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INCORPORATING REAL OPTIONS INTO FLOOD RISK MANAGEMENT DECISION MAKING

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Abstract

Effective flood risk management involves the quantification of flood risk and the implementation of cost effective, sustainable and environmentally and socially acceptable measures that reduce flood risk. Making decisions regarding the most appropriate long term intervention investments is complex. The complexity of the decisions primarily relates to the evolving nature of flood risk, with particular regard to global climate change but also future socio economic development scenarios. Methods are required that are capable of analysing intervention options in a rational manner, taking account of future uncertainties.

Real Options is a recognised approach for facilitating adaptive strategies. It enables the value of flexibility to be explicitly included within the decision making process. In the context of flood risk management, where climate change is influential but uncertain, Real Options offers a practical yet powerful approach that can be used to assist decision makers.

In order to provide sustainable management of flood risk over short, medium and long term timescales whilst adapting to and mitigating the effects of climate change a Real Options based decision framework is being developed. This framework enables the evaluation of the most appropriate set of flood risk management intervention measures and the most opportune time to make these interventions. Investment decisions are evaluated across a range of future uncertainties. The framework will enable the valuation of flexibility within the investment process, underpinning the concepts of real options and will employ an optimised decision framework to evaluate potential flood risk management opportunities.

The framework has been applied to a small section of the Thames Estuary, and preliminary results show that the method allows suitable inclusion and evaluation of different flood defence options previously deemed uneconomical.

1 Introduction

Flooding poses a serious threat to millions of people across the world. Recent floods in the UK such as Boscastle 2005 (Fenn et al., 2005) and the summer floods of 2007 (Environment Agency, 2007b) highlight the serious hazards posed by flooding and the importance of flood risk management. Effective flood risk management involves quantified analysis of flood risk and the implementation of cost effective, sustainable and environmentally and socially acceptable measures that reduce flood risk. In addition, flood risk management must account for the complexities of global climate change and future socio economic development when considering long term intervention investments.

Real Options is a recognised approach to handle future uncertainties embedded in flood risk management by accounting for flexibility in investment decisions. This paper describes a Real Options based framework which analyses and evaluates intervention options in a rational manner taking account of potential climate and socio economic scenarios. In particular it addresses two key issues, what is the most appropriate set of interventions to make in a flood system and when is the most opportune time to make these interventions, given the future uncertainties. The computational framework has initially been applied to an area of the Thames Estuary in London to analyse potential flood risk management options.

2 Background

The threat from flooding in the UK is considerable with approximately 5 million people living in an area with the potential to flood. With continuing development on floodplains and an increasing threat from climate change this risk is set to increase. The Thames Estuary in London is an area that is susceptible to flooding. A large scale flood event could have a devastating impact as it accommodates over a million residents and workers, 500,000 homes and 40,000 non-residential properties (Environment Agency, 2009). The threat of flooding on the Thames Estuary occurs from a number of different sources, including high sea levels and surges propagating from the North Sea into the Estuary and extreme fluvial flows along the Thames and its tributaries. Protection against these sources is provided by a range of fixed defences and actively operated barriers and flood gates. The majority of the defences were designed to protect against a 1-in-1000 year flood however, at the present day these flood defences are gradually deteriorating. In the longer term, with the potential impacts of climate change, it is appropriate to consider a range of intervention measures.

Making decisions regarding the most appropriate long term intervention investments is complex. The complexity of the decisions primarily relates to the evolving nature of flood risk with particular regard to global climate change and socio economic development scenarios. A set of interventions may perform well against a range of criteria under one future scenario, but poorly under others. Complexities also arise due to the wide range of intervention measures. There are countless combinations of different intervention measures that can be implemented at different points in time. Finding the most appropriate set of intervention investments at the most opportune time represents a significant challenge.

Real Options has the potential to overcome these issues to make cost effective and flexible intervention strategies that take into account the effects of future uncertainties. Dobes (2008) identifies the role Real Options can play in adaptation to climate change, providing examples relating to construction of airport runways and flood defences. The UK Treasury has also issued an update to the “Green Book”, that provides guidance on the economic appraisal of investment decisions (HM Treasury and DEFRA, 2009) that proposes Real Options as an appropriate approach for assessing climate change adaptation strategies.

3 Methodology

To make cost effective flood risk management intervention decisions which take appropriate consideration of the potential of implementing flexible and adaptive options, a computational framework is under development. The computational framework will be capable of analysing and optimising Real Option based interventions and contrasting these with traditional approaches. This paper describes a risk analysis method to evaluate the benefits of making long term interventions and describes the application of Real Option techniques to flood risk management. An initial example is presented which compares the Real Option approach with traditional approaches on a simplified flooding system.

3.1 Risk Analysis Method

Flood risk is calculated using a systems approach that has been applied on the Thames Estuary 2100 Project and the Environment Agency's National Flood risk assessment, (Gouldby et al., 2008). In summary, a system of flood defences is assumed to protect an area of floodplain (see Figure 1).

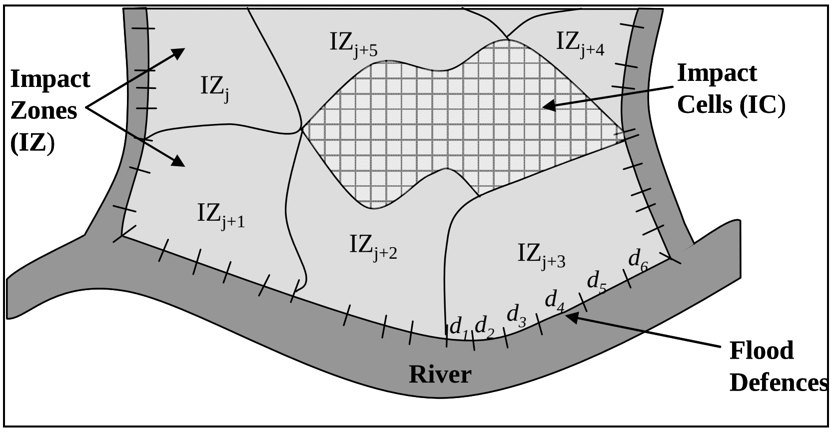

Figure 1 Conceptual illustration of the modelled system

A continuous extreme value distribution of hydraulic loads is discretised into a series of k loading levels $l_1 \ldots l_q$. The flood defences are treated as Bernoulli random variables either remaining intact or breached (structurally failed) with their performance defined by fragility curves. Defence system states are sampled using a standard Monte-Carlo procedure for each of the loading levels and a hydraulic flood spreading model is used to represent the propagation of floodwater across the floodplain according to the topography of the land. An economic consequence of flooding can be estimated using depth damage curves which analyse the damage to properties according to the spread of floodwater. Convergence is monitored on the economic damages associated with each loading level and the risk is then computed:

$$R \approx \sum_{i=2}^{q-1} \left[\left[p\left(L \geq \frac{l_i + l_{i+1}}{2} \right) - p\left(L \geq \frac{l_i + l_{i-1}}{2} \right) \right] \overline{c_{l_i}} \right] \quad (1)$$

where:

R	Risk expressed as Expected Annual Damage (EAD)
L	Random variable for hydraulic load
l	Specific value of hydraulic load
$\overline{c_l}$	Mean economic consequence of flooding from Monte-Carlo simulations
q	Total number of hydraulic loads
i	Hydraulic load index

The risk analysis model can be used to calculate the present day risk to a floodplain area and to investigate potential flood risk intervention strategies. Furthermore, calculation of the flood risk associated with an intervention at a future point in time can be achieved by expressing the future state in the model. Intervention measures can be applied in the model by modifying the fragility curves, defence information or depth damage curves (see Table 1). Climate change scenarios are represented here by modifying the extreme value distributions of hydraulic loads while socio-economic development scenarios are represented by modifying the depth damage curves.

3.2 Real Options in flood risk management

The return on investment decisions relating to flood risk management are subject to significant uncertainty. For example, the future impacts of climate change on the drivers of flood risk are highly complex, involving consideration of the potential impacts of mitigation policies and the subsequent physical response of the climate system. The Real Options philosophy seeks to identify opportunities for incorporating flexibility into the decision making process mitigating the potential impact of these uncertainties.

Table 1 Intervention options considered in Real Options framework and how they are reflected in the risk analysis tool (HR Wallingford, 2002)

Intervention Measure	Represented in risk analysis tool
Raise Crest Level	Crest Level Height – Defence Information
Widen base of defence	Defence Class – Defence Information
Routine Maintenance	Condition Grade – Fragility Curves
Set back defences	Floodplain
Flood proof properties	Depth Damage Curves

For example, where it is beyond doubt that a flood defence has come to the end of its useful life and requires major refurbishment there are a range of possible decisions. Assuming a worst case climate change scenario and constructing a flood defence based on this assumption is likely to be sub-optimum as it requires significant up-front expenditure and may well constitute an over-design should the worst case scenario not be realised. Constructing a defence that is inherently flexible and capable of future modification is one approach for implementing a Real Option within a flood risk system. A wide defence that is constructed in a way that enables its crest to be raised in the future, should there be a requirement, is an example of a Real Option. The option to raise a defence or not is purchased at the outset. The decision whether to exercise the option is delayed to a future date when more information regarding future climate change impacts, for example, is known.

In coastal and estuarine environments, where managed retreat is increasingly likely and habitat loss and creation issues are a consideration. The purchase of land in the lee of the existing defence system can be considered as a Real Option. Future developments in the area can be restricted and decisions delayed regarding the relative extents of setback and habitat creation until future uncertainties that influence these decisions can be reduced. It is thus evident there are a range of potential applications of the concepts of Real Options in flood risk management. It is however, necessary to develop approaches to consider how Real Options investment decisions can be evaluated and compared against more traditional approaches.

3.3 Evaluation of Real Options

The approach adopted in the analysis described here is consistent with the UK Government's existing approaches but extended to accommodate the evaluation of Real Options, including uncertainties associated with climate change. The risk analysis model evaluates the risk, R, of an intervention strategy to enable the benefits of the intervention to be calculated. The standard approach to assess the benefits of implementing an intervention measure is determined by calculating the difference in risk between implementing the intervention and a 'do nothing' option. The 'do nothing' option reflects the decision to not make any investments throughout the life time of the strategy. These are summed up over the life of the option to obtain the overall benefit as follows:

$$B_s = \sum_{i=1}^{T} (R_{NoIntervention} - R_{WithIntervention})_i \qquad (2)$$

where:

B_s	Total benefit in EAD of an intervention strategy for scenario s
$R_{No\ Interventions}$	Risk of the ‘do nothing’ option
$R_{With\ Interventions}$	Risk of the intervention strategy
T	Total number of epochs
i	Epoch index

The costs associated with different interventions are calculated which are based upon standard approaches (Environment Agency, 2007a). The benefits and costs are subsequently discounted back to present day values. The Green book (HM Treasury, 2003) provides a standard declining discount rate to appraise policies and projects (see Table 3). (HM Treasury, 2003) However, the choice of discount rate has been at the centre of debate and primarily depends upon the pure time preference rate. A high pure time discount rate of the future favours avoiding the costs of mitigating against the impacts of climate change now. For the purposes of climate change adaptation, the Stern Review (Stern 2006) identifies a requirement that a low pure time discount rate is necessary to prevent future generations from being valued less than the present generation. It is therefore informative to investigate the sensitivity of different discount rates on the decision.

The value of Real Options is in their inherent ability to value flexibility and in particular their ability to adapt to future climate change scenarios. To appraise the performance of Real Options it is therefore necessary to take an appropriate account of future uncertainties, in particular relating to climate change. UKCP09 (Murphy, 2009) provides information relating to flood risk under three different climate change scenarios. Whilst probabilistic information is available to describe the climate related variables, this is conditional on emission scenarios. Because of this, each intervention strategy is assessed here across a range of climate change scenarios. It is of note however, that no information is provided on the likelihood associated with the emission scenarios. There are a range of formal decision making methods that can be applied under conditions of strict uncertainty (i.e. where no information on likelihood is available). These include methods such as Laplace’s Principle of Insufficient Reason (equal likelihood), Wald’s Maximin Model (Wald, 1945) and many derivatives, including the Minimax regret (Eldar, 2004). These types of method implicitly reflect a particular attitude to risk. Implementation of the so-called vanilla Maximin is well known to be extremely risk averse, whereas the equal likelihood approach is more risk neutral. An alternative is to frame the problem as decision making under uncertainty and seek to describe the emissions scenarios in a probabilistic manner. Whilst a range of these comparisons will be conducted within an ongoing research project, the analysis here assumes risk neutrality based on the UK Government’s adopted position (Defra, 2009).

4 Case Study

The approach has been applied to an area closely resembling Thamesmead on the Thames Estuary, where different intervention solutions have been evaluated. It is assumed at the outset that the defences are beyond reasonable economic repair and refurbishment is required. The three solutions comprise of a Real Options based strategy and two traditional strategies described in Table 2. The Real Options solution captures flexibility within the investment decision to adapt to the uncertainties of climate change once the future state is known, whereas the traditional solutions do not incorporate flexibility. Traditional solution 1 makes assumptions about the future state in order to devise a robust strategy that performs well across all possible futures while Traditional solution 2 waits for the known future state to decide on the correct action but does not purchase the option at the outset.

The climate change scenarios are based upon the high, medium and low emissions scenarios from UKCP09 and a fixed socio-economic development scenario has been used throughout. Each intervention strategy has been analysed for each of the three scenarios. Defence maintenance is applied to each solution throughout the lifetime of the strategy. Two discount rates have been individually applied to each strategy to investigate the influence on the investment decision. These include the HM Treasury's discount rate (Table 3) and a discount rate of 1.4% based upon analysis undertaken in the Stern Review (Stern, 2006).

Table 2 Summary of intervention strategies undertaken

Strategy	Year of implementation	Description of Intervention
Real Options Solution	2010	Widen base of defence
	2040	Raise Crest Level according to the sea level rise increase
Traditional Solution 1	2010	Widen base of defence
	2010	Raise Crest Level according to medium sea level rise emissions scenario
Traditional Solution 2	2010	Refurbish defences
	2040	Widen base of defence
	2040	Raise Crest Level according to the sea level rise increase

Table 3 The declining long term discount rate (HM Treasury, 2003)

Period of years	0-30	31-75	76-125	126-200	201-300	301+
Discount rate	3.5%	3.0%	2.5%	2.0%	1.5%	1.0%

4.1 Results and Discussion

The initial outputs from the analysis show the benefits and costs for the floodplain area for each epoch and scenario. The summary results presented below are preliminary only. Table 4 shows the Net Present Value (NPV) of implementing the strategies across each of the three emissions scenarios over a 100 year period for both aforementioned discount rates. The average NPV has also been evaluated, assuming equal likelihoods of all scenarios. It can be seen that in this instance for both discount rates it is more favourable to invest in the Real Option solution because adapting to the uncertainties of climate change enables a more rational investment. This strategy gives an overall higher NPV than the traditional approaches for both discount rates. The NPV calculated from the discount rate based on the Stern Review produces a much higher NPV than that of the Green Book discount rate. This is due to the lower discount rate placing more emphasis on undertaking the intervention strategy now as these strategies will effect future generations.

Table 4 Net Present Value of benefits for the intervention strategies using two discount rates

		Green Book Discount Rate	Lower discount rate (1.4%)
Strategy	**Scenario**	**NPV (£)**	**NPV (£)**
Real Options solution	Low	9,356,504	24,198,921
	Medium	14,523,730	37,390,319
	High	33,516,220	86,862,913
	Average	**19,132,151**	**49,484,051**
Traditional Solution 1	Low	4,493,496	25,829,233
	Medium	7,411,066	32,553,619
	High	23,272,454	72,081,544
	Average	**11,725,672**	**43,488,132**
Traditional Solution 2	Low	5,581,994	20,275,887
	Medium	10,527,837	33,059,609
	High	29,198,569	81,939,686
	Average	**15,102,800**	**45,091,727**

Figure 2 represents the economic benefit for the Real Options solution and both traditional solutions averaged over the three future scenarios for both discount rates. As it can be seen from this figure, the total benefit (at 2110) for the Real Option is higher than the first traditional approach when assessed across all scenarios. This is due to the flexibility within the investment. The benefit of the Real Option and second traditional solution are however, identical. The crest levels are raised at the same time and are adapted to the height of the scenario providing the same flexibility however a higher cost is incurred on the second traditional solution due to the expense of the refurbishment. The overall cost of the Real Options strategy is less than both traditional approaches (see Table 5) making overall the Real Options investment more favourable. The discount rates have influenced the final outcome of the benefits and costs considerably highlighting the importance of the choice of the discount rate. Figure 3 represents the spread of cost for maintenance and implementing interventions across the life of the strategy before discounting. A significant portion of the costs for the strategies are due to the intervention options at 2010 and 2040. The remaining costs are attributed to maintaining the defences, with a large maintenance cost for the second traditional solution at 2010 for refurbishment.

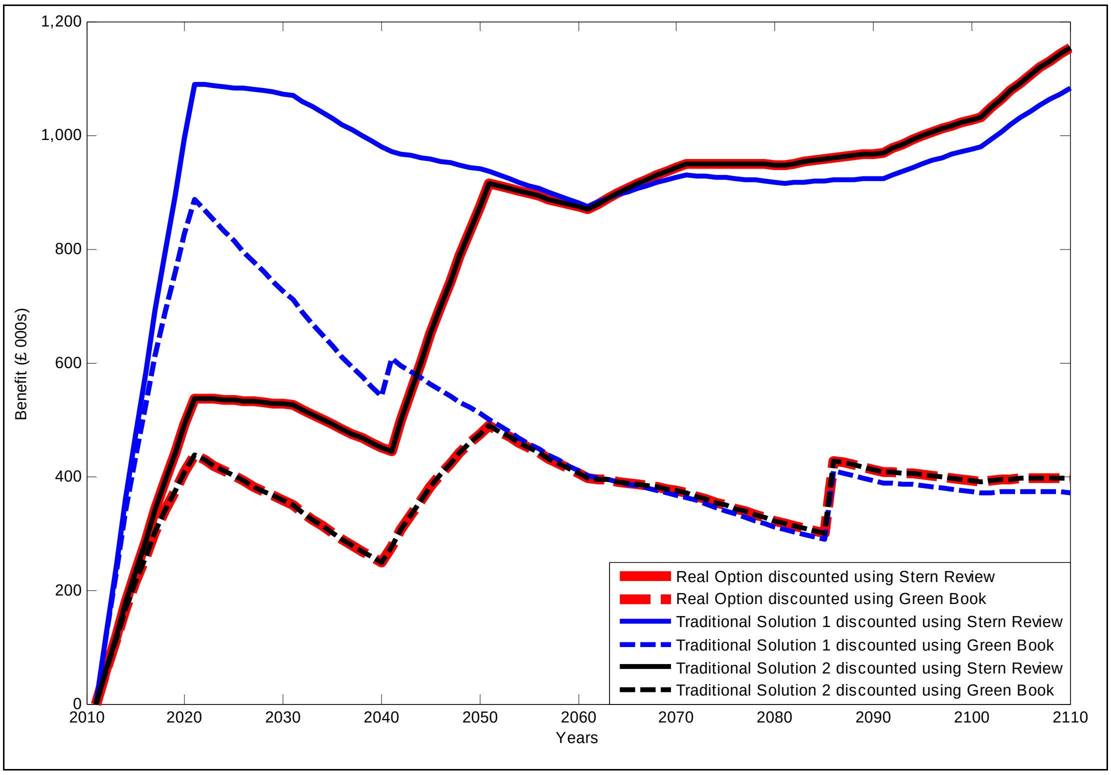

Figure Benefits profile of intervention options averaged over the 3 scenarios and discounted by two different discount rates

Table 5 Cost of different intervention strategies using two different discount rates

		Green Book Discount Rate	**Lower discount rate (1.4%)**
Strategy	**Scenario**	**Cost (£)**	**Cost (£)**
Real Options solution	Low	17,010,490	27,465,831
	Medium	17,243,086	27,894,156
	High	17,681,217	28,700,974
	Average	**17,311,598**	**28,020,320**
Traditional Solution 1	Low	35,467,583	48,693,996
	Medium	35,467,583	48,693,996
	High	35,467,583	48,693,996
	Average	**35,467,583**	**48,693,996**
Traditional Solution 2	Low	20,785,001	31,388,865
	Medium	21,238,979	32,224,865
	High	21,998,868	33,624,201
	Average	**21,340,949**	**32,412,644**

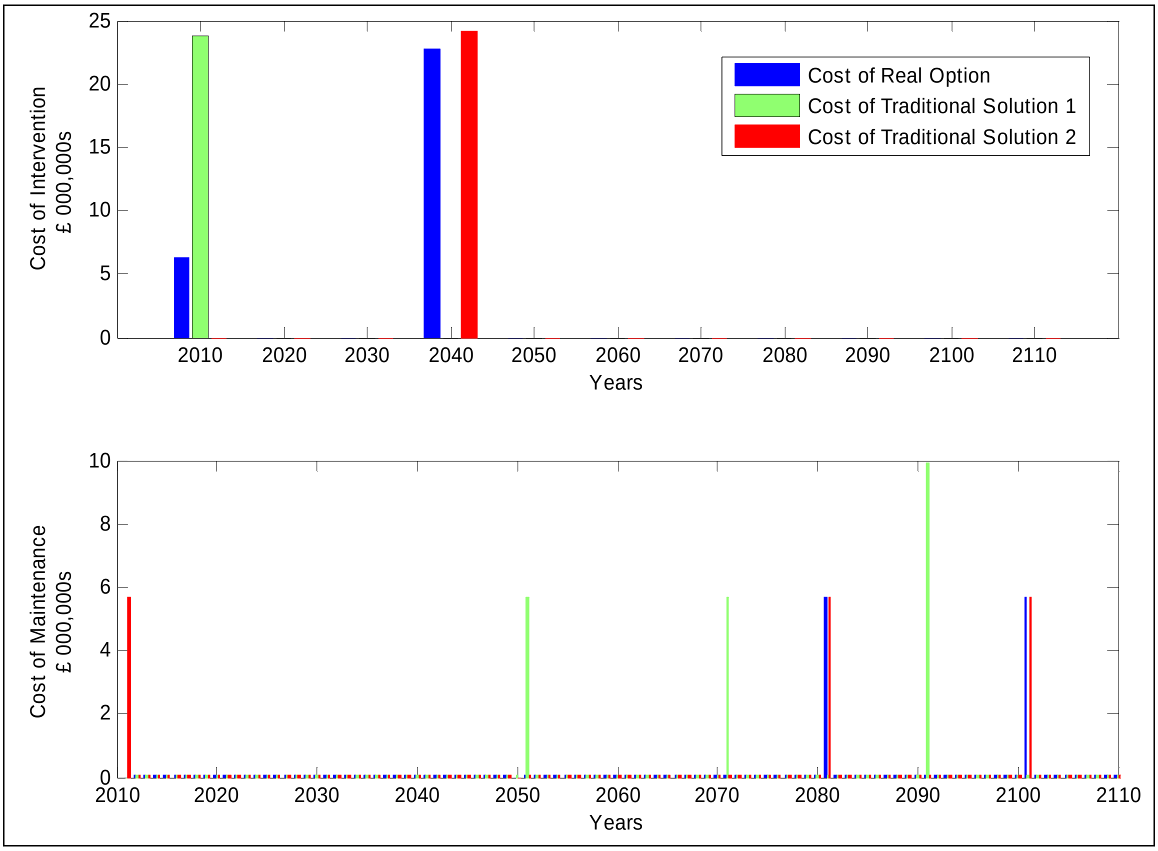

Figure 3 Average annual cost of maintenance (bottom) and intervention (top) implementation over the 3 emissions scenarios for each intervention strategy.

5 Conclusion

Initial results from a Real Options analysis approach have been compared to investment returns from more traditional approaches. Flexibility is inherently captured within this analysis by quantitatively analysing a range of potential options across possible future scenarios at different points in time. Furthermore, the effect of different discount rates on a range of investment strategies has been analysed and the sensitivity of the outcome to the choice of discount rate has been shown. This study has demonstrated that the Real Options concepts have potential to provide significant economic benefits to long term flood risk management investments compared to traditional methods and that the ability to incorporate flexibility in decision making to adapt to future uncertainties merits consideration in developing long term strategies.

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