Tidal Flood Risk in London Under Stabilisation Scenarios

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The Thames tidal defences are the UK's most complex and costly flood defence system and of global significance both as a feat of engineering and in terms of the value of assets protected from flooding. The system includes 200km of dikes on the Thames Estuary and the Thames Barrier, built in the 1970s to protect against a storm surge with an annual probability of 0.001 in 2030. Planning is now underway to scope an enhanced flood risk management plan for the estuary.

Sea level rise in greenhouse gas stabilisation scenarios

Relative sea level rise (RSLR) is the sum of (i) global mean sea level rise (ii) regional factors and (iii) vertical land movement. Figure 1 illustrates global mean sea level rise projections for a range of stabilisation scenarios [1]. After 2050 the choice of stabilisation scenario becomes increasingly important in controlling future sea level rise. Regional factors may cause deviations from global mean sea level rise by up to ±100% over the 21st century but the simulated spatial variations are very uncertain and vary between models [2]. Isostatic settlement of the south-east of England is estimated to be about 0.7mm/year [3].

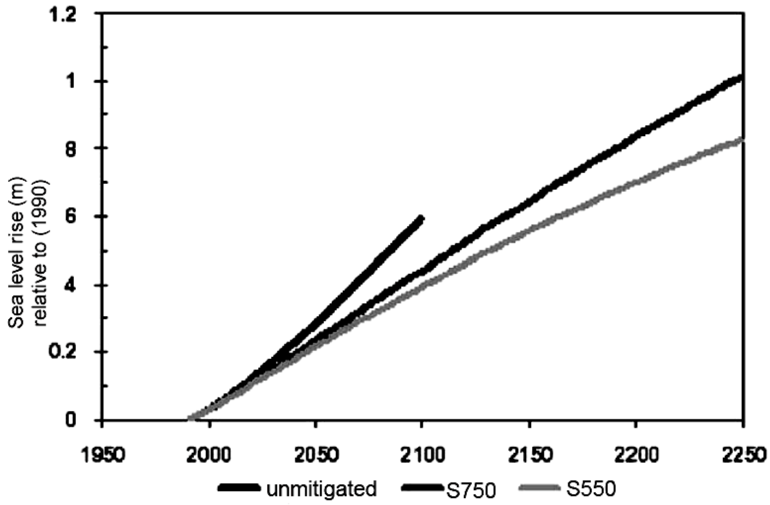

Figure 1: Global-mean rise in sea level (relative to 1990) under unmitigated (IS92a) emissions (top line), S750 (middle line) and S550 (bottom line) (which ultimately stabilise at 750 ppm CO_2 and 550 ppm CO_2, respectively) as simulated with HadCM2 [1]

The benefits to flood risk in London of stabilisation

Mitigation of global warming through greenhouse gas stabilisation will reduce sea level rise when compared with the unmitigated case. We have tested different sea level rise scenarios in our analysis of tidal flood risk in the Thames estuary, assuming, for comparative purposes, that the flood defences are retained at their current level (Figure 2). This base case assumption is unrealistic – future upgrades of the defences will take place in order to adapt to increasing flood risk – but provides a useful basis for comparison of stabilisation scenarios.

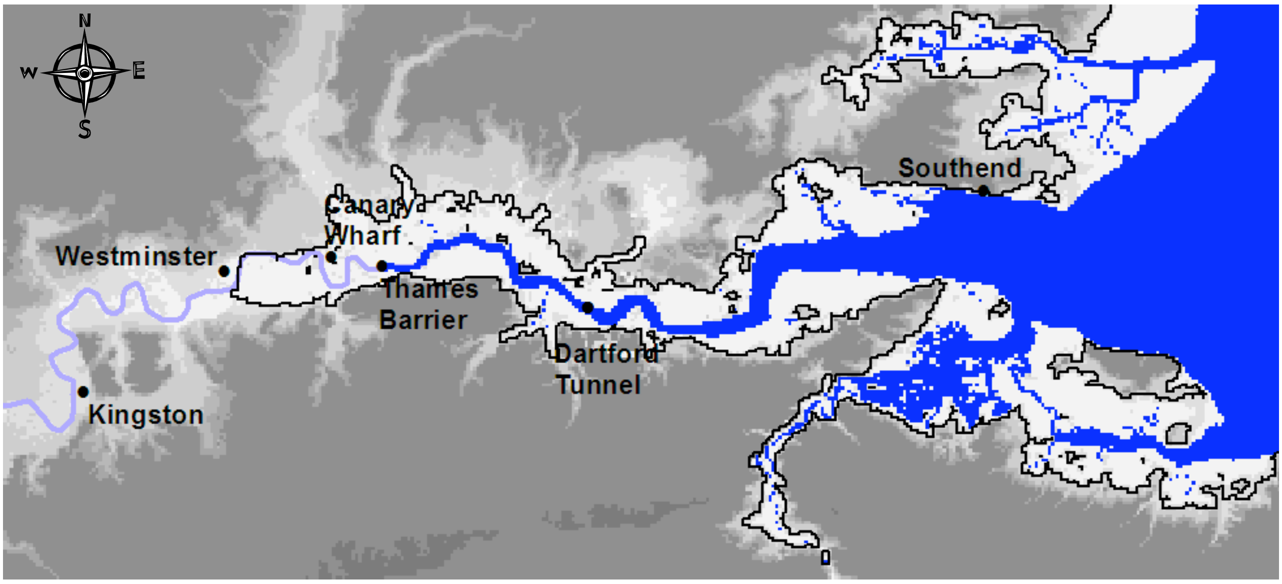

Figure 2: The 1:1000 year flood outline after 1m RSLR (lighter grey shades in the floodplain represent lower ground, the estuary very dark)

We use reliability analysis of the flood defences and hydrodynamic modelling of flood flows to estimate a probability density function, $p(y)$, for flood depth, y, throughout the floodplain. The expected annual damage in year i, R_i, is given by

$$R_i = \int_0^{y_{\max}} p(y_i) D(y) dy$$

where y_{max} is the greatest flood depth from all scenarios, and $D(y)$ is the direct economic damage in a flood of depth y metres [4]. Note that we only assume that the probability distribution of flood depths varies with time (as a consequence of sea level rise), whilst the depth-damage function $D(y)$ is time invariant. In other words we have not considered the increase in flood risk due to future development or increasing household wealth. Furthermore, we have only considered the flood risk due to overtopping of the flood defences. The additional risk due to breaching of the defences will be addressed in subsequent analysis. The total Present Value of flood risk in a given scenario is obtained by discounting over t years:

$$PV(R) = R_i \sum_{i=1}^{t} (1+r)^{-i}$$

where r is the discount rate. Flood risk calculations (Table 1) have been undertaken over a 100 year time horizon assuming a discount rate of 3.5% for the first 30 years, declining to 3.0% for the next 45 years and 2.5% thereafter. It is clear from Table 1 that, without adaptation, unmitigated sea level rise will in due course lead to very severe flood risk, even when discounted to today's values.

Scenario	Relative sea level rise (in m) in the Thames Estuary 2050 (relative to 2005)	Relative sea level rise (in m) in the Thames Estuary 2100 (relative to 2005)	PV(flood risk) (£billion)	Benefit of stabilisation (£billion)
S450	0.16	0.34	0.61	13.9
S550	0.19	0.40	0.62	13.9
S750	0.21	0.46	0.89	13.7
IS92a	0.24	0.61	14.6	-

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

These damages represent the physical impact on property touched by flooding. The damages are of course wider than this, including costs of disruption and business loss which arise from indirect damages, so the benefits of stabilisation are a lower bound. Floods of the magnitude simulated in this study could have a sudden and major impact on the UK economy. The extreme surges being considered, represent a serious threat to human life, particularly given the difficulties of evacuating the densely populated areas of the Thames estuary.

Sea level rise uncertainties

The sea level rise estimates shown in Figure 1 and employed above are of course subject to climate model uncertainties. We examined the effects of climate model uncertainty by consideration of published probabilistic estimates for climate sensitivity (Figure 3). We have constructed an outer envelope on the cumulative probability distributions [5,6] and then propagated this uncertainty structure through the low complexity MAGICC model [7], which generates global mean sea level rise predictions that correspond closely to the GCM results presented in Figure 1.

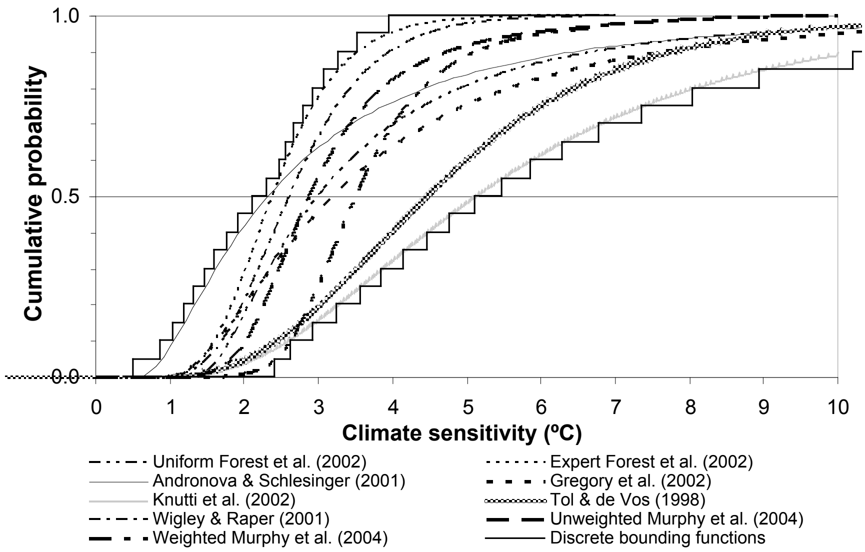

Figure 3: Cumulative probability distributions for climate sensitivity together with the lower and upper envelope and the discrete approximation

One way of representing the effect of uncertainty in sea level rise estimates is to consider the timing of the next upgrading of the Thames tidal defences. Suppose, for example, that the designs for the 2030 upgrade assume the IS92a unmitigated emissions trajectory and are designed so that under the corresponding sea level rise scenario, assuming no climate model uncertainty, the defences will resist a 1:1000 year storm surge event in 2100. Differences between climate sensitivity estimates represent the equivalent of at least 50 years variation in the timing of the next upgrade project. Stabilisation from an unmitigated scenario (IS92a) to S750 delays the next upgrade for about 60 years, whilst S550 yields a further delay of about 20 years. The differences between the S750 and S550 scenarios are more noticeable in this analysis, which, unlike Table 1, does not include any discounting. Given the very significant uncertainties, flood management engineers should be adopting measures that are adaptable and whose life may be extended if necessary.

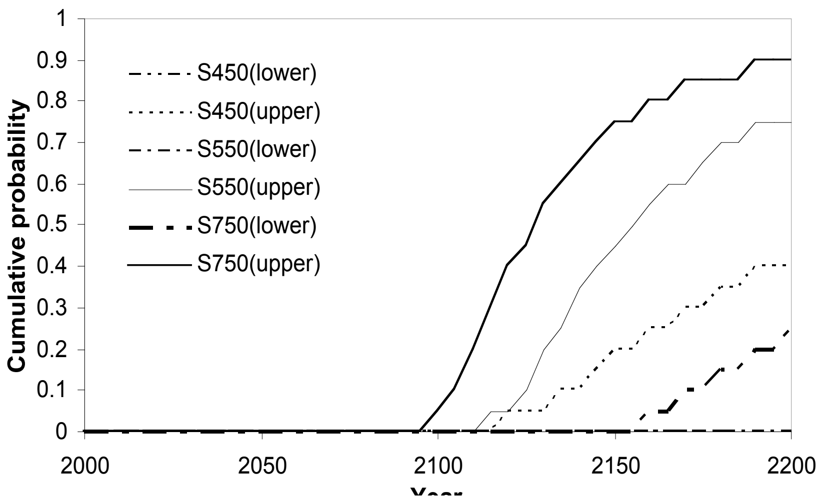

Figure 4: Probable year of next upgrade of the Thames tidal defences given a design for IS92a and a design for a 1:1000 year storm surge event in 2100

Limits to adaptation to sea level rise

There is a wide variety of engineering and soft measures that may be used to reduce flood risk from the sea and adapt to sea level rise [8] (Table 3). Engineered flood defences are currently the most important aspect of London's flood risk reduction measures, however, there may be limits to the amount of sea level rise that the current system could be adapted to protect against. If the Thames Barrier can be operated, say, 10 times more frequently than it is at present it will be able to resist approximately 0.5m of relative sea level rise (roughly a century of sea level rise) before further modification of the upstream flood defences is required. Beyond that point the upstream walls throughout central London and westwards will have to be raised at roughly the same rate as sea level rise. This represents a significant commitment in the 22nd Century and beyond. Engineers suggest that feasible raising of the walls through central London may be limited to about 2m, in which case under more extreme sea level rise scenarios the limits to protecting London are reached in the 23rd Century. More sophisticated control of the Thames Barrier or a replacement could be used to extend the viability of the capital, and these options will need to be studied in the future.

Response Theme	**Response Groups**
Coastal and estuarial defences	Dikes and barriers Realignment of coastal defences Modify estuarial morphology and hence water levels in the estuary
Managing the Urban Fabric	Improve flood conveyance through built up areas
Managing Flood Events	Enhancing preparedness for flooding Forecasting and warming Flood fighting actions Recovery post-events (including insurance and compensation)
Managing Flood Losses	Land use planning Flood-proofing Building codes

Table 2: Potential flood risk reduction measures on the Thames Estuary [8]

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