Impacts of Climate Change on Urban Infrastructure & the Built Environment

A Toolbox

Tool 4.3: Rapid Cost-Benefit Evaluation of Climate Change Impacts and Adaptation Options

Author

S. Oldfield[1]

Affiliation

1. MWH New Zealand Ltd., PO Box 9624, Te Aro, Wellington

Contents

1. Introduction

1.1 Background

This document gives details of one of a number of tools developed to assist Councils, and others, in taking account of long-term climate change effects in their on-going asset development and management, with the broad aim of making urban infrastructure more resilient to climate change effects.

The tool described is part of a 'Toolbox' comprising software tools and various reference and guidance documents designed to assist in assessing asset development needs and solutions that will lead to more resilient urban infrastructure in the face of increasingly extreme weather events.

The tool described here [Tool 4.3] is based on the Cost-Benefit Analysis (CBA) methodology promulgated by the NZ National Asset Management Steering Group in the document "Optimised Decision Making" (NAMS, 2004). The underlying techniques used in formulating the tool described here are widely used in many different contexts. Here, however, the tool has been developed and demonstrated [Keenan and Oldfield, 2011] specifically for prioritising and planning against increasing fluvial flooding hazard. The tool could be adapted relatively easily for other applications.

In Tool 4.3, the basic CBA methodology is adapted to allow the rapid analysis of all costs, both tangible and intangible, arising from a flood event. The increased speed of analysis is achieved by employing subjective judgement in place of a more formal, and time-consuming economic breakdown of costs. In doing so it must be accepted that there will be some loss of accuracy.

The resulting decision tool is referred to as 'rapid' Cost-Benefit Evaluation (rCBE) to reflect both its increased speed of application and treatment of all costs and benefits where these are not all directly monetary.

Designing and developing infrastructure to be more resilient to climate change effects does not require fundamentally different solutions, rather designs need to take account of changing climate-related effects. Detrimental climate change effects influence design through increased 'loading' requirements, and add to other uncertainties because the rate and magnitude of the changes in climate are not known with certainty. Increased uncertainty means that making the 'correct' design choice in any particular context is more challenging that it would otherwise be.

1.2 Purpose of Tool

The rCBE tool is specifically designed to allow prioritisation of actions to prevent or reduce the impact of flooding based on the level of risk these types of event present, taking account of climate change.

1.3 Obtaining this Tool

Contact the author of this report for information about obtaining and using this Tool.

2. Overview of the rCBE Decision Tool

The Decision Tool described here is based on a Cost-Benefit Analysis (CBA) methodology. CBA is commonly used to compare options for large scale costly developments such as alternative flood alleviation schemes e.g. the construction of a river flood stopbank.

The CBA methodology has been adapted here to provide a less resource intensive method of assessing high-level strategic alternative options. The method may be applied more rapidly than would be the case if the standard CBA methodology [see Tool 4.4] were applied. In achieving gains in speed, some loss of accuracy is to be expected. This is considered acceptable in assessing strategic decisions such as whether it is better to prevent flooding or to consider large–scale alternatives such as the managed retreat of properties from flood-prone land.

Here, the tool is presented and illustrated for its application to fluvial flooding, but the same methodology could be applied to many other applications.

2.1 Comparing rCBE to Conventional CBA & CEA Methods

The standard CBA methodology is based on weighing up the costs of a development against the overall benefit that it provides. The scheme that provides the greatest benefit compared to its cost provides a basis for selecting a preferred option. The related method, Cost-Effective Analysis (CEA), has the same basis as CBA but differs in that CEA takes a wider view of the costs and benefits, including both tangible and intangible[1] costs and benefits.

Generally it is to be expected that the greater the level of flood protection required the more costly will be the solution. This inverse relationship is shown in Figure 2.1, which illustrates the rCBE approach for two schemes (1 and 2) that offer different levels of protection: AEP_1 and AEP_2, respectively.

[1] For which costs cannot easily be assigned

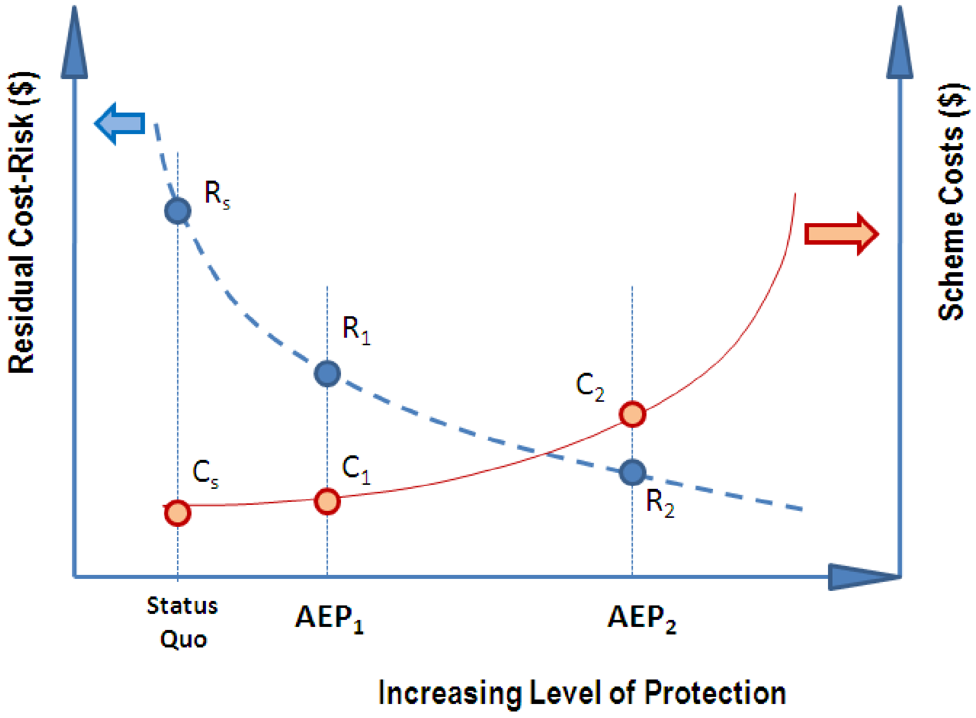

Figure 2.1: Schematic of rCBE Process (AEP is Annual Exceedence Probability)

Applying CBA methodology involves weighing up the cost of the schemes relative to maintaining the status quo (C_1 - C_S & C_{2} - C_s) as compared to the reduction in damage costs each option achieves (R_S - R_1 & R_S - R_2). There may be other indirect costs and benefits associated with either scheme which need to be accounted for, but the fundamental premise is that the best economic option is that which exhibits the greatest benefit over the cost involved. This is explained more fully below.

Rapid Cost-Benefit Evaluation (rCBE) takes the wider view of costs and benefits of the CEA methodology. However, these costs and benefits are derived from subjective judgement obtained using expert elicitation techniques (O'Hagan et al., 2006). The rCBE tool is therefore described as an "Evaluation" tool rather than an "Analysis" tool to recognise there will be some loss of accuracy because the costs and benefits are derived subjectively.

To reinforce the limits of accuracy that can be expected using expert elicitation, the costs and benefits are initially obtained from the experts in the form of a unitary rating from 1 to 7. A log base 10 translation is then used to convert the ratings to an equivalent monetary scale; thus, for example, a rating of 2 converts to $100, and a rating of 3 converts to $1000. To express the converted ratings generically, rather than in dollar terms, they are expressed in terms of 'utility', which includes both monetary and non-monetary costs and benefits.

Table 2.1 contrasts the main differences between the related methods of CBA, CEA and rCBE.

Table 2.1: Comparison of Related Methods

Cost Benefit Analysis (CBA)	Cost Effective Analysis (CEA)	Rapid Cost Benefit Evaluation (rCBE)
Evaluates tangible costs, benefits and risk in dollar terms	Evaluates tangible and intangible costs, benefits and risk in terms of 'utility'.	Subjective rating of costs, benefits and risk in terms of 'order of magnitude scores'
Involves a detailed bottom-up development of costs and benefits	Involves forming functions of utility for the components of cost, benefit and risk	Scores generated using expert judgement, guided by predefined descriptive ratings

2.2 Basis of Rapid Cost-Benefit Evaluation (rCBE) Process

Accepting some loss of accuracy, the time and resource savings in the rCBE process are made through:

a) Using a simplified, but calibrated, flood model to generate flood inundation maps[2];

b) Employing expert elicitation techniques to develop a macro-scale breakdown of order-of-magnitude costs against river reaches;

c) Using a direct tabulation of costs and benefits against river reaches rather than spatial mapping and integration of costs.

The time savings from (a) derive from the ability to run the large numbers of flood scenarios relatively quickly. Using detailed flood models to produce results for all the different scheme options and for a range of different AEP flood events can take weeks to complete. Time savings from (b) derive from the use of what are known as 'decision conferencing techniques' to elicit order of magnitude costs from experts in a structured workshop environment (O'Hagan et al, 2006). This compares with using spatial tools (e.g. GIS) to map the flood model results together with demographic information and derive spatially varying costs on a mesh-grid of cells covering the inundated area e.g. using RiskScape [Tools 3.2 and 3.3].

[2] If costs are order-of-magnitude, then simplified flood models can be used. However, such models should be calibrated against one or two detailed (e.g. 3-D) hydraulic model runs.

To be effective, however, there are certain ‘disciplines’ in how the subjective information is derived which must be followed. These disciplines are achieved by ensuring equivalence (nominally in cost terms) in the ratings across the quadruple bottom line issues[3]. This equivalence is necessary to allow summation of risk contributions across all issues.

Time savings from (c) result because a macro-scale development of costs against river reaches can be tabulated directly into a spreadsheet system and linked directly to the derivation of discounted costs and benefits required in generating decision metrics, such as the Benefit-Cost Ratio.

2.3 Weighing up Benefits over Costs

The classical metric used in making judgements about the most economically advantageous options amongst a number of alternatives is the Benefit-Cost Ratio (BCR), although there are other related measures. The BCR metric is defined as follows:

$$\text{Benefit Cost Ratio (BCR)} = \frac{\sum (\text{Discounted Annual Benefits})}{\sum (\text{Discounted Annual Costs})}$$

Where:

Annual Benefits = (Damage Costs Avoided + Other Benefits)

Annual Costs = (Scheme Costs + Damage Costs Not Avoided + Other Costs)

All costs are developed on an annualised basis and discounted to present day values.

Annualised damage costs and damage costs not avoided are derived from a probability weighted sum of the costs associated with a range of different severity flood events, where the probability used is the AEP of the flood event.

Annual damage costs avoided are estimated from the difference in annual damage costs should the status quo be maintained, and the annual damage costs if the scheme were implemented. ‘Other benefits’ allow for additional benefits realised from implementing a particular scheme e.g. property developments that would otherwise not happen but for the reduced flood risk.

[3] The Local Government Act, 2002 refers to social, economic, environmental and cultural well beings as the focus of sustainability

Annual scheme costs are the combination of scheme capital costs and operating costs. The overall costs include the damage costs not avoided associated with over design events. The latter are the costs that arise from events which are more severe than the maximal event used to determine limits of the scheme design.

2.4 The Impact of Climate Change

Climate change, in the context of flooding, will affect the costs and benefits principally through the long-term change in rainfall patterns and sea-level rise. The latter, for example, can influence the rate at which flood water recedes.

If low discount rates are used in the economic analysis then the study period becomes important. This is because costs do not become vanishingly small so quickly. As a guide, the study period should be chosen to at least encompass the life expectancy of the scheme development and varied to explore its sensitivity.

2.5 Discounting Costs and Benefits

Currently, there is little guidance given on the appropriate discount rate that should be used when considering long-term future-proofing investments. Discount rates used in assessing the merits of transport investments are generally quite high, typically between 8% and 10%. Discounting at these relatively high rates tend to eliminate much of the climate change effect which may not be of significance for 30 to 50 years. For these reasons, it is recommended that a wide range of discount rates are investigated to establish whether or not climate change effects would modify choices, and to ensure sustainable solutions are found.

3. Quantifying Costs and Benefits

In order to make the assessment of costs and damages tractable using expert elicitation, the first step is to divide the river into a number of reaches (Figure 3.1). For practical reasons, between 10 and 30 reaches should be used. However, the actual number will be a compromise between efficiency in deriving cost information versus accuracy.

For each river reach, experts are asked to rate the level of damage on a scale of 1 to 7 against the quadruple bottom line (four community well-beings). Prompt sheets are provided to guide this rating process and to ensure a consistent rating across the quadruple bottom line.

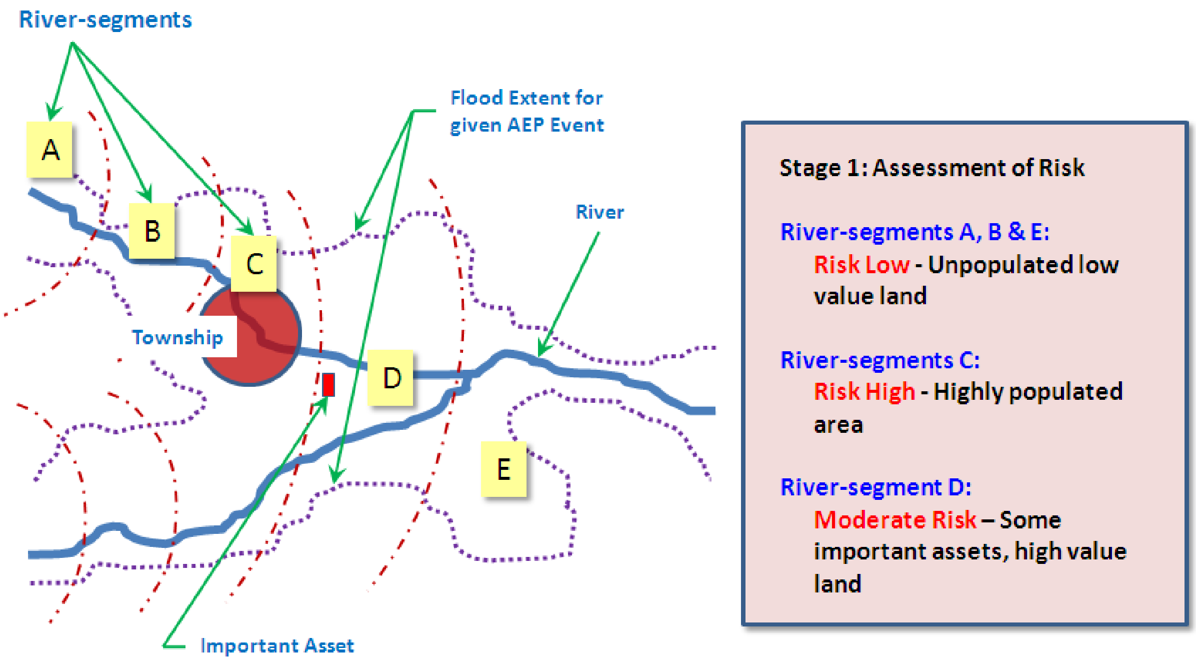

Figure 3.1: Subjective Rating of Flood Impacts against River Reaches

The consequence ratings are then translated to dollars using a log transformation and the quadruple bottom line contribution is summed. It can now be appreciated why the ratings need to:

a) Translate to dollars;

b) Have consistent meaning across the quadruple bottom line component.

Summing the separate components without the above aspects would not be valid.

Expert elicitation is used to rate the consequences for the status quo and each scheme (should it be implemented) for each river reach. This provides the information from which annual average benefits can be estimated using flood extent maps and local knowledge.

Broad scheme costs are obtained from a top-down accounting for the lifecycle development of each scheme. Standard tables of industry costs can be used to provide a first order estimate of costs involved.

3.1 Data Needs

The basic data needs for the rCBE methodology to be meaningfully applied to the management of flood hazard are as follows:

a) Flood extent maps for the status quo and with each flood management scheme in place, with flood extent predictions produced for a range of different AEP events;

b) Risk ratings for each river reach for each scheme and AEP event;

c) Broad costs and added benefits for each scheme;

d) Choice of discount rate and study period.

The intention is that the river of interest would be split into between 10 and 30 reaches and risk ratings for each obtained by a process of elicitation from people with the appropriate local knowledge and other relevant experts (e.g. Council River Managers). Typically one or more decision-conferencing workshops would be held to obtain this information guided by a qualified facilitator using a pre-arranged damage rating scheme, see for example Figure A1.

Flood extent results overlaid on cadastral maps (point a) are essential to guide the discussion and rating flood damage for the different flood event scenarios (point b). However the flood predictions do not need to be highly detailed since the damage across all river reaches will be summed for an event to derive an overall annual average cost.

A breakdown of the broad lifecycle costs of each scheme should be developed at a level of detail and accuracy in keeping with that of the subjectively derived damage costs. Costs would typically be based on published unit costs for land acquisition and physical works, expert judgement on up-front design and planning, lifetime maintenance and any other costs associated with scheme development.

All the cost and benefit information derived from the information sources (a) to (c) referred to above is best captured directly into a spreadsheet and linked to the BCR calculations, as described in Section 4. This approach facilitates the automatic update of the BCR calculations during the iterative development of scheme options.

Alternatively, similar damage cost-based information could be derived from the RiskScape software currently under development by NIWA and GNS [see Tools 3.2 and 3.3]. This system can predict flood losses directly, provided all the necessary information is available for the area of interest within RiskScape. As RiskScape is still under development, the spreadsheet approach described in Section 4 provides a simpler alternative. Either way, flood extent maps are required for a range of events, and for each scheme, prior to performing the BCR calculation.

3.2 Outputs Generated to Aid Decision Making

Figure 3.2 shows a hypothetical comparison between two alternative flood mitigation schemes, including uncertainty in the BCR metric (upper, lower and best estimates). Scheme 1 has a higher BCR if the two schemes are compared on a like basis, i.e. Scheme 1 has a higher best estimate BCR than the best estimate BCR for Scheme 2. However, because of the range of possible BCRs for the two schemes (overlap in lower to upper estimates), there is a small (undetermined) possibility that Scheme 2 could in fact be as good as, or better than, Scheme 1. This is a consequence of uncertainty in the costs and benefit estimates. Reducing uncertainty will provide greater confidence that Scheme 1 is more economically beneficial than Scheme 2.

Figure 3.3 shows the variation in the undiscounted economic benefit of Scheme 1. Initially there is a net cost from the construction works. Over time, a net (positive) benefit is shown as the benefits of preventing flood damage outweigh the capital and operating costs of the scheme. Clearly, the steady increase in annual benefits is artificial since the benefits would occur only if and when flood events occur. Risk-based BCA is based on the long-run statistical assumption of an Annual Exceedance Probability applying.

Figure 3.2: Illustrative Comparison of Schemes Based on BCR

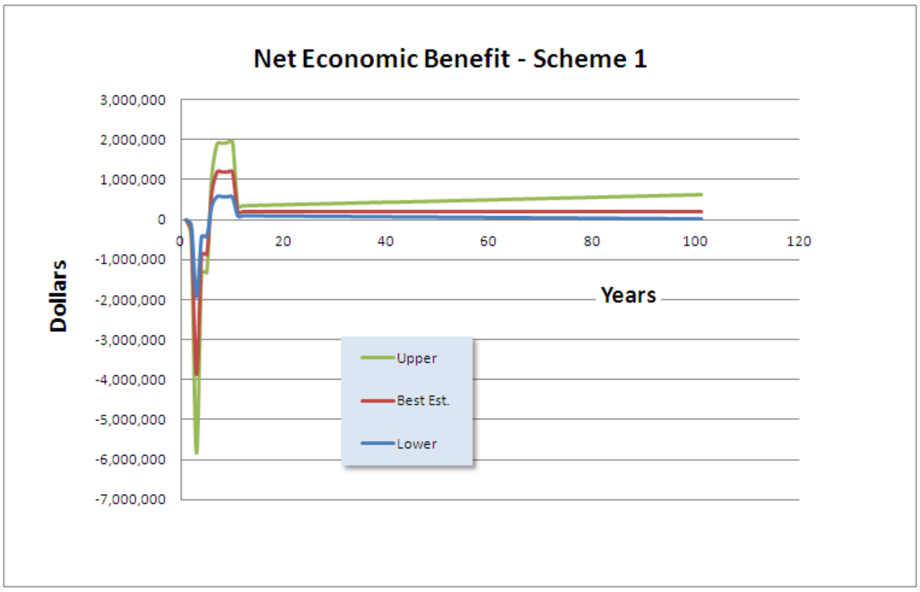

Figure 3.3: Total Undiscounted Annual Net Benefit of Scheme 1

3.3 Assumptions and Limitations

The overriding assumption in applying the rCBE Decision Tool in this context is that it is reasonable to establish priorities for the management of natural hazards on the basis of long-run statistical risk-based economics.

Other key assumptions implicit in applying the rCBE approach are as follows:

a) Subjective judgements are appropriate for the purposes of establishing the relative benefits between options on an economic basis;

b) Common cost-based judgements can be made on both tangible and intangible effects of natural hazards;

c) A discounted approach is a valid basis for making decisions about long-term investments to future-proof against uncertain climate change effects.

It is considered that the first two assumptions above are valid if the rCBE approach is only used to make high-level strategic comparisons between fundamentally different adaptations. Thus the tool would be used to answer such questions as:

"Is it better to protect a community at risk from a natural hazard such as flooding or is it better to move the community to a less vulnerable location?"

Exploring variability and uncertainty in the costs and benefit estimates that are selected is even more important when using subjectively-derived information, so as to ensure that solutions are robust.

Assumption (c) above is a matter of choice, but it is recommended that rCBE/CBA should not be used on its own in making decisions. Other elements need to be included, such as:

a) Seeking community opinions;

b) Exploring the full range of non-economic factors; and

c) Factoring in the possibility of flexibility or staging of options.

4. How to Apply the Decision Tool

The application and use of the rCBE Decision Tool is illustrated using a case study performed on the Buller River [Keenan and Oldfield, 2011]. The presentations and descriptions given here are provided to offer insights into the application of the tool for a flood management application; however the process is applicable to a wide range of other climate change effects and, indeed, not limited to the treatment of natural hazards.

4.1 Application Framework

Figure 4.1 gives a schematic of the overall rapid Cost Benefit Evaluation process. At this level, the process is very similar to a conventional risk-based CBA. The differences are in how the cost and benefit data are derived. The application of rCBE (and conventional CBA) to making decisions concerning long-term climate change impacts does, however, require consideration of the appropriate time horizons and discount factor. Taking an overly short-term view about returns on investment will mean that the longer-term benefits will be 'discounted' to negligible levels.

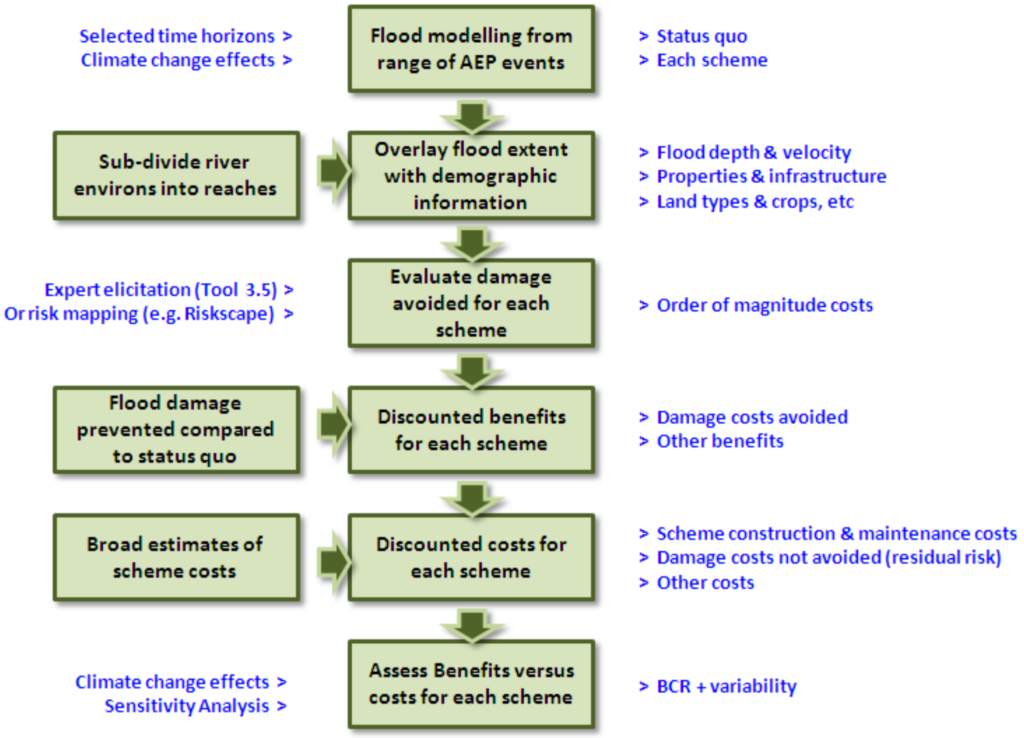

Figure 4.1: Schematic of Rapid Cost-Benefit Evaluation Process

4.2 Tool Structure and Content

The rCBE Tool has been incorporated into a spreadsheet and comprises a number of worksheets as shown in Figure 4.1. Worksheets are provide for the development of the natural hazard risk, the scheme costs (both capital and operational) and for the development of benefits, both in terms of the damages prevented and any additional benefits derived from the implementation of the hazard management schemes.

An overall analysis sheet draws the cost and benefit data together, performs the appropriate discounting and computes the overall economic decision-making metrics such as the Benefit-Cost Ratio. A final worksheet is provided for generating graphical outputs of the result.

An overview of the different worksheets is given in Table 4.1 which also cross-references illustrations of the worksheets presented in Appendix A of this tool guide.

4.3 Illustrative Example

A case study illustrating the use of the rCBE tool is given in "Toolbox Case Study – Westport Flood Hazard" (Keenan and Oldfield, 2011). The Case Study gives an account of an economic evaluation of high-level strategic options under a number of climate change scenarios for reducing the flood hazard risk of the Buller River to the Westport community.

Table 4.1: Description of Worksheets within the rCBE Tool

Worksheet(s)	Description
Consequences Prompt Sheet	This worksheet provides prompt lists to assist experts in assigning consistent risk ratings across quadruple bottom line aspects when assessing the impacts of a natural hazard. Figure A1 (Appendix A) gives an example developed for assessing the impacts from fluvial flood events.
Risk Rating Sheets	A series of worksheets provides for capturing risk ratings for each of the river reaches. Separate columns are provided for rating different severity events, in this case different AEP flood events. A separate sheet is provided for risks associated with maintaining the Status Quo and for each of the schemes to be analysed. A screen shot of part of one of these sheets is shown in Figure A2.
Damage Cost Summary Sheet	This worksheet provides a tabular summary of the overall flood risk damages predicted from the Risk Rating Sheets for each of the flood scenarios considered. An annualised long-run average damage cost is derived by multiplying costs from each flood event by the AEP for that event. Figure A3 provides an illustration of part of this summary sheet.
Scheme Lifecycle Cost Sheet	This worksheet is used to develop a tabular breakdown of the capital and operating costs associated with each scheme. Normally the costs for maintaining the Status Quo can be ignored, however provision is made to allow for the capture of maintenance costs if these are significant. Figure A4 provides a partial screen shot of this worksheet.
Scheme Added Benefits Sheet	This worksheet is provided to allow any additional benefits that may accrue from any of the schemes to be included. These benefits may derive from additional developments as a result of the improved level of protection. For example the provision of a stopbank may initiate additional property development on land that was previously considered at too great a risk from flooding. Figure A5 gives a screen shot of this worksheet.

Worksheet(s)	Description
Master Scheme Assessment Sheet	This is the main rBCE analysis worksheet on which costs and benefits are listed and discounted for each of the schemes from the other worksheets. On this worksheet various economic metrics (such as the BCR) are calculated for each of the schemes. Figure A6 provides a partial view of this worksheet.
Graphical Results	This worksheet is used to generate graphical presentations from the data generated on the Master Scheme Assessment worksheet. Example graphics are illustrated in Figure A7.

5. References

AS/NZS ISO 31000:2009. Risk Management – Principles and Guidelines, Standards New Zealand, Wellington.

Keenan N. and Oldfield S.G (2011) Toolbox Case Study – Westport Flood Hazard. MWH Report No. Z1823603.

NAMS (2004) Optimised Decision Making Guidelines – A Sustainable Approach to Managing Infrastructure, NZ National Asset Management Steering Group Version 1.0 November 2004.

O'Hagan A, Buck C.E, Daneshkhah A, Eiser J.R, Garthwaite P.H, Jenkinson D.J, Oakley J.E and Rakow T (2006) Uncertain Judgements - Eliciting Experts' Probabilities, John Wiley & Sons Ltd., London.

Appendix A: Model Structure

The following are annotated computer screen shots of an illustrative application of the rCBE Tool to the assessment of flooding adaptation schemes.

	Economic	Population At Risk[#1 & #2]	Social	Environment	Cultural	Critical Asset
1	Negligible cost, Typically $10 direct costs per event	No residents at risk	Little or no social disruption	Negligible damage to habitat and/or rapid regeneration of habitat	Negligible damage to cultural heritage or taonga	No critical assets affected
2	Very low cost, typically $100 direct costs per event	No more than 3 people at risk	No more than minor, short-term social disruption and recovery	Minor damage to habitat, vegetation or crop	Minor repairable/rectifiable damage to cultural heritage or taonga	Access to critical asset impaired
3	Low cost, typically $1000 direct costs per event	Between 4 and 30 people at risk	Some social disruption and stress for a significant period	Moderate repairable/rectifiable damage to valued habitat, temporary loss of vegetation	Moderate repairable/rectifiable damage to cultural heritage or taonga	Critical asset damaged and temporarily disabled
4	Moderate cost, typically $10,000 direct costs per event	Between 31 and 90 people at risk	Significant social disruption, moderate chance of injuries, significant stress over a moderate period of time	Major repairable/rectifiable damage to valued habitat, prolonged damage to vegetation or lost crop, some remediation required	Major repairable/rectifiable damage to cultural heritage or taonga of some importance	Major damage to critical asset
5	High cost, typically $100,000 direct costs per event	Between 91 and 300 and people at risk	Significant social disruption, moderate chance of major injuries and/or several minor injuries	Localised degradation or damage to valued habitat, significant remediation of vegetation or land required	Degraded or major damage to cultural heritage or taonga of local significance	Major damage to critical asset resulting in wider impacts, e.g. loss of essential services
6	Very high cost typically $1,000,000 direct costs per event	Between 301 and 1000 people at risk	Prolonged social disruption, high chance of several major injuries and/or one fatality	Permanent loss of valued habitat or degraded land over a small area	Permanent loss of cultural heritage or taonga of regional significance	Critical asset destroyed and wider impacts, e.g. loss of essential services
7	Extremely high cost typically $10,000,000 direct costs per event	More than 1000 people at risk	Prolonged social disruption and high chance of major injuries and multiple fatalities	Permanent loss of valued habitat or degraded land over a wide area	Loss of nationally significant heritage and/or taonga	Several critical assets destroyed and wider impacts, e.g. loss of essential services

Illustrative Example

Note #1: Injuries and health effects factored in using the Disability Adjusted Life Year (DALY) approach promulgated by the WHO, Pruss-Ustun A, Mathers C, Corvalan C and Woodward A, 2003 Assessing the Environmental Burden of Disease at National and Local Levels – Introduction and Methods, World Health Organisation, Environmental Burden of Disease Series, No. 1

Note #2: Itinerants factored in according to temporal and spatial exposure

Figure A1: Illustrative Example of Flood Damage Guidance – Prompt Sheet

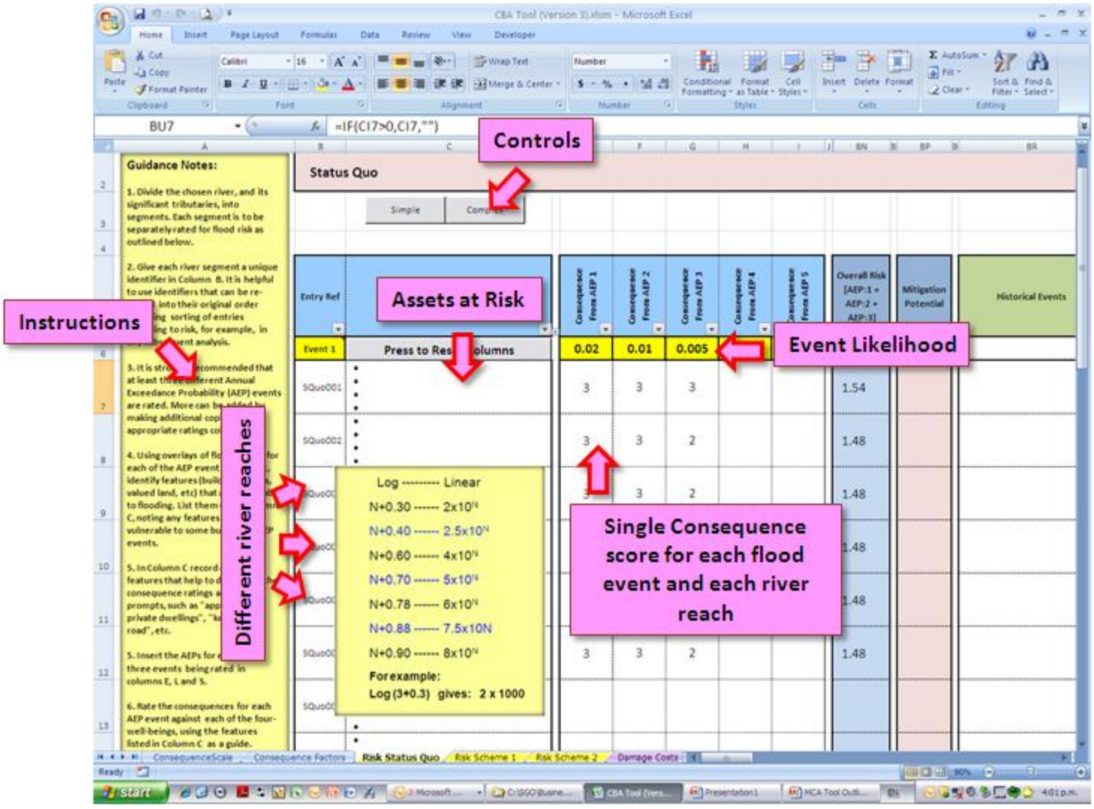

Figure A2: Example Extract from Risk Rating Worksheet

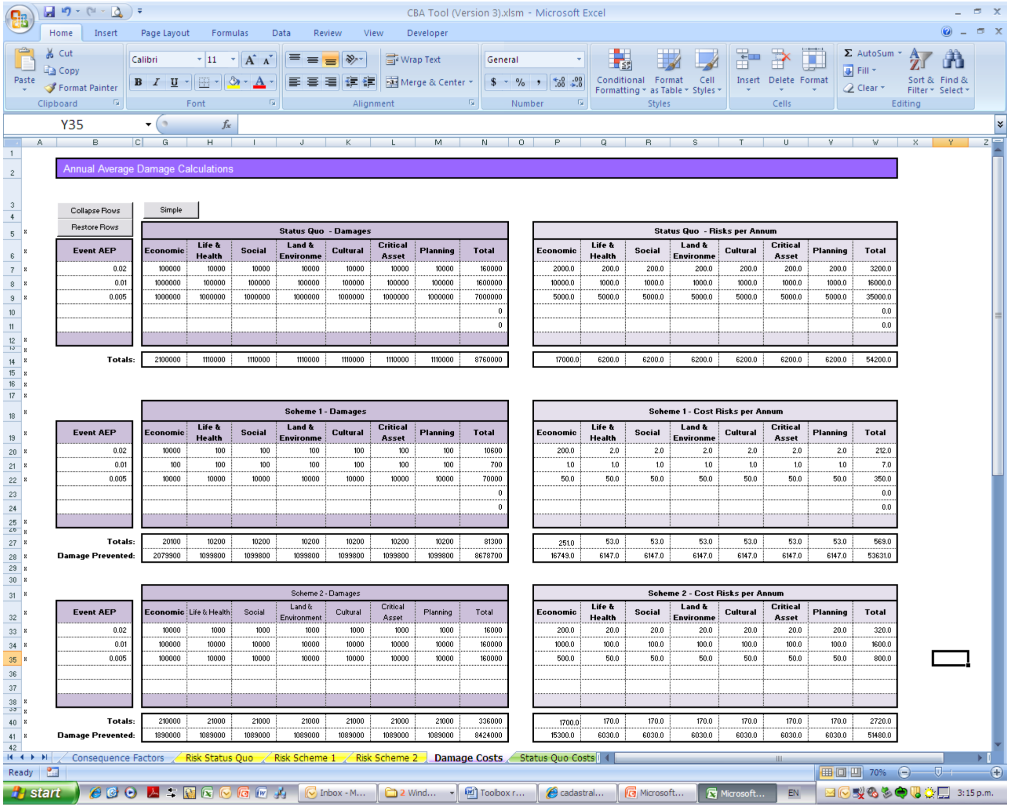

Figure A3: Example Extract of Summary Damage Costs Sheet

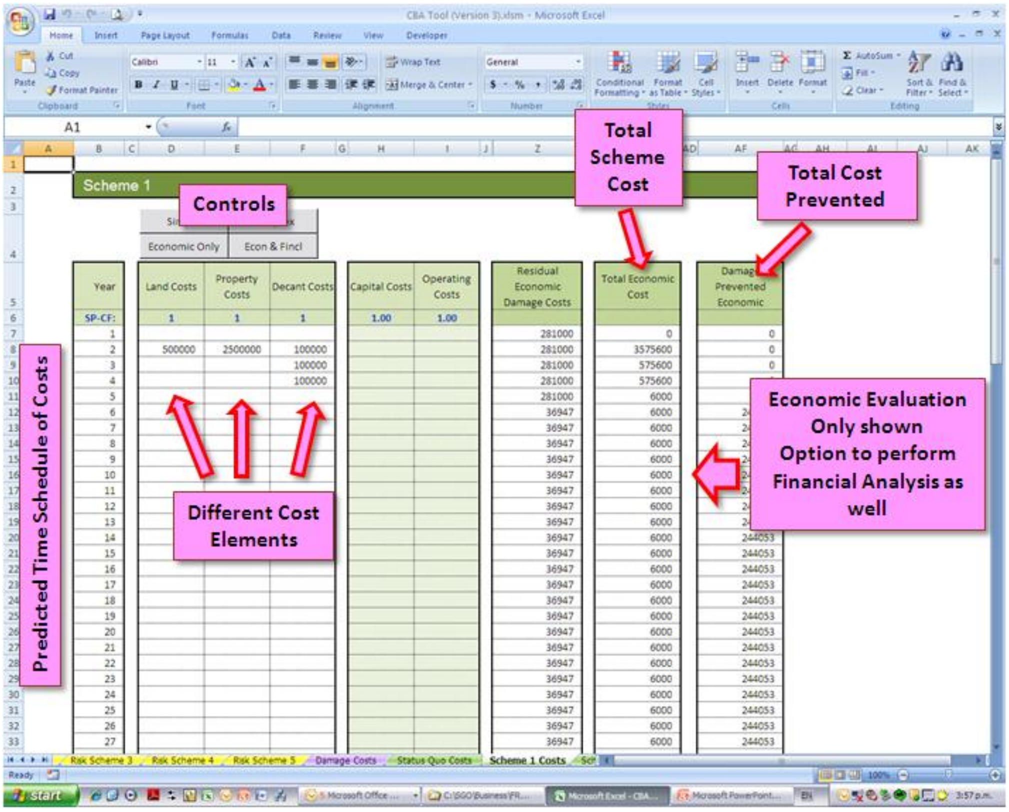

Figure A4: Example from Scheme Lifecycle Cost Sheet

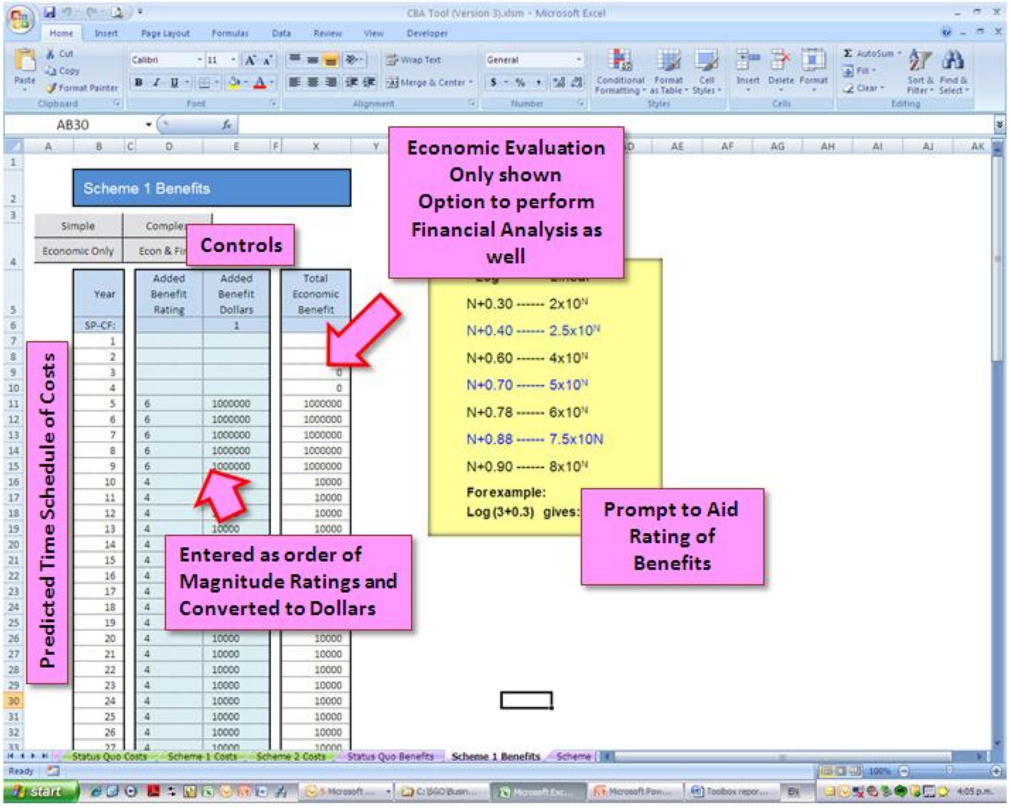

Figure A5: Example Extract of Scheme Added Benefits Worksheet

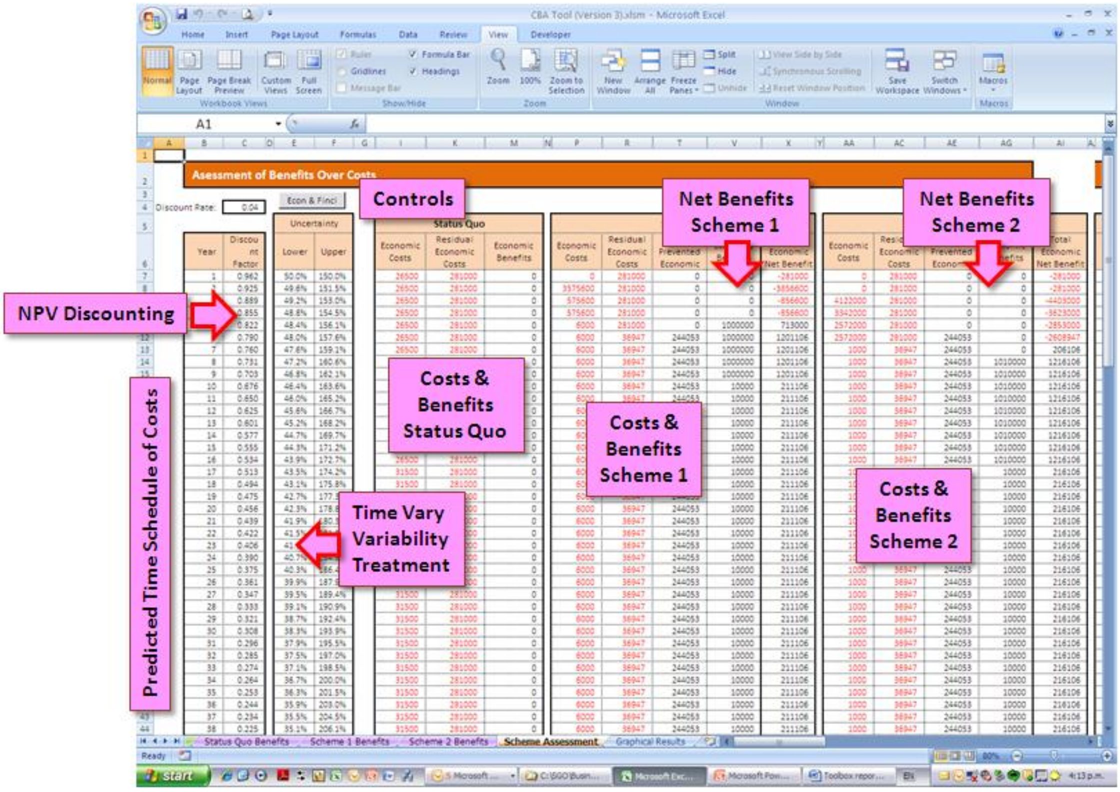

Figure A6: Example Partial View of Master Scheme Assessment Worksheet

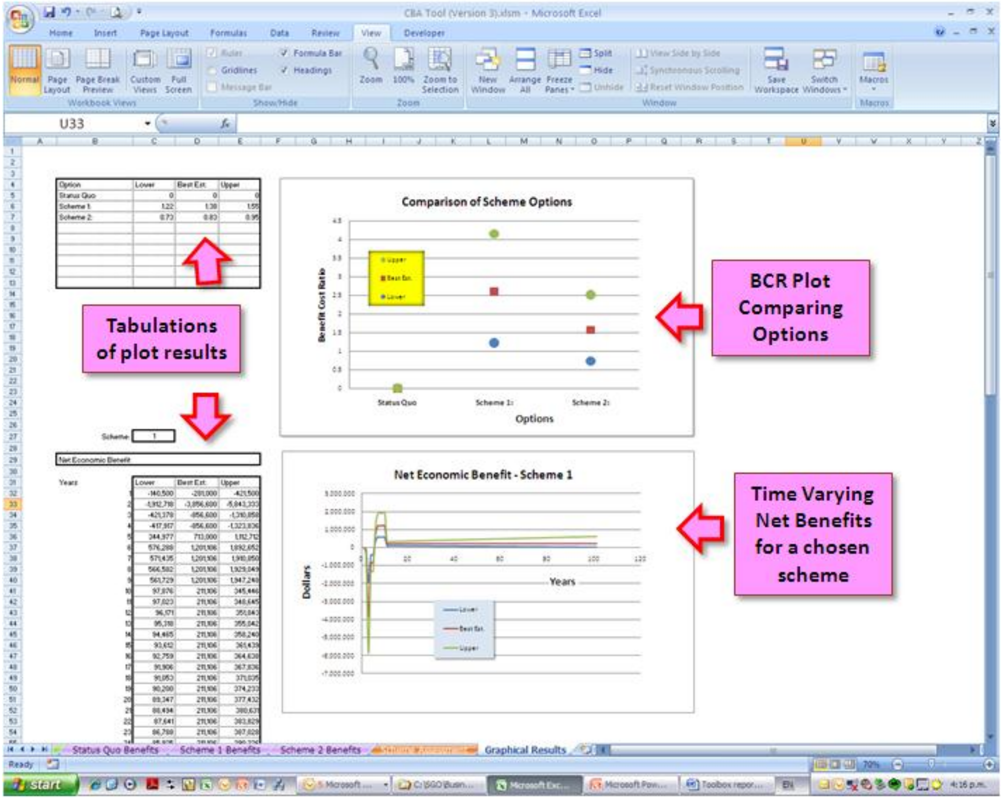

Figure A7: Illustrative Graphical Output