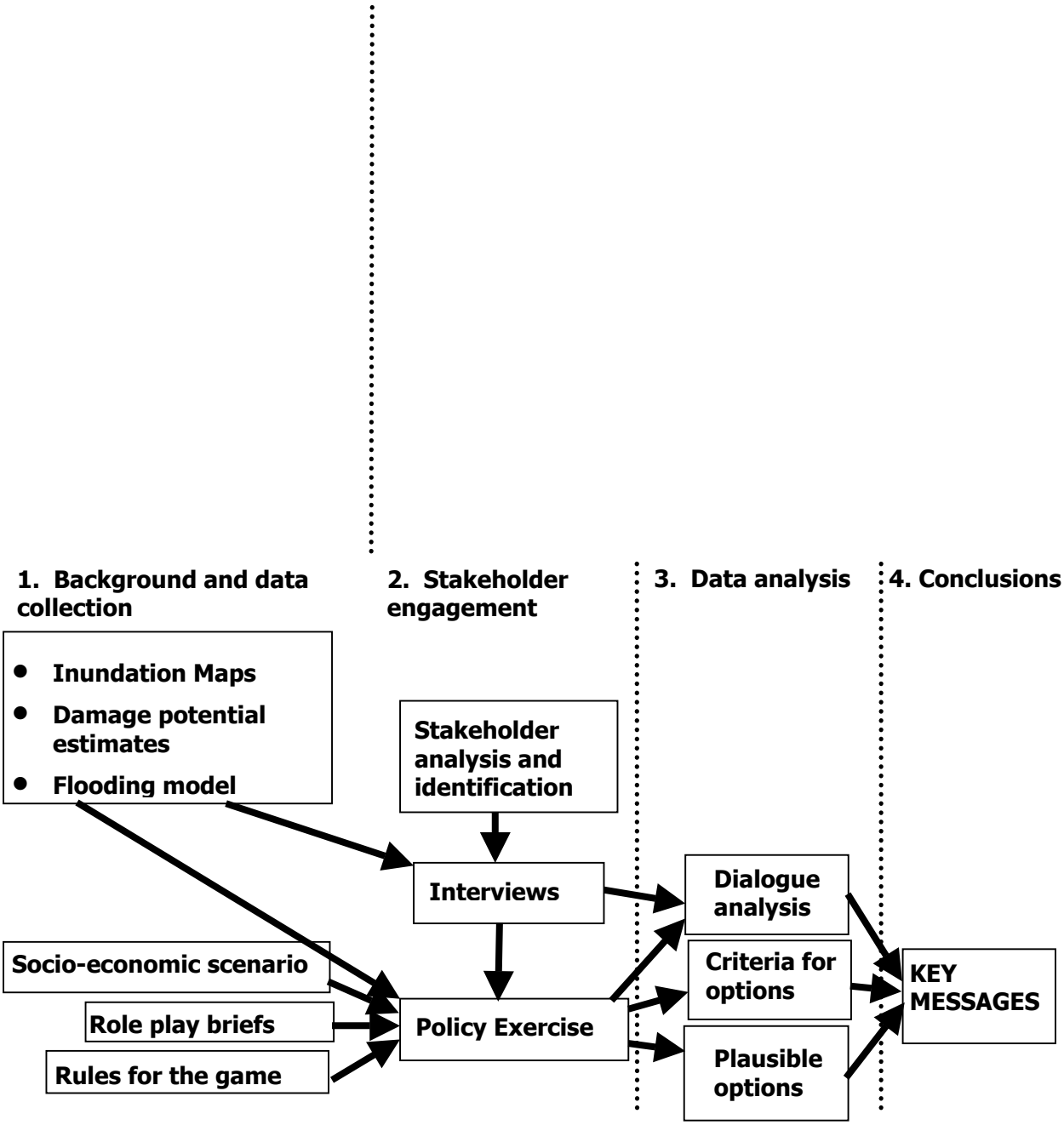


Figure 5. The Thames Estuary case study process



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[1] Association of British Insurers (ABI) Report on how climate change will affect the Government's housing plans for the Thames Estuary – to be published Feb 1, 2005 See http://www.abi.org.uk

[2] The global scale of the phenomena distinguishes the scenario considered here from locally subsiding coastal cities such as Tokyo, which have subsided substantially during the 20th Century (up to 5 m) (Nicholls, 1995). In these cases, the response was always to protect, but this will not necessarily be the case in for a global rise where all coastal areas require action.

[3] The possibility of raising the current embankments was discussed but not pursued as a viable option as it was considered to be impossible to raise them beyond 2 metres. This is not necessarily the case. Embankments can be built very high, if land is available (or made available) to either side.

[4] '*Professor Bondi helped the proponents of the barrier across a notable obstacle. An application for Treasury sanction for a very large sum would be met with a request for a cost-benefit analysis. As the risk element could only be assessed from very imperfectly understood phenomena, there would have been difficulties. But although it would be very difficult to make a case on those grounds , it seems clear from the increasing surge tide levels that something ought to be done. The resolution was fortunate and in many ways typically English. An eminent mathematician bypassed the morass of statistics, categorised the question as philosophical, and gave the ardently desired practical answer: do it. To ordinary engineers who had long believed that philosophy was mainly the use of meticulous argument from premises carefully chosen to lead to the intended conclusion the use of the word*

'philosophical' was extremely welcome. It solved the deadlock and set everything in motion.' Extract from 'The Thames Barrier' by Gilbert and Horner, 1984