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THE USE OF REAL OPTIONS IN OPTIMUM FLOOD RISK MANAGEMENT DECISION MAKING

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ABSTRACT

Making decisions regarding the most appropriate long term flood risk related 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.

A computational framework is under development which will have the capability to assess the most appropriate set of interventions to make in a flood system and the opportune time to make these interventions, given the future uncertainties. This framework captures the concepts of real options to evaluate potential flood risk management opportunities across a range of future climate change and socio economic scenarios. Preliminary aspects of the framework have been applied to a small section of the Thames Estuary, and initial results show that the method allows suitable inclusion and evaluation of different flood defence options previously deemed uneconomical.

INTRODUCTION

Flooding poses a serious threat to millions of people across the world. Recent floods in the UK such as Boscastle 2005 (Fern 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, 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 providing 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.

BACKGROUND

Methods and tools for analysing flood risk are well established, see for example (USACE, 1996, Hall et al., 2003, Apel et al., 2004, Gouldby et al., 2008). However 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. A set of interventions may perform well against a range of criteria under one future scenario, but poorly, under others.

Real Options is a mechanism for evaluating flexibility in an investment decision and is founded in the analysis of financial decision making. A real option applies option valuation techniques to capital budgeting decisions. Essentially it allows a decision maker to make changes to an investment when new information arises in the future. Opportunities such as *delaying* the investment, *abandoning*, *switching*, *expanding*, *contracting* and having multiple options interacting together are potential choices for decision makers. 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" (HM Treasury and DEFRA, 2009) that proposes Real Options as an appropriate method for assessing climate change adaptation strategies.

APPROACH

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 the application of Real Options techniques to flood risk management and provides an initial example comparison of a Real Option approach with traditional approaches on a simplified flooding system.

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 to mitigate the potential impact of these uncertainties.

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 (Figure 1).

There may however, be uncertainty regarding whether to refurbish a defence, set-back a defence or continue with maintenance activities, the cost of which may rise as the structure approaches the end of its design life. Delaying the decision to refurbish and continue with the maintenance is another example of implementing Real Options. Flexibility is maintained and the decision to refurbish or setback is delayed until more information is known. The cost of the option is the increase in maintenance costs as the structure deteriorates. The value of the option lies in the decision to delay major investments until future uncertainties are reduced.

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.

Evaluation of Real Options

The approach adopted in the analysis described here is consistent with Defra's approaches but extended to accommodate the evaluation of Real Options, including uncertainties associated with climate change. The standard approach to assess the benefit of making an investment is determined by calculating the difference in risk between the intervention measure and a 'do nothing' option. The 'do nothing' option reflects the decision to not make any investments at any point in time. These are summed up over the life of the option to obtain the benefits for each scenario and discounted back to present day values using the standard test discount rate.

$$B_s = \sum_{i=0}^{T} (R_{NoIntervention} - R_{WithIntervention})_i \qquad (1)$$

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 years

To evaluate the benefits, the 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). The model currently evaluates the likelihood of extreme hydraulic loading events on the defence system, the performance of individual defences in terms of their propensity for failure and the economic damages as a result of inundation. It is possible to evaluate the change in risk as result of a range of different flood risk management interventions, (see Table 1).

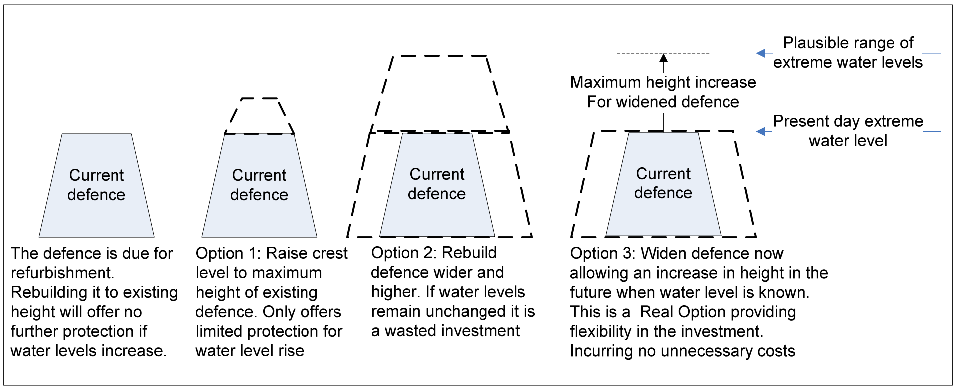

Figure 1 - Description of a flood risk management Real Option

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
Widen base of defence	Defence Class
Routine Maintenance	Condition Grade
Set back defences	Floodplain
Flood proof properties	Depth Damage Curves

The costs associated with different interventions are based upon standard approaches (Environment Agency, 2007a). In the current approaches benefits are compared with costs and a Benefit Cost Ratio is determined. This forms part of the priority scoring system. The value of Real Options, however, is in their inherent 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 et al., 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. 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 et al., 2004). These types of method implicitly reflect a particular attitude to risk. Implementation of the so-called vanilla Minimax 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 Environment Agency’s adopted position (DEFRA, 2009).

CASE STUDY

The approach has initially been applied to an area of the Thames Estuary to analyse potential flood risk management options. Flood risk on the Thames occurs from many different sources including high sea levels 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 approach focuses in particular on the Thamesmead area of the Estuary where three 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. In addition, a ‘do nothing’ option has been implemented where no active interventions occur throughout the life time of the solution.

Table 2: Summary of intervention strategies undertaken

Strategy	Epoch	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

The climate change scenarios are based upon the high, medium and low emissions scenarios from UKCP09 and each intervention strategy has been analysed for each emission scenario. A constant socio-economic development scenario has been used throughout giving a total of nine scenarios when "do nothing" is included. Defence maintenance is applied to each solution throughout the life time of the strategy.

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 3 shows the Net Present Value (NPV) and discounted costs of implementing the strategies across each of the three emissions scenarios over a 100 year period. The overall NPV has also been evaluated, assuming equal likelihood of scenario (Laplace). It can be seen that in this instance it is more beneficial 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.

Figure 2 represents the economic risk for the Real Options solution, both traditional solutions and the 'do nothing' option averaged over the three future scenarios. The Expected Annual Damage (EAD) for the Real Option is lower than the first traditional approach when assessed across all scenarios. This is due to the flexibility within the investment. However the EAD of the Real Option and second traditional solution are identical. The crest levels are raised at the same time and are adapted to the height of the scenario providing the same flexibility. The overall cost of the Real Options strategy is less than both traditional approaches making overall the Real Options investment more favourable. Figure 3 represents the spread of cost for maintenance and implementing interventions across the life of the strategy. 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.

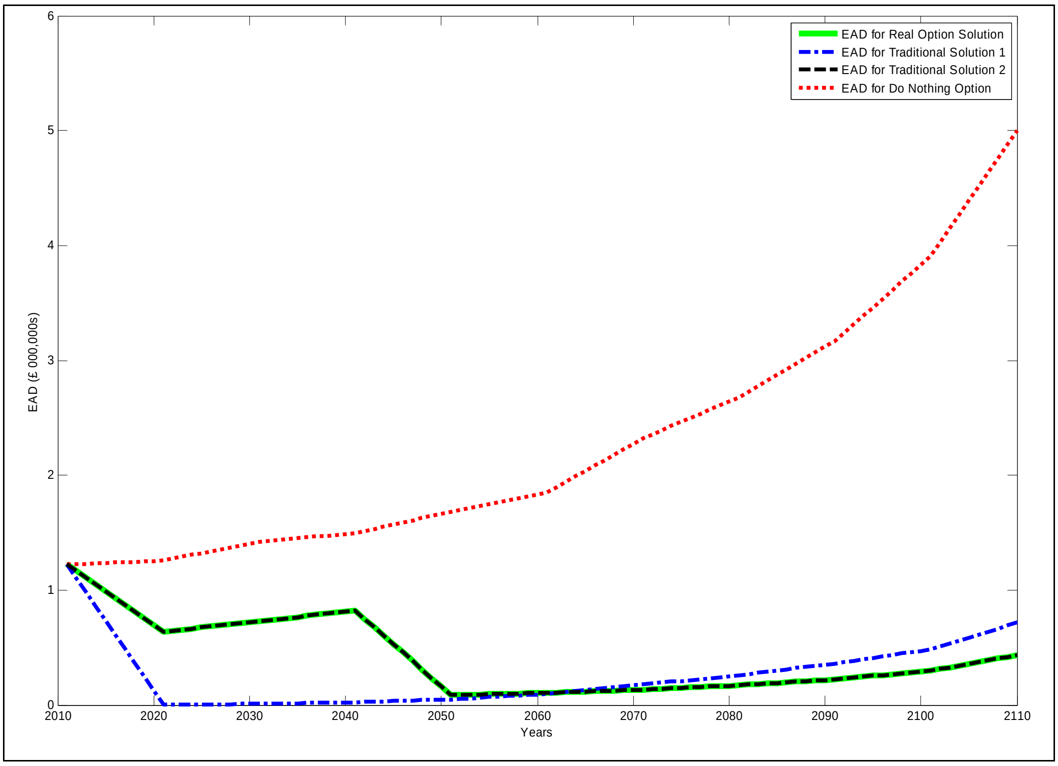

Figure 2 – Risk profile of intervention options averaged over the 3 scenarios

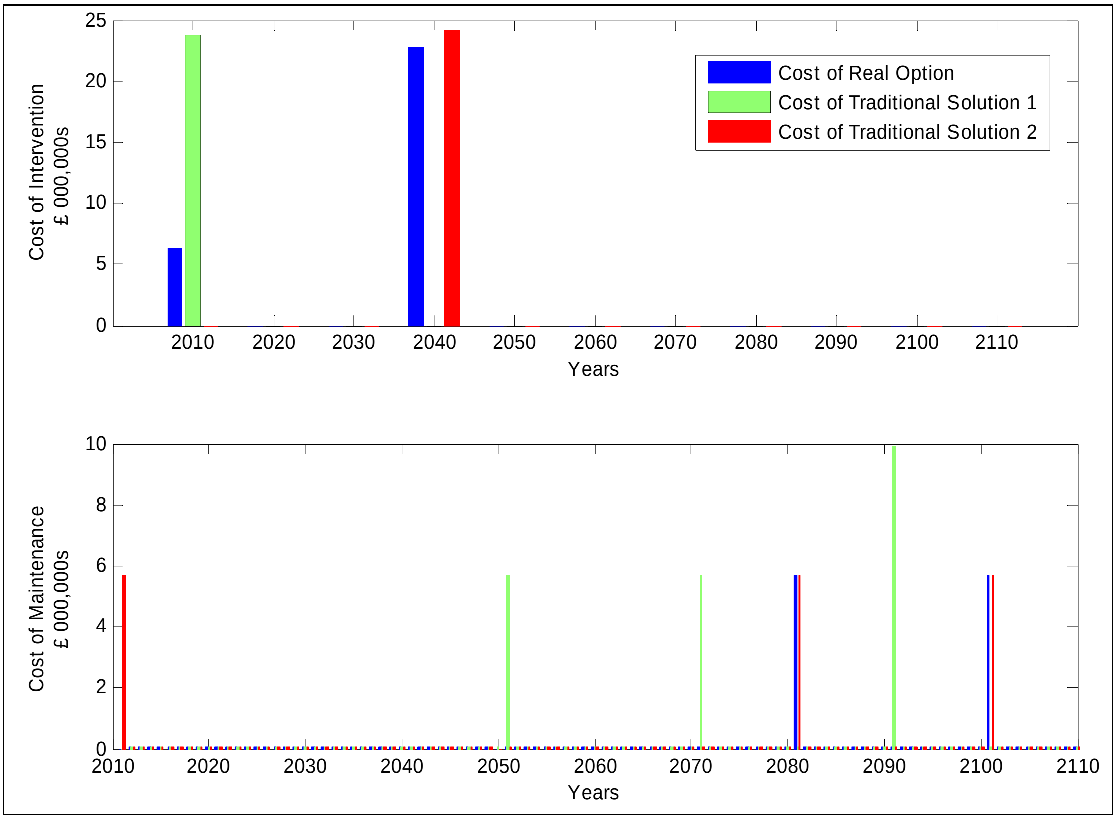

Figure 3 – Average annual cost of maintenance (bottom) and intervention (top) implementation over the 3 emissions scenarios for each intervention strategy.

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. This study has demonstrated that the Real Options approach has 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.

Table 3: Net Present Value of different intervention strategies

Strategy	Scenario	Cost (£)	Net Present Value (£)
Real Options solution	Low	17,010,490	9,356,504
	Medium	17,243,086	14,523,730
	High	17,681,217	33,516,220
	Average	17,311,598	19,132,151
Traditional Solution 1	Low	35,467,583	4,493,496
	Medium	35,467,583	7,411,066
	High	35,467,583	23,272,454
	Average	35,467,583	11,725,672
Traditional Solution 2	Low	20,785,001	5,581,994
	Medium	21,238,979	10,527,837
	High	21,998,868	29,198,569
	Average	21,340,949	15,102,800

REFERENCES

APEL, H., THIEKEN, A., MERZ, B. & BLOSCHL, G. (2004) Flood risk assessment and associated uncertainty. Natural Hazards and Earth System Sciences, 4, 295 - 308.

DEFRA (2009) Appraisal of flood and coastal erosion risk management - A Defra policy statement.

DEFRA & HM TREASURY. (2009) Accounting for the Effects of Climate Change: Supplementary Green Book Guidance.

DOBES, L. (2008) Getting Real about Adapting to Climate Change: Using 'Real Options' to Address the Uncertainties. Agenda, 15, 55 - 69.

ELDAR, Y., BEN-TAL, A. & NEMIROVSKI, A. (2004) Linear Minimax Regret Estimiation of Deterministic Parameters with Bounded Data Uncertainties. IEEE Transactions on Signal Processing, 52, 2177 - 2188.

ENVIRONMENT AGENCY (2007a) Flood Risk Management Estimating Guide: Unit Cost Database. Environment Agency.

ENVIRONMENT AGENCY (2007b) Review of 2007 summer floods. Environment Agency, Bristol.

FERN, C., BETTESS, R., GOLDING, B., FARQUHARSON, F. & WOOD, T. (2005) The Boscastle flood of 16 August 2004: Characteristics, causes and consequences. 40th Defra Flood and Coastal Management Conference. York, UK.

GOULDBY, B., SAYERS, P., MULET-MARTI, J., HASSAN, M. & BENWELL, D. (2008) A methodology for regional-scale flood risk assessment. Water Management, 000, 1 - 14.

HALL, J., DAWSON, R., SAYERS, P., ROSU, C., CHATTERTON, J. & DEAKIN, R. (2003) A methodology for national-scale flood risk assessment. Proceedings of the Institution of Civil Engineers, Water and Maritime Engineering, 156, 235 - 247.

HR WALLINGFORD (2002) Risk Assessment for Flood and Coastal Defence for Strategic Planning: High Level Methodology -Technical Report W5b-030/TR1. DEFRA and Environment Agency.

MURPHY, J. M., SEXTON, D. M. H., JENKINS, G. J., BOORMAN, P. M., BOOTH, B. B. B., BROWN, C. C., CLARK, R. T., COLLINS, M., HARRIS, G. R., KENDON, E. J., BETTS, R. A., BROWN, S. J., HOWARD, T. P., HUMPHREY, K. A., MCCARTHY, M. P., MCDONALD, R. E., STEPHENS, A., WALLACE, C., WARREN, R., WILBY, R. & WOOD, R. A. (2009) UK Climate Projections Science Report: Climate change projections. Met Office Hadley Centre, Exeter.

USACE (1996) Risk-based Analysis for Flood Damage Reduction studies. Engineer Manual EM 1110-2-1619. U.S. Army Corps of Engineers, Washington, D.C.

WALD, A. (1945) Statistical Decision Functions which Minimize the Maximum Risk. Annals of Mathematics, 46, 265-280.

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