MAKING BETTER DECISIONS: CALCULATING THE BENEFITS OF STORMWATER INFRASTRUCTURE

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ABSTRACT

Good decisions are informed by the best available information. In addition, proactive investment in hazard management is more likely to result in value for money than reactive investment in disaster recovery. Economic appraisal of schemes is a fundamental part of the decision-making process to ensure that the benefits of investing in flood risk management deliver the desired improvement in social welfare. However, economic analysis can only provide part of the required information to inform decision makers, and as such can commonly be used as part of a wider Multi-Criteria Analysis.

This paper reports the development of an economic appraisal tool for Christchurch City Council ('Council') to interrogate and evaluate stormwater management approaches, inform climate adaptation and help plan significant infrastructure delivery. The key features of the economic appraisal tool are that it:

- builds on flood damage estimated by NIWA's RiskScape tool;
- applies economic theory drawn from within New Zealand and internationally;
- is flexible to assess economic costs and benefits of a range of mitigation options, flood sources and timescales; and
- is simple to use and tailored to Council's audience and required outcomes.

The tool provides a framework for understanding the damages resulting from flooding, how these damages could be reduced by flood management schemes and how the cost of such schemes compare with the damages avoided. The tool can inform decision making at multiple stages through a project lifecycle; firstly as part of options development and then during the appraisal process to determine how the costs of a scheme compare with its benefits. It combines hydraulic modelling data and estimates of scheme cost and then maps the pattern of flood damage and calculates key economic metrics. Whilst developed for Christchurch, the theory and the approach to economic modeling has wide applicability across New Zealand and other countries for better stormwater infrastructure decision making.

KEYWORDS

Economics, flood, climate change, adaptation, Christchurch, earthquake, stormwater, decision-making

1 INTRODUCTION

Good decisions are informed by the best available information. In addition, proactive investment in hazard management is more likely to result in value for money than reactive investment in disaster recovery. For example, planned investment in United Kingdom (UK) flood management seeks returns of at least 8:1 whereas reactive funds for repair and improvements following a flood event have no such goals set, and are not commonly assessed in terms of benefits and costs. They are therefore unlikely to offer the same economic benefits.

Economic appraisal of schemes is a fundamental part of the decision-making process to ensure that the benefits of investing in flood and coastal erosion risk management outweigh the costs and therefore that funds are used to maximize social welfare. Hughes et al. (2015), based on analysis in Christchurch, highlight the need for locally tailored cost-benefit analyses of climate adaptation options. However, economic analysis can only provide part of the required information to inform decision makers, and as such can commonly be used as part of a wider Multi-Criteria Analysis. In Christchurch, for example, five key decision informing criteria, other than the drainage/flood benefits, of the scheme that are typically considered are ecology, landscape, recreation, heritage and cultural values. MCA can be used during a study to guide the development and/or assessment of a sustainable and adaptive solution, as well as to include important aspects to inform decision making which cannot be captured in monetary terms with a Cost Benefit Analysis (CBA) or are better defined outside that process.

Decision frameworks should be simple and allow for consistent assessments to be undertaken between schemes. The European Union Floods Directive highlights that ‘a significant challenge exists in striking a balance between devising methodologies that allow for a robust assessment of alternative measures, while at the same time not being excessively costly, technical, or prohibitively complex for parties to understand.’ Common examples are:

- Cost Effectiveness Assessments (CEA) which compare the costs of alternatives that provide the same outcome. Effectiveness could be expressed in terms of decreased flood risk, extra storage capacity created, etc.

- Cost Benefit Analyses (CBA) which compare alternatives where differing costs and benefits are all expressed in monetary terms. However, it is widely recognised that certain costs and benefits are difficult to monetise.

- Multi-Criteria Analyses (MCA) that use a range of criteria to assess different alternatives. Important steps are to agree appropriate criteria and then weight the criteria for importance. A general score is calculated for each alternative so that they can be ranked.

An international review of the appraisal of flood risk management schemes undertaken for this paper (Table 1) demonstrated that, whilst countries differed in the appraisal frameworks they used or combined together, there is general consistency in the output metrics which are considered. The City of Townsville conducted a coastal Hazard Adaptation Strategy (2013) which developed possible responses to coastal hazards. An economic assessment of each option was carried out which combined MCA and CBA methodologies, enabling the assessment of each option across a mix of social, environmental and economic factors. The Thames Estuary 2100 project (Environment Agency, 2012) was the first major UK flood risk management project to put climate change adaptation at its core. CBA was used as an already accepted best practice. However, greater consideration of social and environmental impacts not captured within the CBA was required and thus MCA was applied in conjunction with the CBA. Similarly, the economic appraisal tool for Christchurch City Council will be used to carry out CBAs of schemes which are then used within a wider MCA process to ensure all 6 values listed above are considered.

Table 1: Review of international approach to appraisal, metrics and discount rates

Country	Approach	Metrics for CBA	Discount rates
UK	CEA, CBA, extended CBA and MCA	Net Present Value (NPV) Incremental Benefit Cost Ratio (BCR)	3.5% (reducing over time)
Ireland	CBA and MCA capturing impacts in slightly different ways	NPV BCR	4% (sensitivity analysis of 3%-5%)
Australia	MCA then CBA	Not stated	7% (sensitivity analysis of 3% and 10%)
Canada	CBA (and CEA and MCA)	NPV, BCR Internal Rate of Return (not preferred)	8% (sensitivity analysis of 3% and 10%)
European Union	CBA and extended CBA	Not stated	3%-5%
United States	CBA ‘Environmental Quality’ and ‘Other Social Effects’ accounts	NPV Incremental BCR	7%
New Zealand	CBA	NPV BCR	Variable between 6-10%

The economic appraisal tool described in this paper embeds a number of other key principles to allow its use in evaluating adaptive stormwater schemes to be maximised, whilst being as simple as possible to use and interpret the results. These features are:

- **Timing of proposed schemes:** In stormwater and flood management, the importance of adaptive approaches is now recognized. For example, the Paris Climate Conference agreement in December 2015 reinforced the urgency to cut emissions and reduce the impact of global warming, whilst putting adaptation to climate change as a central issue on par with mitigation. The economics of flood management schemes has largely focused on appraising the costs and benefits of precautionary interventions, i.e. building a scheme within a few years of the appraisal that provides benefits over its useful life. Instead, economic appraisal should be flexible to accommodate schemes which may be staged over two or more discrete interventions and understand the cumulative benefits they may provide. Because a key principle of adaptation is that the timing of interventions may be modified according to the impacts of climate change and sea level rise, economic appraisals must similarly reflect this flexibility.

- **Holistic consideration of flood damages:** Flooding in Dunedin in June 2015 was estimated to cost insurers $28.2M whilst the total cost, including the economic and social impacts, was estimated at around $138M (Otago Daily Times, 2016). This example illustrates how the total damage caused by flooding must take into account as many of the diverse impacts of flooding as possible, including the social impacts which are difficult to monetise. Importantly, the Mayor of Dunedin concluded that "being reminded how expensive for our community those sorts of events are, really sharpens our resolve to look at what we can do to mitigate future events. And we have got to get on to it." The economic appraisal tool provides the facility to include a wide range of indirect damage estimates, including social and environmental, into the CBA.

- **Visualisation of damage estimates aids understanding and review:** Economic appraisal of flood schemes can often be left to the end of a project once a design has been developed to meet certain hydraulic criteria. However, having access to a rapid economic appraisal at interim points in a study can help steer a design to be both hydraulically and economically beneficial. Damage costs aggregated over a study area can produce large values which are difficult to interpret and review; maps showing the distribution of damage helps designers and decision makers to understand the pattern of damage which the scheme aims to avoid. It also serves to identify any unplanned outcomes for the proposed interventions, such as increased damages in certain locations, as well as serving to highlight any inconsistencies in the data sets. An appreciation early in the study of the amount of damage likely to be avoided by the scheme can prevent expensive over-design of schemes which may then be difficult to fund and raise local expectations beyond what is feasible or necessary.

2 KEY ECONOMIC THEORY APPLIED IN THE TOOL

2.1 CLASSIFICATION OF FLOOD IMPACTS

Table 2 provides a summary of the impact (damage or benefit) categories relevant to flood risk assessment. These impacts can be categorised as direct or indirect, and tangible or intangible, defined as:

- Direct: caused by immediate physical contact with flood water
- Indirect: caused by the consequences of the physical contact of the flood water with damageable property
- Tangible: effects including all kind of damages that can easily be expressed in monetary terms
- Intangible: impacts to people, good and services that are not traded in the market

Table 2 shows the treatment of flood impacts within the tool. Impacts coloured green are estimated in monetary terms in the economic tool, orange impacts may or may not be material to the decision and so can be optionally included in the tool, purple impacts fit best within a MCA framework and so are not included in the tool. Those coloured grey are unlikely to be material and so are excluded.

Table 2: Treatment of flood impacts in the economic appraisal tool.

Direct		Indirect	
Tangible	**Intangible**	**Tangible**	**Intangible**
Property	Physical and mental health effects	Alternative accommodation costs	Inconvenience caused by disruption of utility services
Crops and land values	Loss of memorabilia and irreplaceable items	Clean up and Emergency services costs	Disruption of communities and loss of cohesion
Damage to goods	Loss of ecosystems including water quality impacts	Increased travel costs	Cultural values
Infrastructure and utilities	Loss of Life	Production and income losses	Increased vulnerability of people and companies
		Land management and pollution effects	

A review was undertaken using available information on the damage or benefit categories applied around the world, from which the following was observed (not intended to be comprehensive):

- **Asia:** studies have quantified tangible damages but not intangible damages;
- **Australia:** tangible damages are considered as those which can be readily monetised whereas intangible damages cannot, and that intangible damages include fatalities;
- **European Union:** since the social effects of floods are rated worse than the economic or financial losses, intangible damages are likely to make up a significant proportion of the total damages;
- **Germany:** intangible damages are classified as social or environmental, where social includes loss of life. A framework for the monetisation of all damages is provided although limitations of monetizing some aspects are clearly recognised;
- **Ireland and the UK:** calculation of direct, indirect and intangible damages are based on the Multi-Coloured Manual methodologies (http://www.mcm-online.co.uk/manual/). Direct damages are largely based on the depth of flooding whereas intangible damages are accrued even for shallow flooding so that these can be equal or even greater than direct damages; and
- **USA:** although the importance of intangible damages is recognised, they are not included in monetary assessments.

A recent New Zealand study (Kerr, 2015) concluded that the value of intangibles cannot be assessed directly, because intangible and tangible effects are always confounded. However, there was evidence that indirect and intangible damages are roughly equal to direct damages. Alfieri et al. (2016) reports that indirect losses are often assumed to be about 40% of the direct ones, but they might actually become much larger if unexpected chains of events take place.

The following sections expand on these classifications as they are applied in the economic tool.

2.1.1 DIRECT DAMAGES

Direct damages are calculated relative to the depth of flooding, although velocity of flooding has been shown to be important in some situations[1]. A number of countries have developed empirical relationships between flood depth and damage but, because of significant differences in property stock, these empirical relationships are not typically transferrable. In New Zealand, comprehensive relationships for flooding and other hazards have been developed by NIWA and implemented in RiskScape (https://riskscape.niwa.co.nz/). RiskScape provides a framework for analysis of the impact of natural hazards (tsunami, flood, wind, volcanic hazards and earthquakes) and, whilst it is not an economic appraisal tool, it does facilitate economic appraisal through its quantification of damages.

Direct damages in the economic appraisal tool are calculated as the sum of the following components which are based on RiskScape depth-damage curves: asset (building) repair, building contents replacement, cleanup, disruption and vehicle damage. These were provided by NIWA for buildings in Christchurch. Building, contents

[1] Velocity is less influential in the majority of Christchurch due to its flat topography

and vehicle damages are the costs to repair or replace items and are therefore capped at full replacement cost. Cleanup costs also vary with flood depth for residential and non-residential buildings. Disruption costs apply only to non-residential buildings and represent functional downtime and loss of income. Figure 1 provides an example depth damage curve applied in the economic appraisal tool at a residential building.

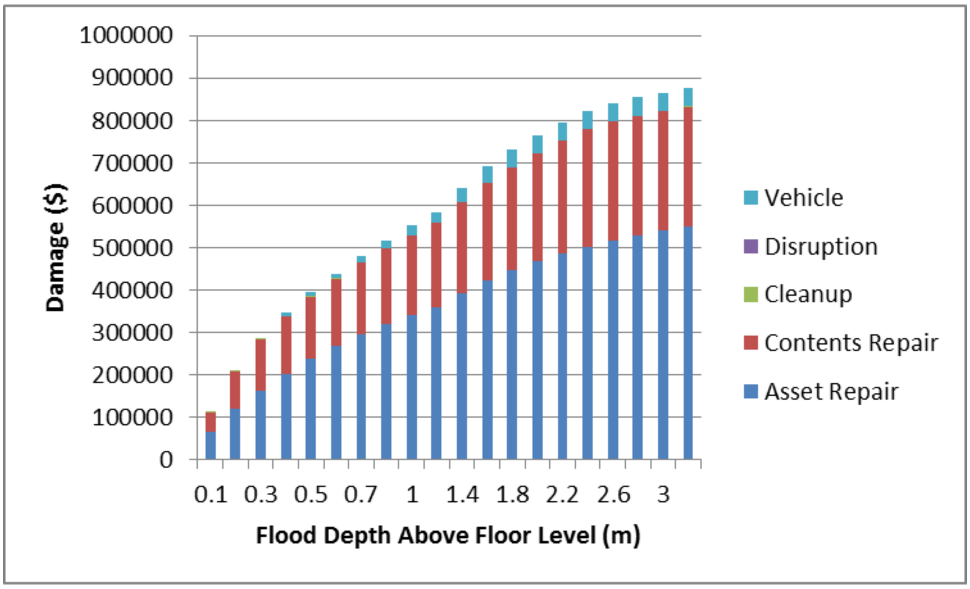


Figure 1: Illustrative residential damage costs relative to flood depth

2.1.2 INDIRECT (TANGIBLE) DAMAGES

Emergency response and traffic management costs together are calculated as a user-supplied percentage of the direct damage for residential and non-residential buildings. No guideline percentage values for emergency service costs in New Zealand were found from past studies during the development of the tool. It is noted that the UK uses 10.7% in rural areas and 5.6% in urban areas. Therefore 5.6% is used in the tool by default, although benchmark estimates should be built up to allow analysts to apply consistent assumptions which can then be varied easily in the model.

2.1.3 INTANGIBLE (DIRECT AND INDIRECT) DAMAGES

For residential properties, direct building damages are doubled to cover health impacts (mental and physical) and temporary accommodation (due to inhabitability of residential buildings) costs. For non-residential properties, direct building damage is doubled to cover loss of income.

2.2 AVERAGE ANNUAL DAMAGE (AAD) AND PRESENT VALUE (PV) DAMAGES

The economic metrics produced within the tool are Average Annual Damage (AAD) and Present Value (PV). AAD is independent of the year within which the damage is accrued.

Within an appraisal period, a range of flood events can occur, each with their probability of occurrence and causing an amount of damage. For each building, integrating under this probability-damage curve gives the Average Annual Damage (AAD) which could be expected to occur in any given year (Figure 2). Defining this curve requires depth-damage data for at least three different probability events, with as wide a range of probabilities as possible. For each probability event, the depth-damage lookup tables from RiskScape are used to estimate the damage at the building relating to the flood depth predicted by the hydraulic modelling.

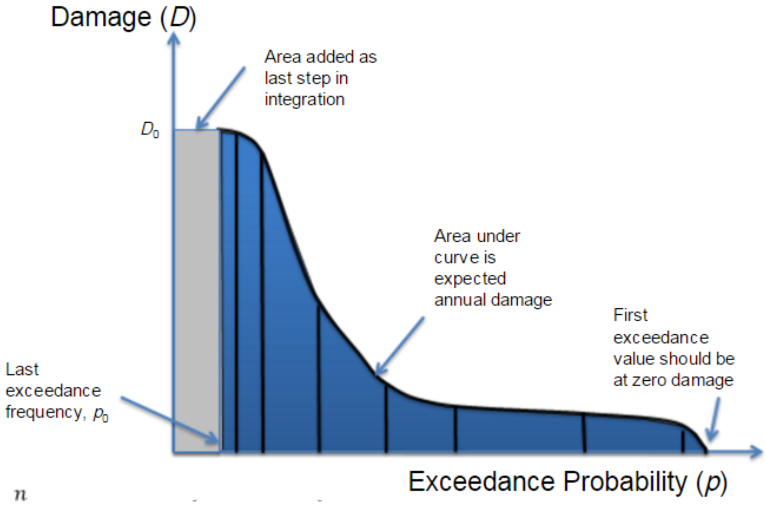


Figure 2: Illustration of integration under the probability-damage curve to calculate AAD (taken from Water Resources Planning and Management Daene C. McKinney Flood Management available at http://slideplayer.com/slide/4571457/)

AAD can be converted to Present Values through multiplication by a PV factor. The PV Factor is determined by the discount rate and the number of years in the appraisal period. Table 1 shows a distinct variance between discount rates applied internationally, with European countries applying lower discount rates to all other countries indicating greater consideration of intergenerational equity and a lesser focus on the cost of capital, which may be a driver for the selection of other discount rates. These can be compared to a default discount rate in New Zealand of 8.0% (for projects that are difficult to categorise including regulatory proposals), 5% for general purpose office and accommodation buildings and 7% for infrastructure and special purpose (single-use) buildings including water and energy, prisons, hospitals, hospital energy plants, road and other transport projects.

The choice of discount rate can make a significant difference to the outcomes of an appraisal. For example, the NPV of 100 years of damage using a 3% discount rate is over three times larger than the NPV over the same period using a 7% discount rate. As a result, the use of lower discount rate tends to result in higher benefit/cost ratios in flooding projects with a long appraisal period. This is especially true when considering flood defence schemes which involve costs in the short term and benefits accruing over the longer term. The tool defaults to use a discount rate of 5%, but can be run to test the sensitivity of the results to different values.

2.3 OTHER KEY ASPECTS

The following are also key aspects of the economic appraisal tool:

- Depth-damage is estimated relative to floor levels of the buildings. No damage is accrued for flood depths below floor level and thus the engineering and/or policy response of house raising can be represented in the tool through an increase in floor levels. This can be applied globally to determine the sensitivity of the results to floor levels (a number of floor levels in Christchurch remain assumed) or to individual buildings to represent a flood management response.

- The RiskScape data provides direct building damage as a cost to repair/rebuild. Direct damages are already capped for each probability event which assumes that over the course of the appraisal period, if a building floods multiple times it will be repaired/rebuilt each time. However, through this cycle of flood and repair, if the direct damages are significantly greater than the capital value of the property, then it may be appropriate to consider not rebuilding multiple times but instead relocating. Therefore, the tool provides the option of capping the damages at the capital value to understand this potential policy option.

- The costs of utilities and communications network damage, as well as the costs or benefits of changing land use as part of schemes, are two separate examples where the tool accommodates values supplied by the user if known, but does not provide default values. Guidance provided with the tool indicates the potential value of different land use types and can therefore be used to guide calculation of the additional value of e.g. creating wetland habitat.

3 RUNNING THE STORMWATER ECONOMIC APPRAISAL TOOL

3.1 OVERVIEW OF OPERATION

The tool provides a framework for understanding the damages resulting from flooding, how these damages could be reduced by flood management schemes and how the cost of such schemes compare with the damages avoided. The tool can inform decision making at multiple stages through a project lifecycle; firstly as part of options development and then during the appraisal process to determine how the costs of a scheme compare with its benefits. It combines hydraulic modelling data and estimates of scheme cost and then maps the pattern of flood damage and calculates key economic metrics. The overall operation of the economic appraisal tool is outlined in Figure 3.

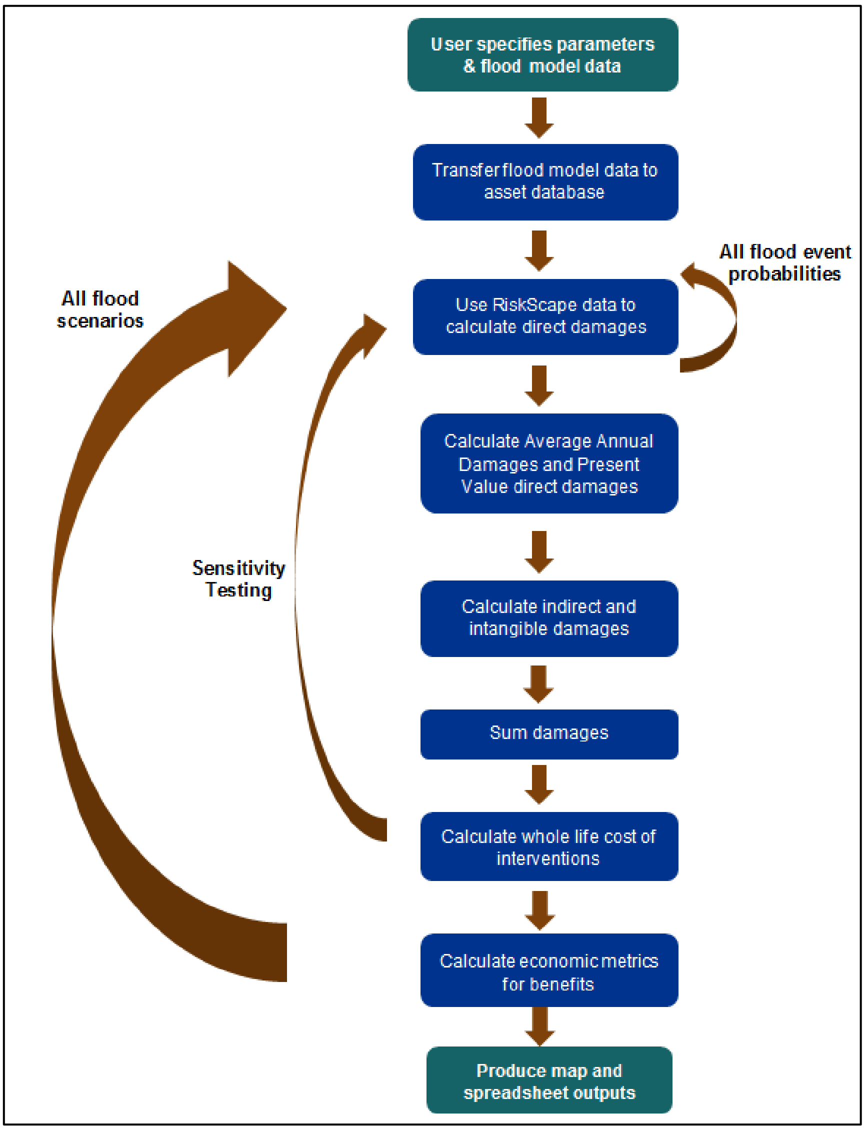


Figure 3: Outline operation of the economic tool

The tool requires GIS layers of water depth (or level) for one or more flood scenarios and the associated costs of implementing these scenarios (Figure 4). A scenario is defined here as the flooding predicted to occur at a given point in time, and can describe the current situation (basecase) or a future situation (e.g. with a scheme operating or with climate change).

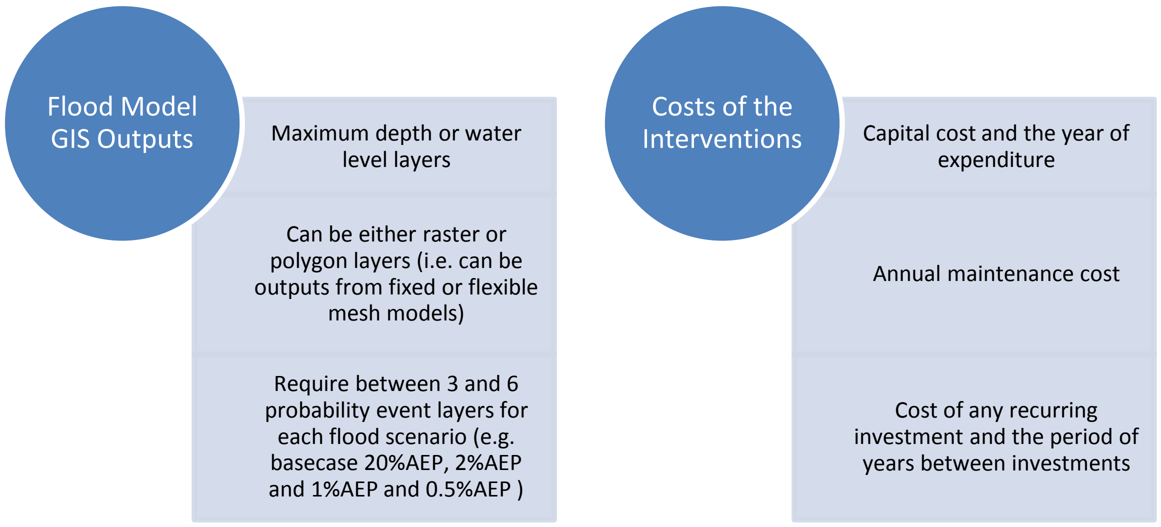


Figure 4: Summary of information required to run the economic appraisal tool

The tool interface runs through Chrome or Internet Explorer. The tool is a web-based GIS which is hosted on Safe Software's Feature Manipulation Engine (FME) Server. A simple menu-driven interface allows the user to guide the preparation of the input data, the economics calculations and output of data. Common parameter values are set as defaults in the menus. Previous appraisals can be adjusted and rerun quickly and easily.

Figure 5 illustrates the four key steps in running the tool. Hydraulic model data must be uploaded once, after which it is always available to the tool until manually deleted. Each time the tool is run, the appropriate data and parameters are selected to define the type of appraisal required. The economic appraisal tool runs in the background on a server and provides a notification when the run is complete. The outputs can then be reviewed and appropriate modifications to the input data or parameters made.

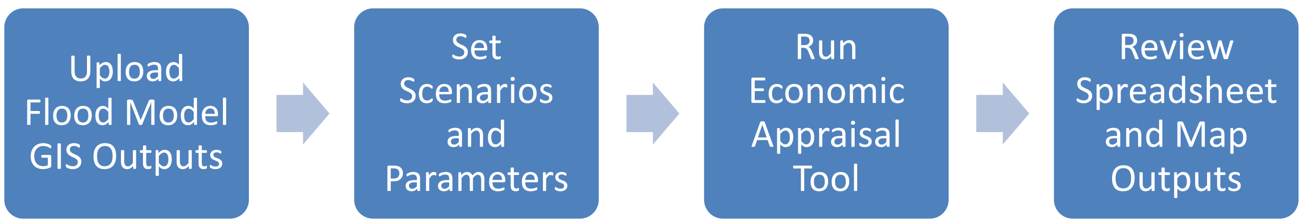


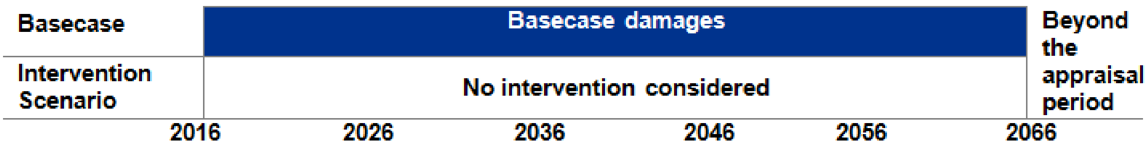
Figure 5: Flowchart of economic appraisal tool operation

3.2 EXAMPLES OF USE

An intervention is defined as any flood management scheme e.g. stopbanks, detention basin, pipe upgrades. Because the tool accepts hydraulic model results which could have represented a range of scenarios and interventions, and because these scenarios can be programmed for implementation over different timescales, the tool is highly flexible to undertake a range of appraisals. Table 3 illustrates a range of appraisals which can be undertaken, from simple understanding of flood damages in the existing situation through to comparing two different interventions with each other and the basecase to understand the incremental benefit:cost ratio of choosing the more expensive of the options offering a higher standard of protection.

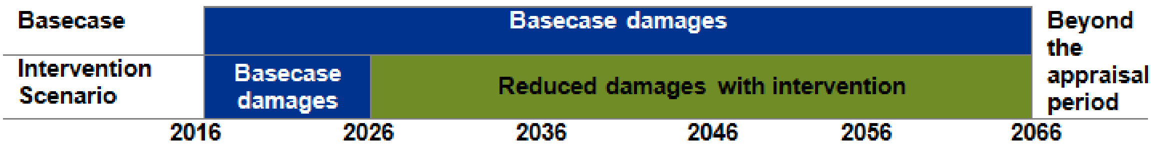
Table 3: Example appraisals accommodated by the tool

Appraisal	Example Scenario Description	Purpose
Basecase	The existing flood situation, without climate change and without representing any interventions	Sets the baseline against which possible interventions are assessed. Can be used to understanding the scale of the existing flood risk.



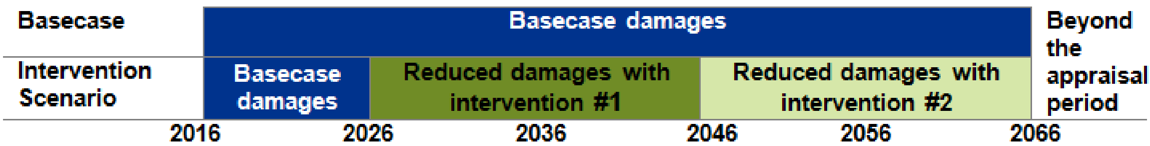
Schematic of basecase damage calculation over a 50 year appraisal period starting 2016

Single intervention	An single intervention (flood scheme) which is implemented either at the start of the appraisal period or in some future year	To understand the impact (i.e. damage avoided) of the intervention, through comparison with the basecase damages. Whole life costs and damages avoided are used to calculate economic metrics for benefits.



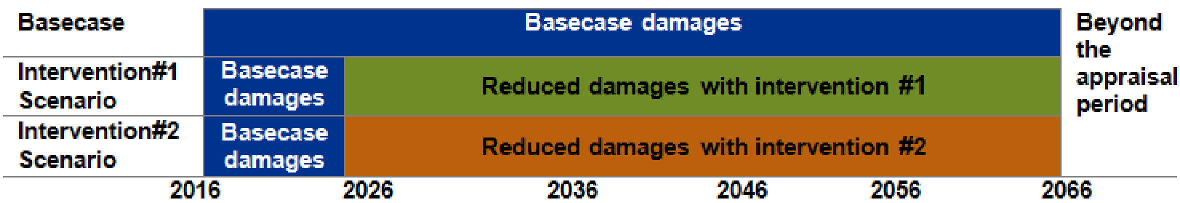
Schematic of intervention damage calculation over a 50 year appraisal period starting 2016 with the intervention being implemented some years after the start of the appraisal period

Staged interventions	Two interventions which are implemented sequentially, e.g. stopbanks are raised as part of adaptive management to rising sea level	To understand the impact (i.e. damage avoided) of the two interventions as a whole, through comparison with the basecase damages. Whole life costs and damages avoided are used to calculate economic metrics for benefits.



Schematic of staged intervention damage calculation over a 50 year appraisal period starting 2016. Note that the interventions may be implemented some years after the start of the appraisal period.

Alternative intervention	Two discrete interventions are being considered to manage flooding in a given area. Only the preferred one will be implemented.	To understand the impact (i.e. damage avoided) of each intervention through comparison with the basecase damages. The costs and benefits of the more expensive intervention offering a higher standard of protection are also compared with the lower cost intervention offering a lower standard of protection. Whole life costs and damages avoided are used to calculate economic metrics for benefits.



Schematic of comparing alternative interventions over a 50 year appraisal period starting 2016. Note that the interventions may be implemented some years after the start of the appraisal period, but must be implemented at the same time.

The tool maps each scenario included in the appraisal (i.e. basecase and up to two interventions), as well as a map for each intervention showing the difference in damage between the intervention and the basecase. Example outputs for a fictitious basecase and a single intervention are shown in Figure 6. For the basecase (map A) and intervention (map B) maps, the points representing the buildings are symbolised according to their fictitious Total PV Damage. The least frequent flood event depths provide background context. For the difference map (map C), the points representing the buildings are symbolised according to the difference between the basecase and the intervention damage (C = A - B), i.e. where positive values (greens) are damage avoided by the intervention. Negative values (red) indicate buildings with increased damage as a result of the intervention. The intervention depths are superimposed on the basecase flood extent in yellow.

It is important to note that the maps showing geographical distribution of damage are useful for a project team to interrogate and gain insight into the data and scheme performance, but are likely to be too sensitive to be distributed publicly. Instead, the individual data points can easily be suitably aggregated (e.g. into 100m grid squares) by the tool for any onward communication, following running of the tool.

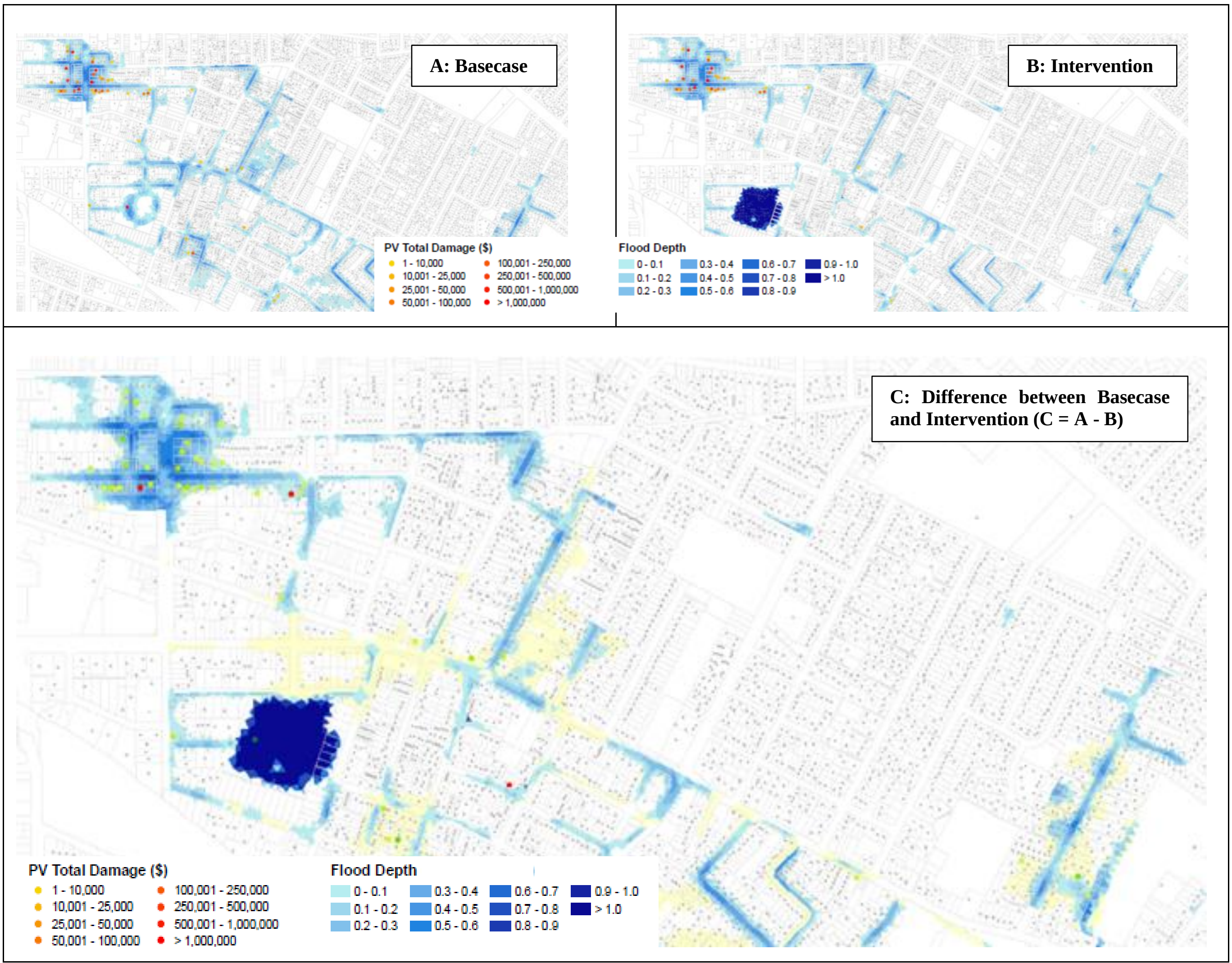


Figure 6: Example map output for a fictitious study (A basecase; B intervention; C difference between basecase and intervention)

Figure 7 shows an example Excel output from a fictitious run of the tool. The results for each flood scenario (i.e. basecase and each intervention) are grouped in columns. Key metrics for each scenario are then grouped in rows. The bottom rows in the spreadsheet report the headline economic metrics which will inform assessment of the economic viability of the scheme. This example illustrates the comparison of two alternate interventions, a lower cost intervention in column 3 and a higher cost intervention which offers a greater standard of protection in column 4. The following is noted:

- **Benefits (Damage Avoided):** As in the example, damage avoided is expected to be positive as an intervention protects areas from flooding. However, where climate change has been represented in the hydraulic modelling instead of an intervention, the damage avoided is likely to be negative, indicating the increased damage anticipated from climate change.
- **Net Present Value:** Compares the total damage avoided by the intervention with the costs of the intervention and gives the value of the intervention over time in present day prices. This should be positive for an economically viable scheme, as shown in Figure 7.

- **Benefit:Cost Ratio:** Divides the damage avoided by the costs of the scheme as a whole which should be greater than 1 for an economically viable scheme. In the example, intervention 1 has a BCR of 1 whereas intervention 2 has a higher BCR of 1.4.
- **Incremental Benefit:Cost Ratio:** Where there is a choice between two potential interventions, the damage avoided by the first intervention (offering a lower standard of protection) is compared with the basecase, and the damage avoided by the second intervention (offering a higher standard of protection) is compared with that of the first intervention. This helps to identify if the second more expensive scheme, which offers a higher standard of protection, delivers sufficiently more benefit over the first intervention. If this value is greater than 1 (as in the example below) then it can be said to make economic sense to choose the second higher cost option.

	Basecase	Intervention (Single or Staged)	Intervention (Alternative)
PV Total Damage	$15,178,006	$11,670,881	$6,701,934
PV Total Damage - Non-residential (excl. Network)	$4,643,772	$2,600,296	$4,368,742
PV Total Damage - Residential (excl. Network)	$10,534,234	$9,070,585	$2,333,192
PV Direct Damage	$7,367,964	$5,665,476	$3,253,366
PV Direct Damage - Non-residential	$2,254,258	$1,262,280	$2,120,749
PV Direct Damage - Residential	$5,113,706	$4,403,197	$1,132,617
PV Indirect Damage	$442,078	$339,929	$195,202
PV Indirect Damage - Non-residential	$135,256	$75,737	$127,245
PV Indirect Damage - Residential	$306,822	$264,192	$67,957
PV Intangible Damage	$7,367,964	$5,665,476	$3,253,366
PV Intangible Damage - Non-residential	$2,254,258	$1,262,280	$2,120,749
PV Intangible Damage - Residential	$5,113,706	$4,403,197	$1,132,617
AAD Total Damage	$908,451		
Number residential buildings with damages	38	23	25
Average AAD per residential building	$16,592		
Average PV Total Damage per residential building	$277,217	$394,373	$93,328
Number non-residential buildings with damages	17	14	13
Average AAD per non-residential building	$16,350		
Average PV Total Damage per non-residential building	$273,163	$185,735	$336,057
PV Total residential damages removed by capping	$4,073,285	$4,046,354	$2,690
PV Total non-residential damages removed by capping	$0	$0	$0
Capital Cost		$3,478,000	$6,087,000
Maintenance Cost		$0	$0
Recurring Investment Cost		$0	$0
Residual Value		$0	$0
Total PV Cost		$3,478,000	$6,087,000
Benefits (Damages Avoided)	N/A	$3,507,125	$8,476,072
Net Present Value	N/A	$29,125	$2,389,072
Benefit:Cost Ratio	N/A	1.0	1.4
Incremental Benefit:Cost Ratio	N/A	N/A	1.9

Figure 7: Fictitious 'Results' tool output

Different metrics aggregating results across the study area are shown in Figure 7 and can be grouped as:

- Flood damage summary
  - Damages in this section represents the sum across the study area, which compliments the geographical pattern of damage on the mapped outputs. Results are summed separately for residential and non-residential buildings according to their building use classification. The PV Total Damage for each scenario is the sum of direct, indirect and intangible damages for all buildings in the study area.
  - Average Annual Damage (AAD) values predict the flood damage expected to be accrued, on average, in any year during the appraisal period. The Present Value (PV) flood damage is the sum of these average annual damages, discounted back to appraisal year prices.
  - All flood damages accrued during the appraisal period are summed to report total values for the scenario.
- Flood damage indicators
  - To be counted as having damages, a building accrues flood damage in at least one of the probability events used as input. The 'per building' AAD and PV values are the study area totals divided by this number of residential and non-residential buildings.
  - Capping suggests that the cumulative repair/replacement cost of the building asset during the appraisal period exceeds the capital value of the property. The greater the capped damages, the more the capital value will have influenced the predicted damages.
- Intervention costs
  - The total intervention cost is the present value sum of capital, maintenance and recurring investment costs, but minus any residual asset value at the end of the appraisal period.

Sensitivity of the results to discount rate and/or floor levels provides an indication of the robustness of the economic appraisal to uncertainties in the scenario data, the parameters chosen and indicates how robust a business case may be. The same outputs as above are provided for the sensitivity scenarios chosen.

4 CONCLUSIONS

Christchurch City Council recognises the need to appraise options for repairs to the earthquake damaged drainage infrastructure in the wider context of adapting to climate change and the longer term principle and value planning for the city. The Land Drainage Recovery Programme (LDRP) is proposing location-specific engineering options and wider planning options across the city. The net economic benefits of these need to be understood so that appropriate and evidence based investment decisions are made, both between scheme options for individual catchments, as well as between strategic approaches across the city in the context of climate change.

Christchurch City Council has developed an economic appraisal tool which monetises many key damages caused by flooding, and hence the damage avoided by a scheme. By including some social and environmental benefits that go beyond avoiding damage, schemes can demonstrate achieving multiple benefits. This fits with Council's multi-disciplinary aim for drainage to work with natural features and processes and integrate with ecology, landscape, recreation, heritage & culture. The following are key attributes of the tool:

- designed so the informed non-expert (e.g. economists, engineers and planners) can interpret results;
- aggregates the various tangible and intangible, direct and indirect costs and benefits to provide CBA outputs for decision makers;
- produces maps to illustrate the spatial distribution of the damages;
- capable of informing both engineering (e.g. stopbank) and planning (e.g. floor level zoning) strategies;
- can accommodate combinations of mitigations implemented at different times, based on hydraulic modelling;
- informs a truly sustainable solution by seeking to quantify some social and environmental aspects;
- makes detailed calculations at individual asset level but can run city-wide assessments rapidly; and
- is simple and fast to use, including rapid testing of multiple scenarios and sensitively tests and querying of results to ensure that the tool is not a 'black box'.

An international project team reviewed best practice prior to deciding the theoretical basis for the tool. The project has been guided through workshops between stakeholders which have developed an understanding not just of how the tool works and how to use it, but how Council can modify its flood management studies to integrate the tool and maximize its usefulness. For example, allowing for at least three probability events to be modelled for each flood scenario, and for scheme costings to consider capital, maintenance and recurring investment elements. The tool has been developed, calibrated and tested using a number of case studies and will continue to be refined as it is used within projects.

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